# SYSTEMS ELECTRONICS FOR CRAFT, DESIGN AND TECHNOLOGY

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## Abstract

This thesis examines, defines, clarifies and establishes a coherent theoretical framework to support the application of systems concepts, in a C.D.T. (Craft, Design and Technology) electronic design context. The literature based research highlights the hierarchical nature of systems, the supporting terminology and the manner in which the term denotes the interaction between the objective world and the subjective perception of observers. The central holistic concept of system, synthesizes the notion of a set of interconnected elements, which generate emergent properties that may not exist in the elements embodied within it. Systems approaches, are argued to, encourage the building of structure and assist us in making sense of complex situations, by focusing on "what" is of interest, to the exclusion of other information, thus permitting order and meaning to be established. A range of theoretical and practical modelling techniques, are developed, to demonstrate the support systems offer in helping clarify and make sense of complex electronic design activities. Control concepts are discussed and developed to assist in the communication and conceptualization of the structural and process features of any system.

The process and principles of designing the questionnaire based research, provides information concerning the adequacy and selection of the sample, the data capture techniques, the methods of analysis and the tests for validity and reliability. The interpretation of the results provides information concerning; C.D.T. teacher technological capability; the perceived expertise and ability of teachers to deliver technologically based courses; electronics in C.D.T. schemes; pedagogical considerations of systems approaches; plus a range of other associated information.

The application of the theoretical and practical concepts developed in this thesis, supported by the questionnaire research, provide a foundation for a new systems based design methodology. Design focus is directed away from the linearly sequential approach and moves towards an iterative and cyclical systems method, which offers support for the more intuitive aspects of design. The classic top-down systems approach, expresses a movement from low to high resolution of detail, comprising seven stages; conceptual modelling; process modelling; electronic(black-box) system building; experimental optimization; dissemination of the essential supporting theory and finally the practical realization of optimized circuit. The testing of the developed methodology, allowed an all-ability group, without previous electronics experience, to undertake electronic design activity, by means of commercially available kits.

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# SYSTEMS ELECTRONICS FOR CRAFT, DESIGN AND TECHNOLOGY

## INTRODUCTION

## Introduction

## SYSTEMS ELECTRONICS FOR CRAFT, DESIGN AND TECHNOLOGY

Craft, design and technology (C.D.T.) has undergone substantial changes in both pedagogy and syllabus content, evolving through problem solving and design centred approaches. The changes have moved the subject forward from practical, skill-based instruction to wider design based approaches; from the use of predominately single materials and the production of artifacts to the teachers specification, to combined materials and interdisciplinary design, realization and evaluate methodologies. In essence the progression is one from a practical skills and knowledge orientation to a wider design and process base.

C.D.T. in the school curriculum is essentially concerned with identifying and responding to the changing needs of mankind, by means of a range of techniques, processes and methodologies of an aesthetic, technological, practical, theoretical and graphical nature. Within a design and realization context, C.D.T. focuses on the use of a range of technologies, being more concerned with the application of scientific principles, rather than the study of unrelated facts. C.D.T. encourages students to identify and satisfy real world needs - and thus children, no matter that it be in a small way, have the opportunity to make a real contribution toward the control and improvement of the local and wider environment. Importantly the new design emphasis of the subject equips children with a transferable methodology which is applicable to other aspects of life, permitting the use of the problem solving approach to help discover solutions in other subjects of the school curriculum and in the wider society. Significantly, the response of some students to these curriculum changes has resulted in a movement away from the more "passive" type of design project, marked by a static non-interactive nature; to the more "dynamic" electronic and mechanical type of project, which involves movement and the interaction and control of the environment. It will be shown that the new demands of the subject, has created a considerable demand amongst C.D.T. teachers to be provided with a comprehensive and wide ranging technological expertise to better support students design activity.

Pressures external to the C.D.T. School and L.E.A. (Local Education Authority) based movement, such as the M.E.P. (Microelectronic Project), National Centre for School Technology, British Schools Technology and the influential examination boards and universities, have maintained the initial momentum for design and technologically based project work. The relatively recent requirement for the subject to initiate, support and encourage the discovery of solutions to quite complex technological problems, may place an unrealistic demand on C.D.T. teachers to become proficient in a wide range of scientific specialisms.

Many C.D.T. teachers, it will be suggested, have responded to the challenge of increased technological complexity by incorporating additional elements of scientific theory into their teaching schemes, which are perceived essential in supporting the new emphasis of the subject. At G.C.S.E. and G.C.E. Advanced level, the examining boards require both a knowledge of scientific principles and applications. Unfortunately, such pressures may result in courses which have lost sight of the underlying principles of the subject and which most commonly offer children an analytical study of electronic circuit theory, structures, mechanisms, pneumatics and the other supporting aspects of technology. The constraints thus imposed on time and resources, often results in a failure to proceed far enough, for students to develop any real awareness of the problem solving capability or potential applications, of scientific principles. Disappointingly, it will be argued, some C.D.T. departments offer students a watered down physical sciences course at the expense of the design and realization fundamentals of the subject.

If one takes the area of electronics, an alternative to the analytical approach of focusing on electron theory and the functioning of components within circuits, is one which views electronics in terms of functional "black-boxes" which can be assembled into systems to perform useful operations as a solution to a problem. Emphasis for C.D.T. design activities is placed on how a range of systems may be used, rather than a detailed knowledge of the internal operation of each system element. It is often sufficient for understanding to be restricted at the earliest stages to the methods of interconnection and the general function of individual subsystems and requires neither a mathematical nor scientific background for students to be involved in real problem solving activity of quite considerable complexity.

Systems approaches offer a potential resource of considerable power and versatility to any person involved in electronic design activity. Systems approaches will be demonstrated to offer a means of coping with the dynamic and increasingly complex nature of C.D.T. from Years One to Six in the school curriculum, enabling the opportunity for students from a wide age and ability range to engage in complex design activities and to lessen the constraints of detailed technological capability. It will be shown that reconciliation problems occur between the fundamental aspects of the analytical, scientific method (hypothetico-deduction) pursued by some C.D.T. departments and the increasing educational pressure which emphasizes the identification and solution of real world needs. The time/cost equation of studying sufficient technological electives to acquire competence may be unfair in that certain aspects of technology are accented and others given secondary importance irrespective of their relative significance. Electronic systems for C.D.T. design activities will be argued, to offer girls and boys, greater scope for the distillation of intellectual, aesthetic and creative skills than the present emphasis on prescriptive, analytical methodologies. The way forward for C.D.T. may no longer lie in didactic exercises in circuit design and the detailed construction and electron theory of components. It will be argued that systems approaches more fully support the established principles of C.D.T. and offer students the opportunity to apply the new fundamentals of the subject in their proper perspective.

# Chapter One

# SYSTEMS - AN APPROACH TO ELECTRONICS FOR CRAFT, DESIGN AND TECHNOLOGY: AN OVERVIEW

# Chapter One

## Systems - An Approach to Electronics for Craft Design and Technology: An Overview

This chapter provides an overview of the research undertaken into Electronic Systems for Craft, Design and Technology (C.D.T.) during a period of part-time study from September 1985 to December 1987. It provides a concise summary of the aims of the research, describes and justifies the research method and finally identifies the limitations involved. To enable the progressive assimilation of the information contained within the thesis, conclusions are drawn at the end of each chapter as suggested by P.M.E. Figueroa, 1981 ("Writing Research Reports"). The conclusions reviewed at the end of each chapter are supported by the conclusions offered in the final chapter.

### 1.1 Primary Aim

The primary aim of this research project was to examine, define, clarify and to establish a coherent theoretical framework, to support the application of Systems concepts, in a C.D.T. electronic design context. Initially the focus of the project was directed towards Electronic Systems but developed into the more general concepts associated with a Systems approach to design.

### 1.2 Defining Systems

#### 1.2.1 Central concept

The central holistic concept of System, synthesizes the notion of a set of interconnected elements, which generate new or emergent properties that may not exist in the elements embodied within it. A System is something with interconnected parts but which is viewed as a single entity. The single System entity is easier to understand than the complex whole. Systems have no existence of their own but are ideas aroused within the perception of observers. Systems approaches, are argued to encourage the building of structure and to assist in making sense of complex situations by focusing on "what" is of interest, to the exclusion of other information, enabling order and meaning to be better established.

### 1.2.2 Examining and defining the concept of System: Literature Based Research

An important aim of this research project was to establish a clear statement and philosophy of the concept of "System" and to then justify the inclusion of a Systems based approach, within a C.D.T. design and realization context. The review of existing literature helped establish a clear theoretical framework and highlighted the hierarchical nature of Systems, the supporting terminology and the manner in which the concept denotes the interaction between the objective world and the subjective perception of observers.

## 1.3 Establishing a Systems vocabulary: Modelling and Control

A range of theoretical and practical modelling techniques, are developed within this thesis, to demonstrate the support Systems offer in helping clarify and make sense of complex electronic design situations. Control concepts are discussed and developed to assist in the communication and conceptualization of the structural and process features of any System. To support the Systems concepts established within this thesis, a clear vocabulary and terminology is generated together with those essential System control and modelling concepts, necessary for the essential dissemination of theory into practical realization. The development and justification of Systems concepts is designed to lead to the analysis, production and testing of a Systems based methodology to help support students design activities.

## 1.4 Questionnaire and Interview Based Research

The questionnaire based method of research was selected because of the potential it offered to the collection of large amounts of information in a relatively short period, at a reasonable cost in terms of time and money. The design of the questionnaire permitted comparisons to be made between individuals, the methods adopted to teach electronics and other aspects of technology. Some of the problems encountered with the design of the questionnaire are dealt with later. The process and principles of designing the questionnaire based research in chapter five, provides information concerning the adequacy and selection of the sample, the data capture techniques, the methods of analysis and the tests for validity and reliability. The questionnaire attempted to determine the perceived needs of students and teachers and identified five main areas:

(1) the educational benefits of following a general Systems approach as perceived by C.D.T. teachers;
(2) the perceived technological expertise of C.D.T. teachers;
(3) the resource value of technological disciplines;
(4) the main approaches adopted to introduce electronics into C.D.T. design activities;
(5) the levels of resourcing required to support curriculum innovation in the area of Systems:

Additionally, the perceived educational benefits of different approaches to electronics teaching, were assessed to determine the relative advantages and disadvantages of the various strategies adopted by teachers. At a more general level the questionnaire indicated the extent and level of initial and in-service teacher training in aspects of technology and the perceived competence of C.D.T. teachers to deliver technologically based courses, electronics in particular and additionally a range of other specific supporting technologies. The results obtained from the questionnaire, supported by follow up interviews with L.E.A. advisers, M.E.P. in-service training providers and teachers was confirmed by information held elsewhere (ie. L.E.A. records).

### 1.4.1 The limitations of the questionnaire based research

Questionnaire based styles of research have distinct advantages and disadvantages. The power of rapid data collection and the comparative analysis of information, was measured against the problems of obscuring the subtler differences in replies, which may be discovered by structured interview or observational methods. The use of a standard measure over a large sample, in order to find regularities and patterns in the characteristics of the respondents, still remains a strength of the questionnaire method. The price of simplification of the replies has had to be paid.

### 1.4.2 Problems associated with the sample

It must be stressed that the sample drawn from the total C.D.T. population was not a true random sample and consequently any inferences drawn from the survey cannot be applied with any certainty to the national scene. The extent to which the results are reasonably applicable to the wider population and the extent to which inferences may be obtained is also limited by the size of the sample and the extent to which control could be exercised over its distribution. It will be demonstrated however, that the results are reasonably representative of the local C.D.T. population of Derbyshire, Staffordshire and Lincolnshire.

The information collected does offer new insights into the needs of students and teachers, and the values and the attitudes that are attributed to technological areas of the C.D.T. curriculum. The questionnaire results therefore, tentatively identify perceived weaknesses and strengths, provide useful pointers towards the future in-service training needs of teachers, possible future research and the development of more effective strategies towards electronic design activity in C.D.T. The questionnaire based investigation primarily identifies needs and therefore determined the direction and the nature of the research project.

### 1.4.3 Problems associated with the interpretation of the questionnaire

It is acknowledged that some respondents to the survey found several questions ambiguous and experienced difficulty interpretating and then responding to the questionnaire. These problems could have been overcome by better use of the information obtained from the pilot survey and also by the inclusion of a more detailed information sheet to accompany the questionnaire. In retrospect it seems clear that many questions were leading and biased towards the Systems approach. Clearly the questionnaire could have been better designed in respect of the construction of the questions, the terminology adopted and the extent to which supporting literature was provided.

## 1.5 Development of Systems approaches for C.D.T.

The application of the theoretical and practical concepts developed in this thesis, supported by the findings of the questionnaire based research, were designed to provide a foundation for a new Systems based design methodology. Design focus within the Systems methodology being directed away from the limitations of the linear-sequential approach and moved towards an iterative and cyclical Systems method, which offers support for the more intuitive aspects of design.

### 1.5.1 From generality to specificality

The classic top-down Systems approach, will be demonstrated to express a movement from a low to a high resolution of detail. From the preliminary conceptualization of a System, to the practical realization of a tangible product, the progression will be demonstrated to be hierarchical in structure, expressing a movement from low resolution of detail and generality at the System level, to high resolution of detail and specificality at the component and realization level. It will be shown that the process of electronic design using Systems is cyclical and iterative, and can be based on a model comprising seven stages:

[1] The identification of a need, the conceptualization of the system and the development of a preliminary model.
[2] Process modelling by means of symbolic techniques to determine control requirements and the mode and quality of the links of connectivity between subsystems.
[3] Development of an electronic system by means of "ready-made electronic building blocks".
[4] Experimental optimization of the designed system. The practical determination of a realistically viable system.
[5] Discussion of the essential electronic theory (if appropriate).
[6] Translation of the optimized electronic system into a practical reality by means of appropriate printed circuit board construction techniques.
[7] Integration of the electronic elements into the wider system, involving the completion of the total design activity.

These seven distinct stages were developed, trialled and an initial evaluation conducted to determine the effectiveness of a Systems approach to electronic design activity. Further research is needed to establish the validity of such an approach.

### 1.5.2 Macro and Micro System levels

The major educational contribution offered by this thesis, will be shown to be the development of a clear Systems philosophy and the generation and initial testing of a new Systems based methodological resource for C.D.T. electronic design activity. Systems approaches will be argued to offer support for C.D.T. at two distinct levels, at a macro and a micro level. At a macro level, involving an emphasis on the iterative and cyclical nature of the Systems approach, to help structure design situations and to encourage innovative and wider perspectives. Systems at the macro level provide support to C.D.T., offering an alternative methodological tool, as a complete design resource. At a micro level Systems approaches are shown to involve an emphasis on the use of ready-made electronic building blocks to support electronic design activity, permitting students to investigate circuit design and to resolve electronic problems.

[1] Macro level: System based modelling approaches to establish key concepts. Preliminary conceptualization and process modelling.
[2] Micro level: Electronic modelling through System approaches, by means of commercially available System teaching resources to explore quickly new design opportunities and to solve specific problems.

## 1.6 Feasibility Study of the Systems Methodology

The effectiveness of the developed Systems methodology was evaluated by means of a small-scale feasibility trial, involving an all-ability group of boys and girls, without prior electronics experience, over a ten week period. It will be shown that the use of a Systems approach, enabled the subjects of the experiment, to attempt electronic problem solving activities and to subsequently incorporate their designed electronic Systems into functional products. The appropriateness, of the developed methodology, was experimentally trialled to examine its role as an additional and powerful problem solving resource and also the extent to which it permits girls and boys to explore the new design opportunities offered by the use of electronics in C.D.T.

It must be stressed that the trial described in Chapter Eight was intended to test the feasibility of a Systems approach, it is descriptive rather than inferential. The research style adopted for the experimental trial of the Systems approach was based on ethnographic principles described by M.J. Wilson et al 1981. As a method it studies groups and individuals in their natural settings and relies upon the role of a participant-observer, to infer meanings by understanding the context and accounting for the groups collective purpose. Ethnography is not a method in the sense of fixed rules of procedure which can be written down and followed by another observer. Wilson et al describe principles of good ethnographic method but these are not precise and are hence open to inspection.

1.6.1 The limitations of the small-scale feasibility trial

The ethnographic approach has disadvantages in that it requires the observer to fulfill two roles simultaneously (participant in the design activity and impartial observer of the methodology) and relies heavily on the subjective interpretation of the researcher. The style of research adopted had the advantage of naturalism, argued by Wilson et al, but suffered the considerable disadvantages of being time consuming, difficult for the researcher to practice, questionable as to the representativeness of the group under study, and is less reliable than survey and experimental methods. Other limitations of the adopted approach are outlined below.

1.6.2 Subjectivity.

The problem of subjectivity associated with a single participant-observer could have been lessened by the use of one or more independent observers who could have offered a more objective assessment of the experimental trial. Additionally triangulation techniques (M.J. Wilson et al ,"Research Methods in Education and the Social Sciences", 1981), involving a participant-observer, an independent observer and the observations of the students (the subject of the trial) would have made the results more meaningful.

1.6.3 Typicality (or representativeness)

Financial resources and the limitations of time, restricted the experimental trial to the observation of one group only. It was initially planned to repeat the trial with another teacher but unfortunately this was not possible. It cannot be stated with any certainty that the group selected was typical of the many groups in the Secondary Education sector. Additionally, numerous other factors will affect the performance of a student, investigating each source to ensure typicality would have placed an undue burden upon the researcher.

1.6.4 Reliability

A major limitation of the feasibility trial is the reliability of the observers analysis. The selection of significant actions or comments had to be made by the researcher and thus what was seen as unimportant was not recorded. The researchers observations were necessarily unique in behaviour (and how it effected the respondents), in what was chosen to record as important and the interpretation of the findings.

1.6.5 Replication

The replication of the experimental trial in order to check the findings would be difficult to achieve, because the observer was necessarily unique in his behaviour and also the experimental group would be different. Had resources of time and money permitted, a more appropriate experiment could have taken the following form:

[1] Two groups of similar educational background: one following a Systems approach, the other following a component based approach.
[2] More extensive pre-trial testing to establish the representativeness of the groups under observation.
[3] Experimental method (ie The developed Systems methodology) applied to one group but with held from the

control group.
[4] Post-trial testing of both groups.
[5] Differences between the two groups after the experiment compared by triangulation techniques.
[6] Summarization: the differences between groups could be accounted for since the two groups were identical before the trial began.

Ambiguities concerning cause and effect could have been lessened by the following of a more tightly controlled experiment involving more than one group and the observation of an impartial observer. Unfortunately, because of school curricular pressures it was not possible to use two groups and also administrative difficulties at a school level, made triangulation techniques difficult to practice. The principles of a Systems approach is substantially different from the traditional methods of introducing electronics, at the component level (hypothetico-deduction). It was therefore difficult (in the short term) to compare "like-with-like". Similarly post-trial evaluation would prove difficult, because the criteria for a component based approach could well rest upon the recall of factual information concerning the function and circuit theory, whilst those for Systems approach would rest upon wider criteria.

The limitations outlined above detract from any inferences which may be drawn from the experimental trial, however, it is hoped that the experiment provides useful insights into the developed Systems methodology and provides pointers for future research.

## 1.7 Chapter Review

This chapter provides a brief overview of the research project into Electronic Systems for Craft, design and Technology. It concisely sums up the aims, describes the research approach adopted, justifying that approach and then highlighting the limitations involved.

# Chapter Two

# SYSTEM CONCEPTS

## Chapter Two

# SYSTEM CONCEPTS

The understanding and application of a systems based approach in C.D.T. electronic (and other) design activities requires an explicit statement of the conceptual foundations upon which the methodology is based. This chapter is attempted in the context of an understanding which reflects previous research into systems thinking and the existing knowledge which has been generated. This research project is preceded by the establishment of logical categories of systems and by the posing of questions which attempt to reduce confusion and which more clearly define the nature of the systems concepts to be employed. This chapter, by the review of existing literature and thought in the area of systems theory, attempts to establish a clear terminology of general systems concepts for subsequent application and the development and trialling of a systems design methodology. The aims of this section are therefore to develop the essential concepts, classifications and the terminology underlying systems thinking.

Systems methodology "... marks a genuine, necessary and consequential development in science and the world view", Ludwig von Bertalanffy (1974). The concept of system has gained importance in all aspects and levels of contemporary society, which is marked by a rapidly expanding technological base of increasing complexity. Systems approaches are proving to be a powerful methodological tool in supporting the new technological opportunities offered in all aspects of the industrial, scientific, commercial and social environment. Systems provide a means by which solutions can be found to complex and diverse technological problems. The steady but relentless increase in the complexity of man made systems and the parallel unprecedented technological advances has established the need for cross discipline approaches to problem solving in all aspects of the man made world.

# Chapter Two

## 2.1 Perception and cognition

2.1.1 "Systems are perceptions of reality in the mind of the observer" B.Wilson (1984). All systems have a root definition which describes the main characteristics of the system or its essence. In "Themes in Speculative Psychology" (1968) Nehemiah Jordan asserts the importance of a systems core meaning, he helps make clear the "...vague, fuzzy and ambiguous" confusion often associated in obtaining a coherent definition for the term system. Jordan legitimates systems as a useful and valuable concept by the following:

(a) reviewing facts of perception and cognition;
(b) making explicit the implication of (a) and offering a core meaning to the word;
(c) different definitions are legitimate to different "concrete cases";
(d) formulating a taxonomy of applications.

## 2.2 Modes of visual organization

Jordan makes use of analogies between perception and cognition in clarifying system concepts. The ability of man to segregate the punctiform-stimulus on the retina of the eye, into a visual figure and background and the particular ability to organize and reorganize, neural stimulation patterns according to what is perceived to be of interest, makes possible clarity and sense in an ever changing visual field. Shifting figure-ground relationships, are essential in allowing clarification of the meta-physical, and permitting us to make sense of the environment. The same visual field may at will be reorganized by the perspective of the perceiver into a variety of modes of visual organization. Similarly the ideas we think about can be reorganized against a background of shifting focus. The manner in which an idea is expressed reflects what is of interest and relevant, other information being temporarily excluded from focus, if by its exclusion, order and meaning to the object of focus is achieved. Jordan suggests that such concepts of figure-ground relationships hold good for cognition.

## 2.3 Modes of cognitive organization

Similarly to modes of visual organization, modes of cognitive organization reflect the ability to structure thought, by focusing on the figure, with partial exclusion of the ground. Similarly, by focusing on the purpose of systems, with the exclusion of the system elements we are able to more readily achieve order and meaning.

Nehemiah Jordan contends that "...systems have a core meaning, which expresses a discriminable, distinguishable invariant that can be identified despite a host of different conditions and circumstances". The concept of system does not express simple meaning, simple definitions are too difficult to describe. To establish a core meaning of systems it is necessary to establish its mode of perceptual/conceptual organization. Nehemiah Jordan further suggests that "... a thing is called a system to identify the unique mode by which it is seen". A thing is called a system when we wish to express the fact that it is perceived/conceived as consisting of a set of elements, parts, that are connected to each other by at least one discriminable, distinguishing principle.

"If it is possible to explain, or give meaning, to a set of elements, and the nature of the connectivity between these elements, then the recipient of the explanation can perceive/conceive of the set as an entity. The word system can then be applied as the adequate expression, as a proper name for the set. A system is an interaction between the figure-ground relationships. Systems denotes the interaction between the objective world and how it is looked at, or thought about. It denotes the mode of perceptuo-cognito organization". Nehemiah Jordan (1968).

System therefore is an invariant term, that reflects much variation in detail. An unambiguous term, such as a computer system is as clear as the term, my computer system. A computer system acknowledges the existence of many details that are in principle unknowable to the former. Both concepts embrace the key elements of an input device, a processor and storage device, and an output unit. The general concept provides little insight, irrespective of the clarity of the description of the specific cases, or sets of cases that are instances of the concept. A computer system tells nothing of the presence of the type of microprocessor, it does however suggest minimum conditions that a computer system must posses to meet the requirements of the concept of a computer system. Within the bounds of the concept there is infinite variety.

### 2.4 Bi-polar classification of system types

2.4.1 Systems may be classified and ordered according to the aspects of connectivity between the system elements. Jordan sees this classification in terms of three distinct dimensions.

### 2.4.2 Static/Structural and Dynamic/Functional systems

Under the above heading systems phenomena can be thought about in two separate ways; those that change over a defined or delineated period of time and those that do not. The former reflecting static or structural systems, the latter dynamic or functional systems. The relevant time span under consideration largely determines whether a system is defined as structural or functional, change has no logical sense without reference to the period in which it has taken place.

Systems may be regarded as static if the connections between the systems elements can be understood during observation during any one time period. Functional systems require at least two observations within a time period for the identification of the connectivity between system elements to take place. The shifting figure-ground or perspective of the observer makes it possible for a system to be viewed as either static or dynamic. A person sleeping may be regarded statically (an inactive living organism) or conversely, dynamically (a physiological organism undergoing an anabolism for which sleep is necessary).

2.4.3 Purposive and non-purposive systems

Purpose denotes a distinguishable pattern of action, the characteristic of this pattern is the terminal state known as the system goal. Purposive systems generally interact with either the environment or towards the system itself. Behaviour directed towards the environment is directed at the creation of a new state or to modify an existing condition. Non-purposive systems are goal directed and exhibit low entropy. Goal independent systems although demonstrating high entropy, constantly take action to decrease entropy to maintain order.

2.4.4 Mechanistic and organismic systems

Since systems comprise a set of elements and the connection between elements, it is possible to change, remove or destroy elements and or the connections between elements within them. A system in which the remaining elements and their connections undergo no change with extirpation or removal are perceived as being intrinsically different from those that do change. Jordan perceives those systems that undergo no change as being mechanistic, and those that do exhibit change as being organismic. When a machine breaks down and is replaced with a new component the system functions as before. However many mechanistic and static systems completely breakdown when single component parts are removed, most typically those from electronic systems.

2.5 Jordan's Systems Taxonomy

2.5.1 Jordan's three bi-polar system dimensions generate eight further cells. Jordan admits that "...a certain amount of mental elasticity" is required to fit real world examples into some aspects his taxonomy. Such a range of examples follows the list of eight system dimensions:

[1] Structural, purposive, mechanical
[2] Structural, purposive, organismic
[3] Structural, non-purposive, mechanical
[4] Structural, purposive, organismic
[5] Functional, purposive, mechanical
[6] Functional, non-purposive, mechanical
[7] Functional, non-purposive, organismic
[8] Functional, non-purposive, mechanical

2.5.2 Structural, purposive, mechanical

A railway network exemplifies structural, purposive organismic systems. Maps represent the system at any given instance, two instants being unnecessary; hence it is a structural system. It is purposive in facilitating a means of travel and is mechanical since it is possible to remove one section without introducing change into the remaining parts. A lighting system wired in parallel, is an example where the removal of a single bulb does not effect the performance of the rest of the system.

2.5.3 Structural, purposive, organismic

An aeroengine is an example of a structural, purposive, organismic system, its purpose being clearly defined, diagrams adequately represent it any one moment in time. It is organismic since the removal of a single component (ignoring minor components) will result in engine failure and the plane will no longer function. Similarly a serially connected Christmas tree lighting system will not function if a single bulb is removed.

2.5.4 Structural, non-purposive, mechanical

These systems are well represented by physical geographic systems such as islands in the sea. They fulfill no obvious purpose (though the differing figure-ground relationship of the geologist would argue differently) they are just there.

If one part of the system is removed there is no obvious affect on the remainder. Difficulties arise in suggesting a suitable analogy for electronic systems, perhaps the most suitable being the colour coding system for various components, the removal of the colouring has no influence on the functioning of the system.

2.5.5 Structural, non-purposive. organismic

Any physical system in a state of equilibrium may serve as an example of a structural, non-purposive, organismic system. An electro-magnetic field, Jordan suggests, can be determined by knowledge of the state at one instant in time. He goes further to suggest that a magnetic fields has no purpose (reflecting his own figure-ground relationship). Correctly he points out that any alteration to the electro-magnetic field may change the state of the entire system or its state of equilibrium.

2.5.6 Functional, purposive, mechanical

Examples of these systems are numerous in all aspects of the man-made world. Jordan is somewhat contradictory, in that he suggests that the removal of any single component in a production line does not result in changes to other system components. However, the breakdown of a single component in any electronic system invariably results in the breakdown of the entire system, reflecting organismic rather than mechanical classification.

2.5.7 Functional, purposive, organismic

Functional, purposive, organismic systems are best exemplified by living organisms. Almost every electronic system is organismic, in that they are interdependent on the performance of other system elements, the removal or failure of one resulting in system failure.

2.5.8 Functional, non-purposive, mechanical

Functional, non-purposive, mechanical Jordan suggests are demonstrated by water flowing in a river system. It is functional since it can not be made sense of unless two instants in time are taken into account. The apparent arbitrary flow manner in which the volume changes is non-purposive. Finally the changing water volume has no effect on the entire river system. The water analogy is often applied to a study of the movement of electrons in circuits with obvious similarities to the above example.

2.5.9 Functional, non-purposive, organismic

Functional, non-purposive, organismic systems are well demonstrated by atomic structure.

2.6 Hypothetico-deduction

Where the practical and theoretical pressures of making sense of complexity are acute the establishment of systems concepts provide and offer an alternative to detailed analysis, a solution by permitting the perceiver to exclude detail and focus on the general invariant. Systems thinking diverges significantly from the hypothetico-deductive scientific method. The scientific method encourages the formulation of an hypothesis, an idea that connects known facts, or accounts for them. The hypothesis is studied and deductions are made about the new information. Experiment and observation tests the predicted outcome. Scientific method is distinguished by its emphasis on reductionism and is often at odds to the expansionist approaches of C.D.T. problem solving and systems electronics approaches. The process of reductionism may create rather than solve complexity. It operates at the level of accounting for events by comparison of known events and properties at a lower level. Reductionisms possible creation of complexity is demonstrated by the example that from molecules that form structures, to atoms and atomic theory the movement is an inward and increasingly complex spiral. Systems methodology embraces some of the elements and patterns of the scientific method in that hypothesis, deduction and prediction of behaviour form an essential part of the process. However, complexity is largely ignored until the later stages of the investigation in the systems approach. Similarly to hypothetico-deduction, the systems approach offers a structured and logical approach to the solution of real world complexity with a more limited prerequisite of specialist knowledge.

## 2.7 Reductionism: Method of detail

Reductionism is founded in historical philosophy. An important exponent of reductionism was Galileo (1564-1642), when he was faced with questions about the strength of a ships hull he avoided discussion of the problem as a whole by analyzing instead the strength of a single beam, a considerable technological and methodological innovation for those times. Galileo's "method of detail" is still the guiding principle behind the work of many scientists and engineers. When a bridge is designed the elements of the structure are broken down into separate sub problems of manageable proportions. Unfortunately what originally was an imaginative and powerful solution to a methodological problem, has become transmuted into a "...philosophy and way of life" J.Naughton (1976). Naughton further suggests that:

"When systems people complain about reductionism and the way it has limited our potential for understanding complex wholes, they are complaining not so much about a particular methodology for solving problems as a complete way of thinking about the world - a philosophical system".

## 2.8 Holism

2.8.1 The most characteristic feature of a systems methodology is the manner in which attention is focused on the properties of "wholes" rather than the components which make up the whole. This means that focus is placed on

complete interlocking entities and interacting systems and that the behaviour of the entity is the primary subject of the system. This approach encourages a view of entities in terms of relationships with other systems, the environment and the particular useful function that they perform.
Holism (a term devised by J.C. Smuts) has its roots in the classical philosophy of the Greeks and the modern movement in the ideas of the German philosopher Hegel (1700-1831).
D.C. Phillips writes:

"The Hegelians regarded the whole of reality as forming a system, the parts of which were originally or internally interrelated. Being a system, reality could not be studied successfully by dividing it into parts each of which was studied in isolation. For when a part was isolated from the whole system its nature changed - it was no longer a part of the whole system, and it became an inaccurate guide to the nature of the whole".

2.8.2 Emergent properties and synergy

The systems emphasis on wholes reflects the philosophical perspective of Holism. Holistic emphasis on the emergent properties of systems focuses on the important notion that assemblies of parts (systems) organized together in special ways can reveal unique properties - properties not possessed by single elements of systems. These new properties emerge from the particular assembly of systems and are new or emergent properties. Where unexpected properties emerge synergy is used to describe the process of combined action.

2.9 General Systems Theory (G.S.T.)

The principal philosophical idea of Holism existed until the early part of this century as an implicit, largely unrecognized approach used by engineers, biologists and other thinkers. The explicit recognition of systems gained greater momentum after the work of Ludwig von Bertalanffy in the 1920's and the 1930's. During the 1950's the different strands of system thinking began to converge and during this period Bertalanffy, Rapoport, Miller and Von Foester formed the Society for General Systems Research. The early pioneering work of this group established and further developed a general system theory (G.S.T. for short). G.S.T. was designed to produce a general theory of systems methodology applicable to a range of different systems and subjects. The early philosophical perspective of the pioneers of this new discipline became translated into the practical applications of Operations Research and Management Science (O.R.M.S.). The range of techniques and the number of applications of this methodology proved limited and the status of the approach declined. Russell Ackoff an early exponent of Operational Research, in his paper "The future of Operational Research is Past" (1979) summarized the failure of O.R.M.S. to make a significant impact on system methodology and applications in the context of real applications. world context.

2.10 Systems Analysis

An expansion in computer applications prompted a need for greater emphasis on systems analysis. Analysts needed to understand the processes and procedures going on in industrial and commercial activities so that computers could be programmed to take control of routine operations. The American RAND Corporation successfully used and established a generally applicable methodology, mainly developed from the Space and Defence construction programme. In more recent times a broadly based methodology has established itself in response to the need to cope adequately with increasing complexity in all aspects of modern technological society. Peter Checkland (Lancaster University) has emerged as a leading advocate of broad based systems thinking, as a practical method for grappling with complexity. Checkland's methodology starts from an analysis of fairly simple questions designed to lead to an understanding of the systemic aspects of situations. From a simple beginning complicated and complex procedures can be applied to solve problems. Checkland's methodology is eclectic in that it draws on many different methods, methodologies, concepts and techniques.

## 2.11 General Systems Concepts

The concepts of synergy and emergent properties are fundamental to systems thinking. Systems will only possess particular properties when organized in a particular manner and that this ceases when the system is broken into component parts. Significantly the particular outcome can only be studied by the analysis of the complete system and not by an analysis using reductionist focus at elemental level. The hypothetico-deductive, reductionist scientific method diverges at this juncture from the holistic systems approach. The strength of systems approaches, in the use of electronics in C.D.T. problem solving and design activities, is the additional resource it provides in understanding how entities behave and in helping predict emergent properties and synergies. It provides a means of dealing with the mathematical and scientific complexity found in electronic design projects. It is characterized by a methodology which views wholes, is dynamic, focuses on interacting behaviours and the emergent properties associated with the complexes of interacting systems. Peter Checkland (1981) defines systems in terms of an assembly of parts, connected in an organized manner, that behaves in a particular way and which may be regarded as a whole and single entity "...the central concept of system embodies the idea of a set of elements connected together which form a whole, thus showing parts of the whole rather than the component parts".

## 2.12 Establishing a Systems vocabulary

A system may be regarded as a transformation process converting inputs to outputs. The processing of inputs to outputs is achieved by the organization of the component parts of a system. Systems are the organized assembly of components, such that each component is connected either directly or indirectly to other components. The presence of components in systems contributes to the output and the behaviour of a system may be changed if the component is removed. Importantly component parts themselves experience changes in behaviour when removed from a system. Electronic and other systems take their name from the inputs, control procedures or outputs which they produce or the purpose they serve. The statement of purpose of the system is an essential step in deciding the component parts within the design context. It is important that the terms used throughout this text are clear and unambiguous and by necessity use made of an elaborate terminology. Systems Methodology is an approach to the study of a particular phenomena that employs system concepts, which focuses on cause and effect, highlighting the function of systems rather than the internal operation of the connected whole. Systems View refers to the analysis of phenomena as if they were taking place in a world of systems. Systemic refers to the properties of a phenomena as a system, whilst systematic refers to a step by step procedure. The development of an elaborate terminology extends beyond its use in theorization and plays a particularly useful part in the precise definition and discussion of assembled systems.

## 2.13 Young's System Categories

O.R. Young (1964) usefully classifies systems into a number of categories. His classification commences with a universal set which may be labelled systems concepts; ie. concepts which are inherent in using a systems approach. Within this set are two subsets comprising structural and procedural concepts. Structure is seen as a relatively stable framework comprising the manner in which the elements and the subsystems are put together to perform processing tasks on received information from inputs. Process is the change in state effected by environmental influences. Structural concepts are further broken down into structural features and structural dimensions. Process concepts are further broken down to; dynamics and change; regulation and maintenance and decline and breakdown. The table below outlines Young's classification and is further extended to included other concepts established within this text.

| Structural Concepts | Process Concepts |
|---|---|
| (Features) | |
| Boundary | Entropy |
| Interaction links | Disorder |
| Environment | Decay |
| Component/element | Order |
| Subsystem | Control |
| Hierarchy | Communication |
| | Stability |
| | Equilibrium |
| (Dimensions) | Homeostatis |
| Open-closed | Feedback/feedforward |
| Hard-soft | Emergent properties |
| Abstract-concrete | Synergy |
| Evolved-designed | Goal/goal seeking |
| Continuous-discrete | Learning/adaption |
| Deterministic-probalistic | Passive |
| | Purposive |
| | Loop |

2.13.1 Structural concepts

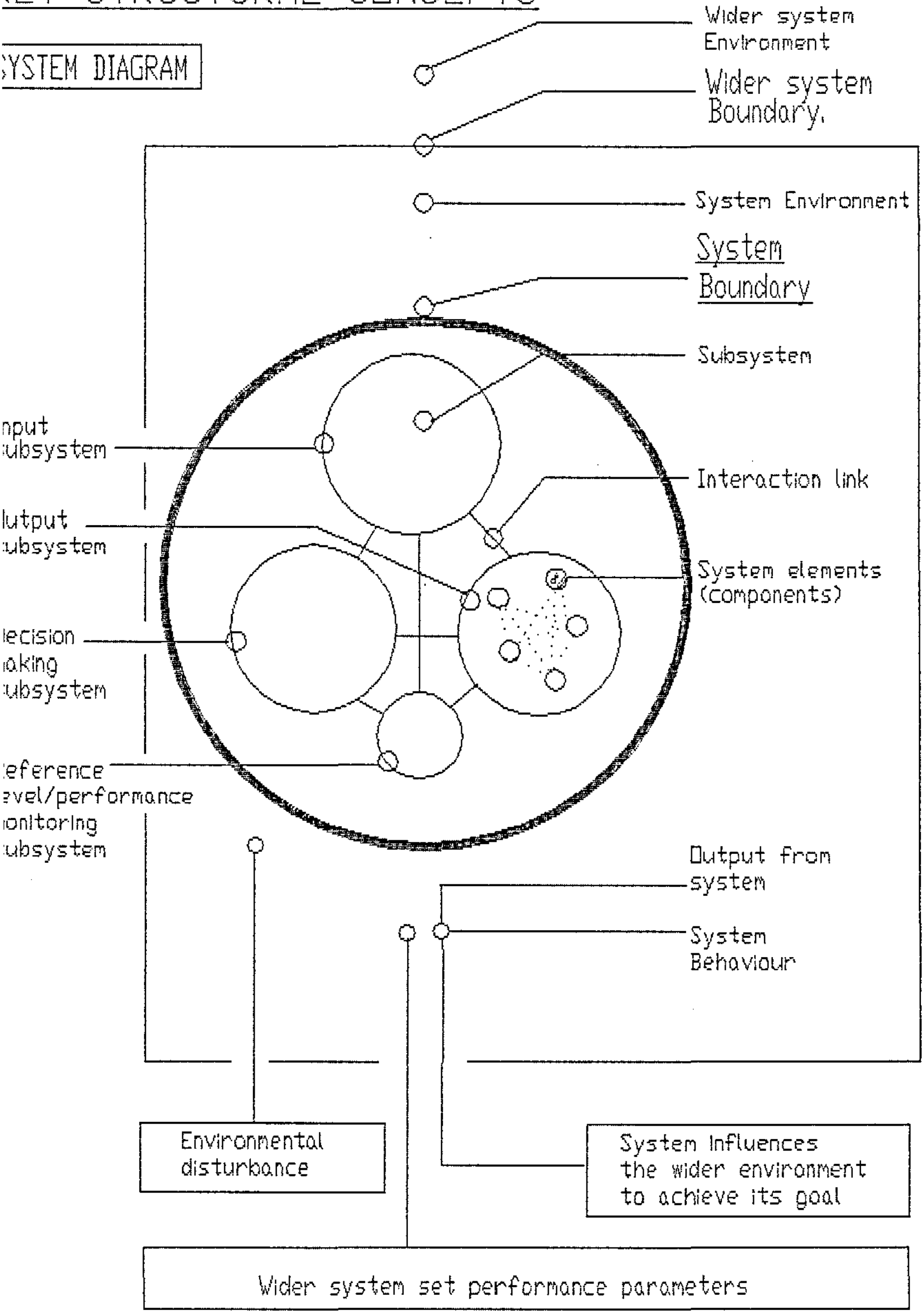
Figure 2.1 graphically illustrates the key structural and process concepts which are further outlined below.

2.13.2 Systems boundary

The act of drawing a boundary around a system and listing the elements within comprises the process of boundary identification and system delimination. Systems have boundaries and are contained within a system envelope separating the system from its environment. In systems approaches it is essential that both the envelope and the boundary are clearly defined.

gure 2.1

# KEY STRUCTURAL CONCEPTS




Ref.J.Gl

2.13.3 Environment

External to the system is the systems environment which includes all those aspects which influence or are of interest to the system

2.13.4 System elements

A system may be progressively broken down into the smallest sub-atomic particles. In most situations this degree of detail is unhelpful. The term element denotes the smallest part it is useful to consider.

2.13.5 Subsystems

To be considered a subsystem a component of a system must possess qualities and characteristics of a system and must be capable of being broken down into a number of components which will also be elements or subsystems.

2.13.6 Hierarchy

The concept of system is closely related to that of hierarchy, but it is applied in a manner different to that used in describing hierarchies in social sciences. Checkland (1981) in discussing hierarchy closely allies it with emergent properties which do not exist at lower system levels. A system is a subsystem of a wider system, the differences are in the level implied by the idea of hierarchy. Lower level systems are less likely to demonstrate emergent properties.

2.13.7 Interactions

Included within the structural and process concepts are the instances of interaction between systems, subsystems, elements and the subsequent cause and effect involved between the system and its environment.

## 2.14 Structural dimensions

### 2.14.1 Open and Closed Systems

Systems theory identifies and distinguishes between open and closed systems. A closed system is a theoretical tool for theorization, it has no connections with other systems or the environment. Because systems may not be isolated from the real world of which they form a part, by definition they may not exist. The idea of an open-closed continuum is useful in that it allows comparisons to be made. Some systems are more open than others and exploring the ways in which one system differs from another is helpful in understanding the properties of systems. Additionally a closed system has important theoretical properties that follow from the laws of thermo-dynamics, namely conservation of matter and the concept of entropy. The concepts of open and closed loop control systems are discussed in chapter three.

### 2.14.2 Hard and Soft Systems

Similarly to the open-closed continuum, it is best to regard hard and soft systems in similar terms, hard systems being distinguished from soft systems in that they possess clearer objectives. G. Vickers (1964) suggests that it is more appropriate to see soft systems as relationship maintaining rather than goal seeking systems "...in harder systems there will exist some sort of recognizable hierarchy of systems. The system will exist in the real world rather than being, as with softer systems a way of looking at a collection of factors which can vary dramatically from the view point of the observer, and from purpose to purpose".

### 2.14.3 Abstract and Concrete Systems

Cameron (1983) sees abstract systems in terms of conceptual tools for problem solving rather than "...real and touchable" concrete systems.

2.14.4 Evolved and Designed Systems

Systems may be classified into evolved and designed systems. Biological systems are a prime example of evolved systems, however, this concept may also be applied to any system which has evolved in response to change. Designed systems are constructed to fulfill specific purposes.

2.14.5 Continuous and Discrete Systems

These structurally based control concepts relate to the sampling incidences on inputs and outputs relevant to a control system.

2.14.6 Deterministic and Probalistic Systems

Deterministic systems perform behaviours which are predetermined, these being most commonly a set sequence of operations. Probalistic systems exhibit behaviour which are inherently probalistic. Traffic lights exhibit deterministic behaviour whilst roulette wheels exhibit probalistic behaviour.

2.15 Process Concepts

2.15.1 Open systems, unlike closed systems, are effected by the systems environment and a range of other external influences. Open systems can input information through various input transducers, process the information and output information possibly in a different form. Open systems in theory would seem to exhibit low entropy and retain and achieve steady state existence by the balancing of inputs and outputs. From this useful theoretical tool is developed the concept of dynamic balance for open systems and passive balance for closed systems. The concept of an open system is a particularly useful tool for electronic design activities, because it permits continuous processes to be described and regarded as if they were a single system. Particular elements of the system may change but the organized pattern remains constant. The behaviour of a particular assembly may change under the influences of various input, process and output transducers but the organized pattern of interactions remains constant. This allows an understanding to develop of the function without distraction from the changing variables.

2.15.2 Young's classification of Process Concepts

Young divides process concepts into three distinct categories:

[1] Dynamics and change
[2] Regulation and maintenance
[3] Decline and breakdown

Many of the concepts listed in Young's system categories in 2.12 above are obvious and need no further clarification, others however, because of their specific meaning in a systems context need further clarification which is provided below.

2.15.3 Entropy

Entropy measures the extent to which a system possess disorder. Closed systems demonstrate a maximum entropic state of order. Because closed systems receive neither energy nor inputs they can only move towards a state of increased entropy (or disorder). The theoretical concept of a closed system, should not be confused with a closed loop control system. Open loop control systems demonstrate greater entropy than closed loop systems which are able to adjust through a feedback or feedforward loop.

2.15.4 Homeostasis

Homeostats are the complex grouping of components at an organismic level which maintains one or more outputs at a predetermined level, even though disturbances and changes occur both within the system envelop and its environment. A fire control system attempts to maintain a predetermined and fire free environment by monitoring its environment (smoke and temperature) and turning water sprinklers on when the predetermined environmental conditions change. Homeostats are reactive in that they deal with conditions of the immediate present or the past.

2.15.5 Equilibrium and stability

The concepts of equilibrium and stability apply to almost all systems. Central to the maintenance of homeostasis is the concept of information (feedback and feedforward loops) fundamental to all regulatory control systems. This concept will be dealt with in greater detail in chapter four.

2.15.6 Communication

Communication, control and information are closely linked. Without adequate information, control is mostly impossible. Communication is the process of information transfer. Important to the concept of communication is the notion of context. Without context information is reduced to simple data; data plus context equals information.

2.15.7 Purpose

Systems are designed to perform useful purposes, primarily to fulfill predetermined objectives. When the objectives are complex, interacting systems (and subsystems) are necessary to fulfill the particular objective. The entire system complex is directed and given meaning by a particular objective or useful purpose.

2.15.8 Reaction and Response

Russell Ackoff (1967) differentiates between reaction and response. A reaction is an event deterministically caused by another event. A response is an event which occurs to a system but which requires more than simple reaction. Thus a response is an event of which the system is itself a coproducer. A person turning on a light when it gets dark is responding to darkness, but the light going on when the switch is pressed is reacting.

2.15.9 Goals

Ackoff (1967) suggests that goals are short term or intermediair states. Subsystems therefore achieve short term goals to fulfill the objectives of the system complex. Subsystems are goal seeking, a thermistor achieves its goal to fulfill the objective of temperature determination. The determination of objectives and goals is an essential pre-requisite to successful systems electronic problem solving. Sheila Cameron (1983) distinguishes between goals, objectives, purpose and supergoals. Goals are regarded as short term end points, towards which behaviour is directed. Objectives are seen as acting over a longer and less clearly defined timeperiod. Purpose refers to an even longer lasting and higher level need to which goals and objectives support.

2.16 Boulding's Systems Classification

Kenneth Boulding (1956) developed the first and (and perhaps the most famous) systems classification. Boulding's classification has much to commend itself to current systems practice, it being a simple hierarchical model which is readily assimilated. There are nine levels to Boulding's classification:

[1] Static systems (structures): frameworks, the anatomy of the universe.
[2] Simple dynamic systems: clockworks.
[3] Cybernetic systems: self regulating in maintaining equilibrium (thermostat level).
[4] Open systems: self maintaining structures.
[5] Genetic societal systems: the plant.
[6] Animate systems: animals and systems with increased mobility.
[7] Human systems: typified by the ability to use language and symbolism.

[8] Social systems: socio-technical systems include both human and technical components. Socio-technical systems are responsive and decide upon a course of action to deal with past, present and projected future conditions.
[9] Transcendental systems.

2.17 Behavioural classification of Electronic Systems
2.17.1

| SYSTEM TYPE | BEHAVIOUR | BEHAVIOUR OUTCOME |
|---|---|---|
| Static (manual) | Unpredictable | Flexible |
| Static (mechanized) | Invariant | Fixed |

Manual systems: Operator directed, flexible because of the link with human operators. Guitar player and amplifying equipment.
Mechanized systems: Systems directed, rigid. A mechanized static system behaves in a predictable and unchanging pattern with fixed outcomes, similarly to a room lighting systems.

2.17.2

| SYSTEM TYPE | BEHAVIOUR | BEHAVIOUR OUTCOME |
|---|---|---|
| Static - Operator controlled | Determined variable. | Fixed |

Highly interdependent physical parts allowing an operator determined behaviour. Manual control of a motors speed.

2.17.3

| SYSTEM TYPE | BEHAVIOUR | BEHAVIOUR OUTCOME |
|---|---|---|
| Equilibrium - maintaining | Determined variable reactive. | Fixed |

Equilibrium maintaining systems include heating system controllers. When temperature changes occur the system either responds by turning on or off the heating subsystem to maintain a steady state. It can only react to changes, it cannot respond because its behaviour is determined by the causing event. Its process is reactive. Within this group are included collaborative man-machine systems, involving one or more operators. Where human operators are involved the behaviour is likely to be explorative and flexible.

2.17.4

| SYSTEM TYPE | BEHAVIOUR | BEHAVIOUR OUTCOME |
|---|---|---|
| Goal determining | Selected variable. | Fixed |

Goal determining systems are ones that can respond differently to one or more external or internal states. They can respond differently to an event in an unchanging environment until the objective of steady state or the production of a particular state (its goal) is achieved. An automatic frequency controller for a television tuning receiver can respond to variations in signal intensity. A goal determining system is responsive.

2.17.5

| SYSTEM TYPE | BEHAVIOUR | BEHAVIOUR OUTCOME |
|---|---|---|
| Multiple goal determining and purposive. | Selected variable. | Variable but not determined. |

In the function of multiple goal determining and purposive systems the different goals are determined by the initial events but the system is not able to select the means by which to pursue its goals.

2.17.6

| SYSTEM TYPE | BEHAVIOUR | BEHAVIOUR OUTCOME |
|---|---|---|
| Purposeful | Selected variable. Homeostatic. Adaptive. | Variable and selected. |

Purposeful systems can produce the same outcome in a number of different ways to the same inputs into the system. Purposeful systems are capable of producing different outcomes to the same system inputs. A Purposeful system can change its goals under constant conditions and is capable of prioritising goals and also of making the appropriate selection of alternative goals and the mean by which to achieve them. A computerised target selection and directional control system on a nuclear missile is capable of selecting the most suitable target from a range of alternatives against changing flight and target conditions.

## 2.18 Fundamental System Laws

Beishon et al (1978) suggest that the first step in the scientific analysis of phenomena is the identification of the predictable aspects of any system and the development of these regular patterns into descriptive laws.

The straight forward recognition of patterns and the subsequent description of systems, is of value in its own right. To know of, to recognize, to describe and to be aware of the usefulness or otherwise of phenomena is more important than knowing the reasons for the phenomenas behaviour. Bieshon makes the important point that "...man did not need to know why the seasons repeated themselves to take advantage of the fact and to develop agricultural methods". The early stages of any science consists in the production of descriptive laws concerning the behaviour of simple isolated systems. Similarly persons engaged in design activities may be able to apply laws, provided they are able to develop a descriptive analysis of the phenomena. The next and perhaps the most important stage is the development of a quantitive connection between the variables in the system. The identification of laws to further predict behaviour of systems is an essential part of the descriptive-connectivity process.

Complexity is related to description, predictability and control, and the understanding of the demonstrated phenomena. If the phenomena is both predictable and subject to easy control the actual level of complexity is largely irrelevant. In these terms of cybernetics, Ross Ashby's law of requisite variety is important in determining the capacity of one system to exercise control over another. Complexity is therefore relative to the perception of the system user and observer.

## 2.19 The Law of Requisite Variety

Ross Ashby's law of requisite variety (1956) may be simply stated that to cope with the behaviour of a system, it is essential to have as much or more variety available to the controlling system as is present in the subject of control. The concept of variety may simply be defined as the number of states a system can exist in. The concept of variety in defining complexity is important in determining the different possible input, process and output states necessary for effective control. Essentially Ashby says that to control a complex system you need a requisite variety in the control system. Hence if the amount of variety in the subject of control is high then it is possible to predict the amount of variety in the controlling system. The usefulness of Ashby's laws lie in the ability to predict complexity from the variety of input, process and output conditions. The application of Ashby's law will be demonstrated later in the text. Significantly although many electronic systems are complex in terms of their construction, physical characteristics and the physics which underpin their function, the scale of complexity need be of minimal concern if it is possible to describe, predict and have the requisite variety in the form of systems resources to exercise control. The description and construction of consistent and logical frameworks into which system ideas can be fitted is fundamental to the formulation and the establishment of quantitive connections among the variables of any system. Without such quantitive links the development of more general laws are unlikely to develop.

## 2.20 The Law of Equifinality

Ludwig von Bertalanffy (1968) "General System Theory" further makes clear the distinction between open and closed systems. A closed systems in the final state is only able to achieve its goal by following a predetermined and fixed path. Given a set of initial conditions the system must follow a single trajectory to the end state. An open system can achieve an end state by a number of different routes and from a number of different starting points and conditions. The important idea of equifinality suggests that (and encourages the search for) there are more than one "best route" to a successful solution or final goal.

## 2.21 Chapter Review

This chapter has attempted to demonstrate the all pervasiveness of systems which are found at extremes of scale, ranging from the subatomic to the galactic system level and are present in all aspects of life. Systems have been demonstrated to exhibit a hierarchical structure, with large systems encompassing smaller systems. Jordans's analysis of the word system revealed that systems have a core and an invariant meaning which is made up of two elements. An out there aspect which relates to the actual system (its objective sense) and an inside sense which refers to the definition from the person doing the defining (its subjective sense). A system was summarized as being:

[1] An assembly of elements connected together to form a whole, demonstrating properties of the whole rather than the component parts.
[2] The particular assembly forming the system has been identified as being of special interest to humans.
[3] The parts of a system are effected by being in a system and are changed by leaving it.
[4] The assembly of parts forming the system fulfill a function or purpose.

## Chapter Two

Systems were shown to be capable of classification under four major headings, P. Checkland (1971). Each classification being found in a number of different dimensions, including; hard-soft, abstract-concrete, discrete-continuous, deterministic-probalistic and evolved and designed systems. The four major classes are:

[1] Natural systems.
[2] Designed systems.
[3] Human activity systems (man-machine interface).
[4] Social and cultural systems.

Systems were demonstrated to have a number of structural features:

[1] Boundary and envelope.
[2] Environment.
[3] Elements.
[4] Subsystems.
[5] Hierarchy.
[6] Interaction links of interconnectivity.

To aid the communication of ideas and concepts and to further assist the extension of systems thinking, an analysis was made of the elaborate vocabulary which is used to discuss systems and the behaviour of systems. This vocabulary has developed under the major headings of systems classification, category description, structural concepts (including features and dimensions) and process concepts. Additionally an extensive control vocabulary has been developed which will be examined and applied in chapter four which is concerned with the control principles of systems.

# Chapter Three

# MODELLING STRATEGIES FOR ELECTRONIC DESIGN ACTIVITIES

# Chapter Three

## MODELLING STRATEGIES FOR ELECTRONIC DESIGN ACTIVITIES

This chapter supports the need for a change in emphasis from the use of the reductionist techniques discussed in chapter two to solve electronic problems, towards the development of systems modelling methodologies to help overcome complexity and to better structure the design opportunities offered by electronics in C.D.T. schemes. The power of modelling for C.D.T. electronic design activity may be judged in the same way as any model to:

[1] Clarify and structure complex situations.
[2] Make possible the analysis of alternative solutions and to assess the probability of successful outcomes.
[3] Quantify the risk profile and the estimated value of the solution against the constraints of present and future expertise.
[4] Analyze the constraints of time and money.

### 3.1 Modelling strategies for electronic design activities

3.1.1 The improved clarity of modelling strategies holds considerable potential for students engaged in design activities, to help overcome much of the confusion and incompleteness found in verbal and written description and to permit fuller explanation and deeper analysis of the subject of the design investigation. When used in the context of electronic design, modelling is a useful means of description, explanation, control and discovery. A model is a simplification of what it represents. By the construction of models mental images may more clearly be exposed, allowing more concrete statements to be constructed that can be more easily understood and communicated. The use of models in electronic design activities is examined in this chapter to describe and understand systems, to communicate this understanding, as a tool for analyzing real world complexity and as an aid to expanding design experience and opportunity.

# Chapter Three

"There is nothing in the physical (or social) sciences about which we have perfect information. We can never prove that any model is an exact representation of "reality". Conversely among those things of which we are aware there is nothing of which we know absolutely nothing. So we are always dealing with information of an intermediate quality... it is better than nothing but short of perfection. Models are not then to be judged on an absolute scale that condemns them for failure to be perfect, but on a relative scale that approves them if they succeed in clarifying our knowledge and our insights into systems". J. Forrester "Principles of Systems" (1968).

Forrester's comments have a particular significance for any person engaged in design activities in electronics. The fact that a persons knowledge is incomplete or limited is largely irrelevant if through the media of modelling, a successful outcome or solution can be arrived at by the process of clarifying the structure of one or more systems. The modelling representations of electronic systems need not be entirely accurate, but in clarifying thought and allowing the capture and recording of what is understood and known and by enabling the consideration of solutions beyond the present capability of a student, a major advance is made in viewing the consequences of assumptions. These assumptions ultimately may be perceived as right or wrong but this may be irrelevant if the modelled situation is successful in improving the accuracy with which we represent reality. By the reduction of any system to diagrams, statements and equations, by studying its underlying assumptions and when these may be communicated, analysed and seen in the context of time and the interreaction matrix with the wider social system we can reasonably expect to determine behaviour patterns and to better understand and overcome complexity. Ackoff and Sasiene (1964) describe four major classes of models:

Classes of model: [1] Iconic
[2] Analogue
[3] Conceptual
[4] Symbolic

# Chapter Three

### 3.1.2 Iconic modelling Systems

Iconic models represent the properties of the subject of the model, by the same properties in the model itself. Iconic models are usually facsimile copies made to a smaller scale. Small scale representations of the full size object of similar appearance may be usefully constructed during the design research and investigation stage when such factors has proportion, shape, form and colour may be analysed at a smaller scale but with close fidelity to a possible future solution. Iconic models are of limited value in circuit design.

### 3.1.3 Analogue modelling Systems

An analogue is one where the properties of the subject are represented by different properties in the model. The water analogy is often used to represent or model the flow of electrons in a circuit. A clock face is an analogue of time by the varying angular position of the hands. Since analogue models make use of properties different from those being represented, knowing what the model is about requires a knowledge of the representational media and the conventions being developed. Analogue models are more abstract than iconic models but are useful in aiding an understanding of complex concepts and processes.

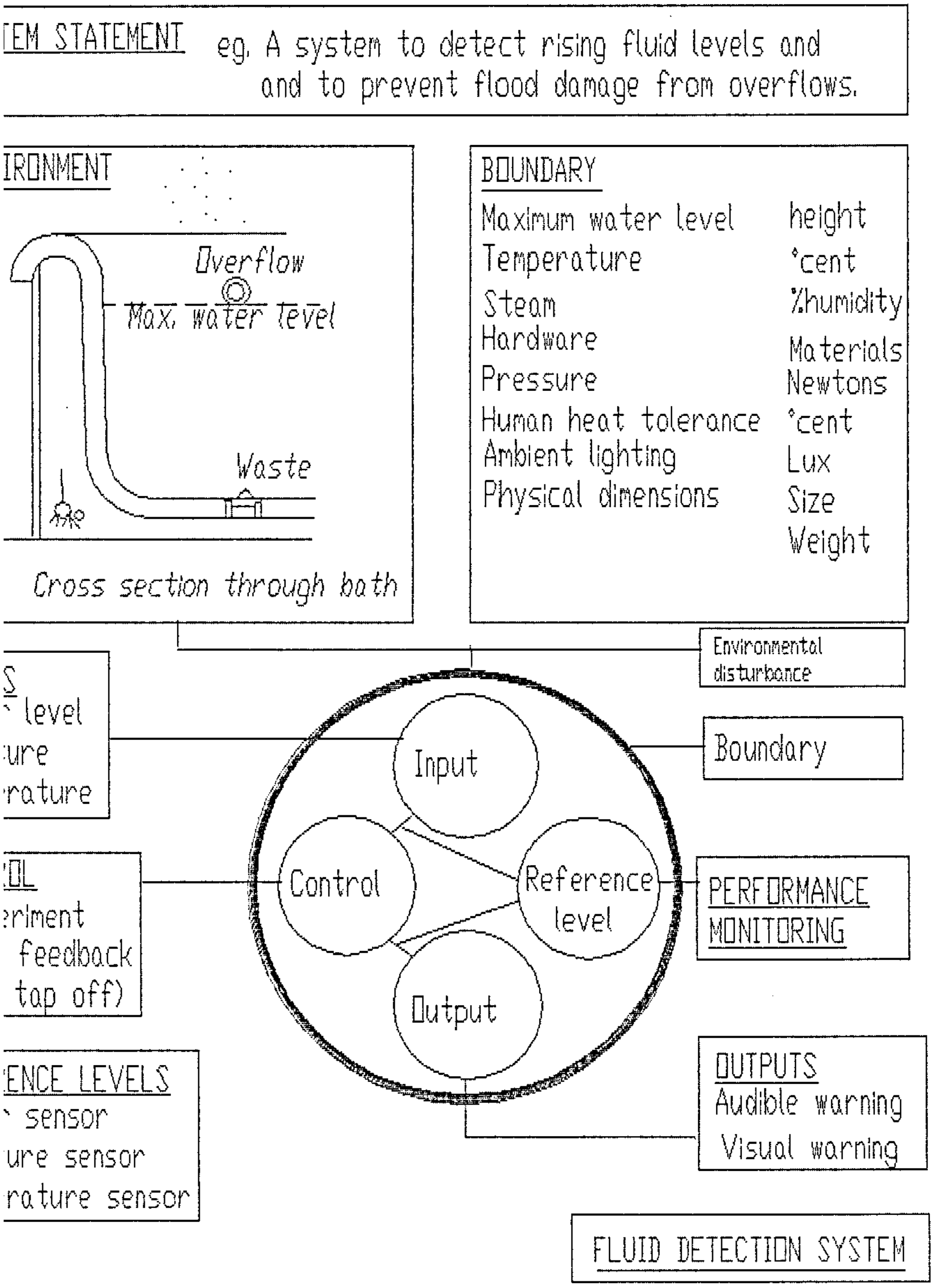
### 3.1.4 Conceptual modelling Systems

Conceptual modelling involves the early defining of a system, delimiting its boundaries and identifying its environment. First attempts at developing a solution to a complex electronics problem involves the establishment of a systems description by the use of early tentative models. Conceptual modelling, a term used in the early methodologies of Operational research (O.R.) refers to the initial representations that are made of any system. These are usually diagrams which record the conception of those properties of the system that are relevant and their inter relationships. They are formulative in their function, they help to clarify thinking and enable the communication of this thinking to others. Figure 3.1 demonstrates the key concepts of conceptual modelling by reference to the design of a system to detect rising water level.

The questionnaire and interview based research described in chapters five and six suggests that many C.D.T. teachers have relied on a linear design methodology to aid their students in finding solutions to electronic design situations. Typically this begins with a statement of a problem or design situation from which students are required to establish a real world need. Following on from the identification of a problem situation, students are required to conceptualize a possible solution, involving the selection of the most suitable predicted outcome from a range of alternatives. Moving from the development of a possible solution an investigation is conducted at two levels, preliminary research and finally an analysis of the various factors relevant to the selected solution. Limitations are typically placed on the range of possible outcomes by the restrictions of student expertise in following a design route which demands a preliminary knowledge of the subject of analysis. Essentially the linear approach reflects an emphasis which is analytical and reductionist in nature. Students may be restricted in the range of possible outcomes by the necessity to follow a controlled design route. When problems of expertise are encountered difficulties can be experienced in breaking out of the tightly bounded paradigm generated by the nature of the approach. Unfortunately little research has been undertaken to establish the usefulness or to identify the limitations of this linearly based approach. Interview responses indicate that at the earliest stages in conceptualizing a solution to the design situation using the linear design method (formulating a brief), students are not provided with a formalized resource methodology to help analyze the effectiveness of their ideas. One possible alternative, to the problems experienced by students adopting the linear sequential approach, is a conceptual modelling system which allows the range of design opportunities to be e 3.1

# ELIMINARY CONCEPTUALIZATION

ing the system, identifying the environment and deliminating the
daries.



more fully compared and analysed. Conceptual modelling systems are a powerful tool for helping make sense of the range of possible outcomes from a number of design decisions and for determining the relative merit of the developed solutions.

### 3.1.5 Symbolic modelling Systems

Symbolic models are those that are least likely to bear any resemblance to what they are intended to represent, and are the most abstract. Real world quantities and qualities are represented in the form of symbols. Common forms of symbolic models are mathematical models, electronic circuit and component symbols. In electronic modelling, abstract circuit symbols are used to model and describe concrete phenomena. Symbolic models often have least immediate communication value, in that they must be assimilated into a persons schema prior to application. There are many purposes for which symbolic models are the most convenient, particularly electronics where a range of complex concepts can be represented by simple symbolic blocks. Symbolic modelling offers a useful resource in the preliminary stages of electronic design experiences. From the development of an early tentative conceptual model, the progression is to symbolic modelling techniques. The systems approach considers the four primary subsystems of any system:

[1] Primary function of the system (process).
[2] Causes to which the system responds (inputs).
[3] Effects the system generate (outputs).
[4] Steady state maintenance (reference levels, interaction links of connectivity and communication).

One solution in helping students make sense of complex electronic design situations, is to create a variety of symbolic models of the key system parts (subsystems). This may be achieved through the media of three dimensional symbolic models (coloured shaped plastic with suitable icons engraved on their surface) representing the stages in the decision structure. Model building using symbolic techniques, allows decision structures to be more rapidly manipulated, constructed and modified, than graphically produced models. Symbolic modelling systems allows students to more rapidly see the inter relationships between the key concepts of system design; namely input, process, output and communication. At the earliest stages in electronic design experiences students need to identify the key elements of the system which in turn leads to the development of the control algorithm demonstrated in figure 3.6. An essential requirement of any modelling system is a set of symbols to express the various logical processes which occur. Such a set and their application is shown in figures 3.2 to 3.6 under the following five headings:

[1] Input transducers.
[2] Process/action elements.
[3] Interface transducers.
[4] Output transducers.
[5] System modelling algorithms.

## 3.2 The purpose of modelling Systems for C.D.T. electronic activities

3.2.1 Modelling is a key feature in helping students cope with complexity in electronic design activities. Analysis of questions relating to the value and purpose of modelling, for students engaged in C.D.T. electronic design experiences, needs to take cognizance of two key points; the different uses of modelling systems and the use of modelling methodologies compared with other methods. At the earliest stages of design, models help make clear and gives insights into how systems function and additionally are an aid to the communication of this understanding to others. Modelling helps predict the consequences of design decisions and how a systems will operate under a range of different circumstances and conditions. The purpose of any model is to represent the object of study and in this context all models fulfill a descriptive role. Some models are intended to fulfill more than a purely descriptive function. In O.R. (Operational Research) methods, the model building methodology is intended ıre 3.2

BOLIC MODELLING
JT TRANSDUCERS

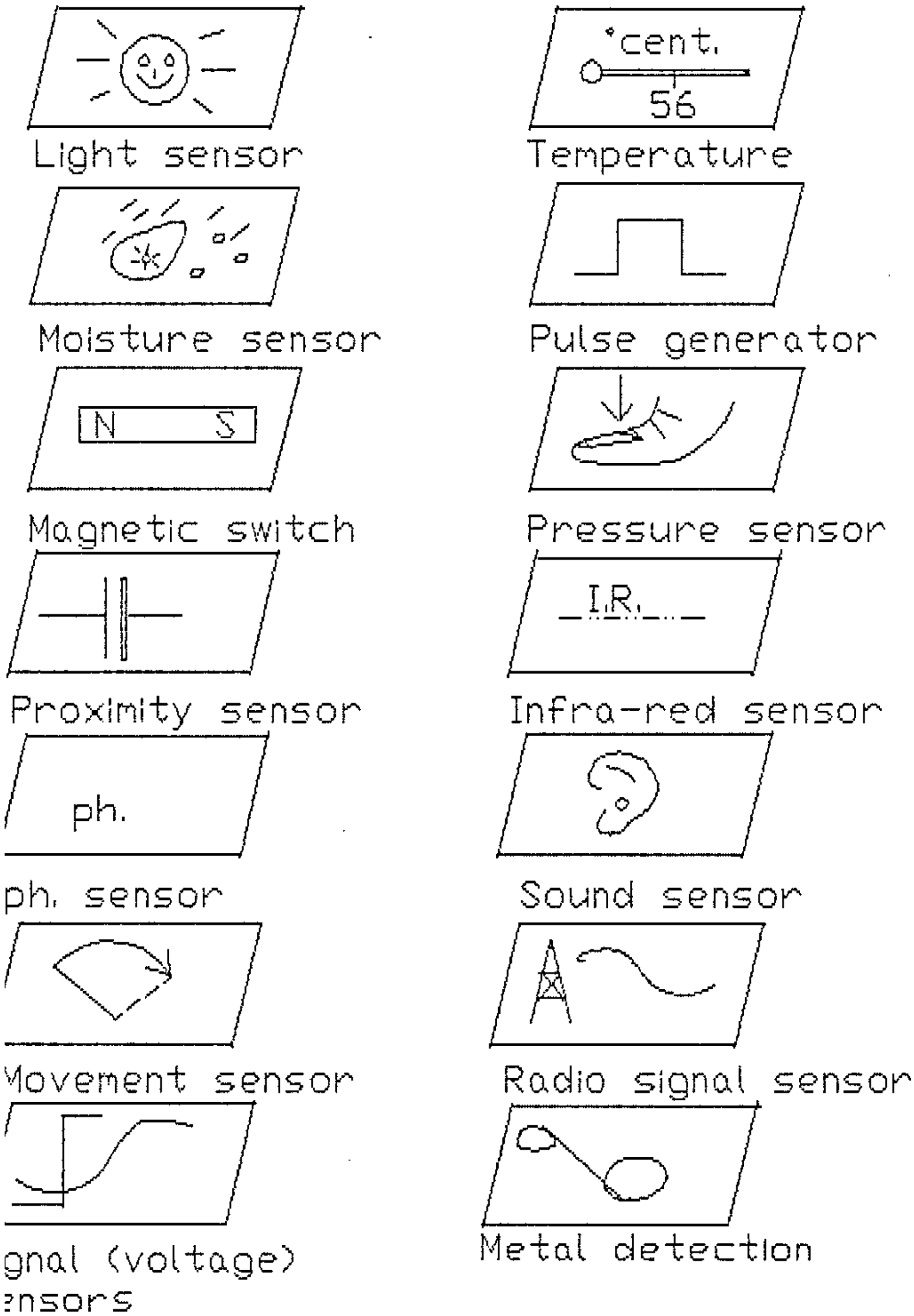


Figure 3.3

SYMBOLIC MODELLING TOOLS
CONTROL/PROCESS SUBSYSTEMS

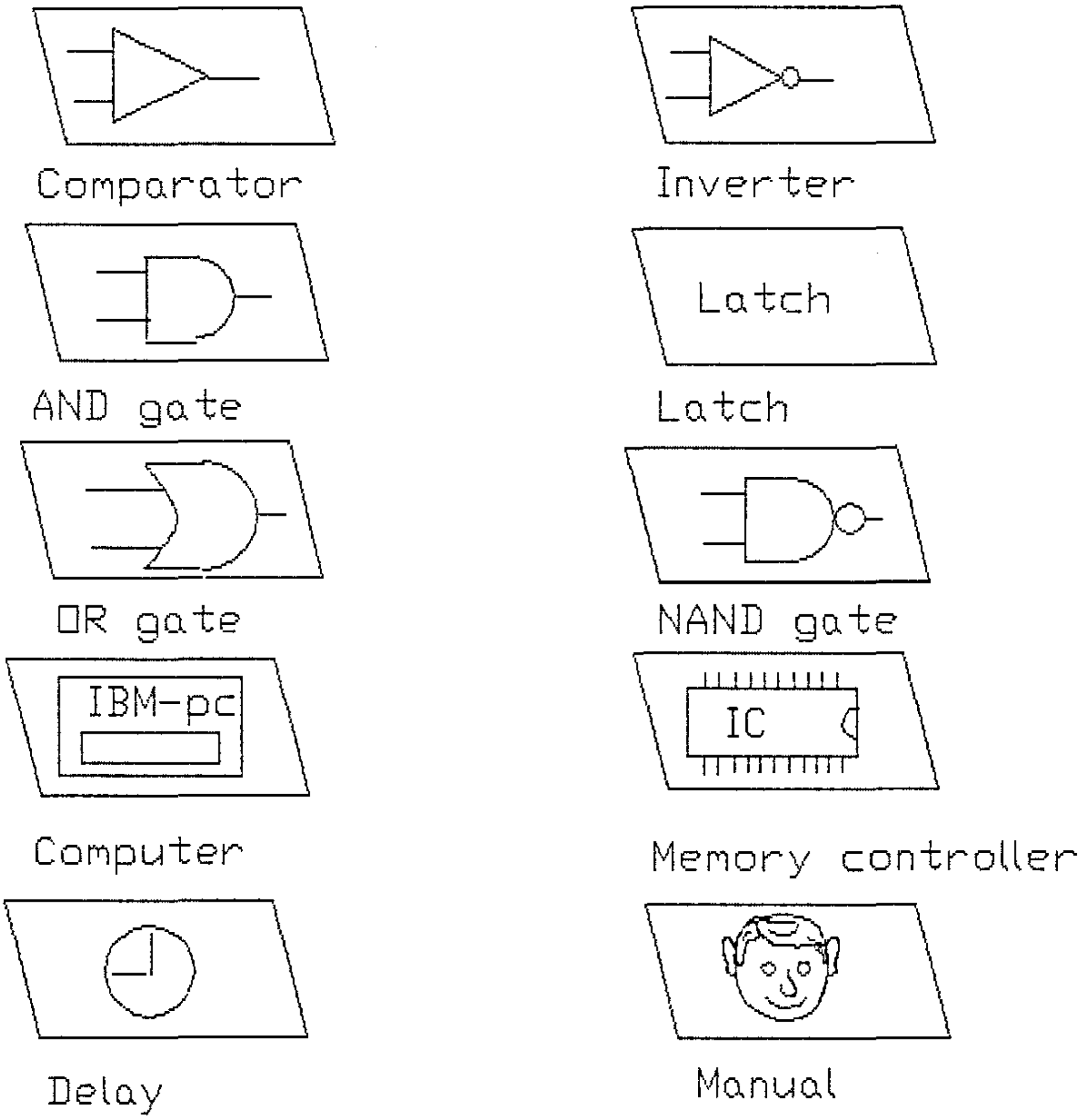


Figure 3.4

INTERFACE SUBSYSTEMS

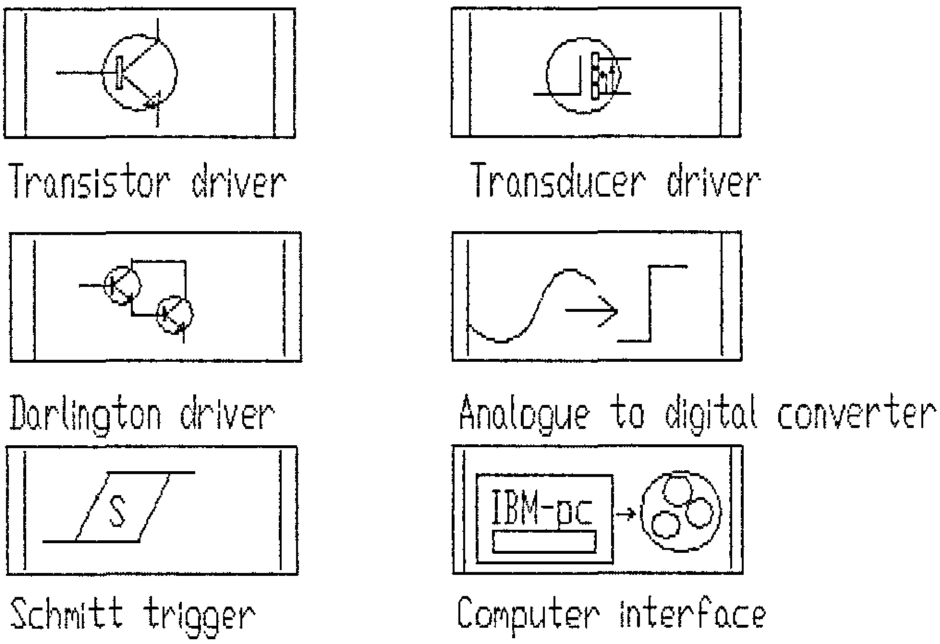
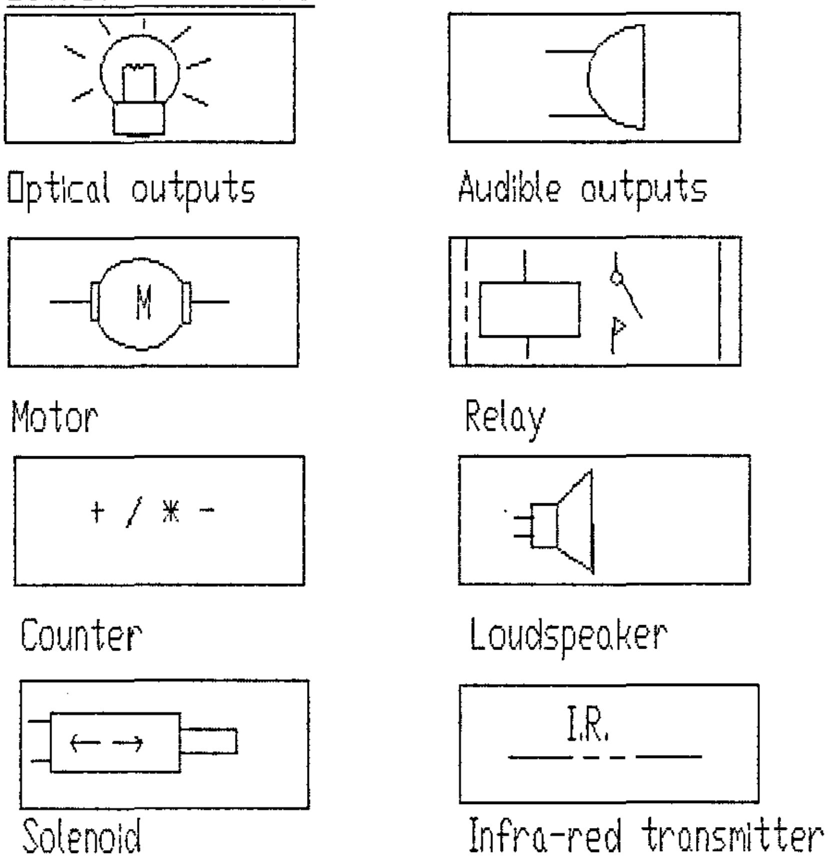
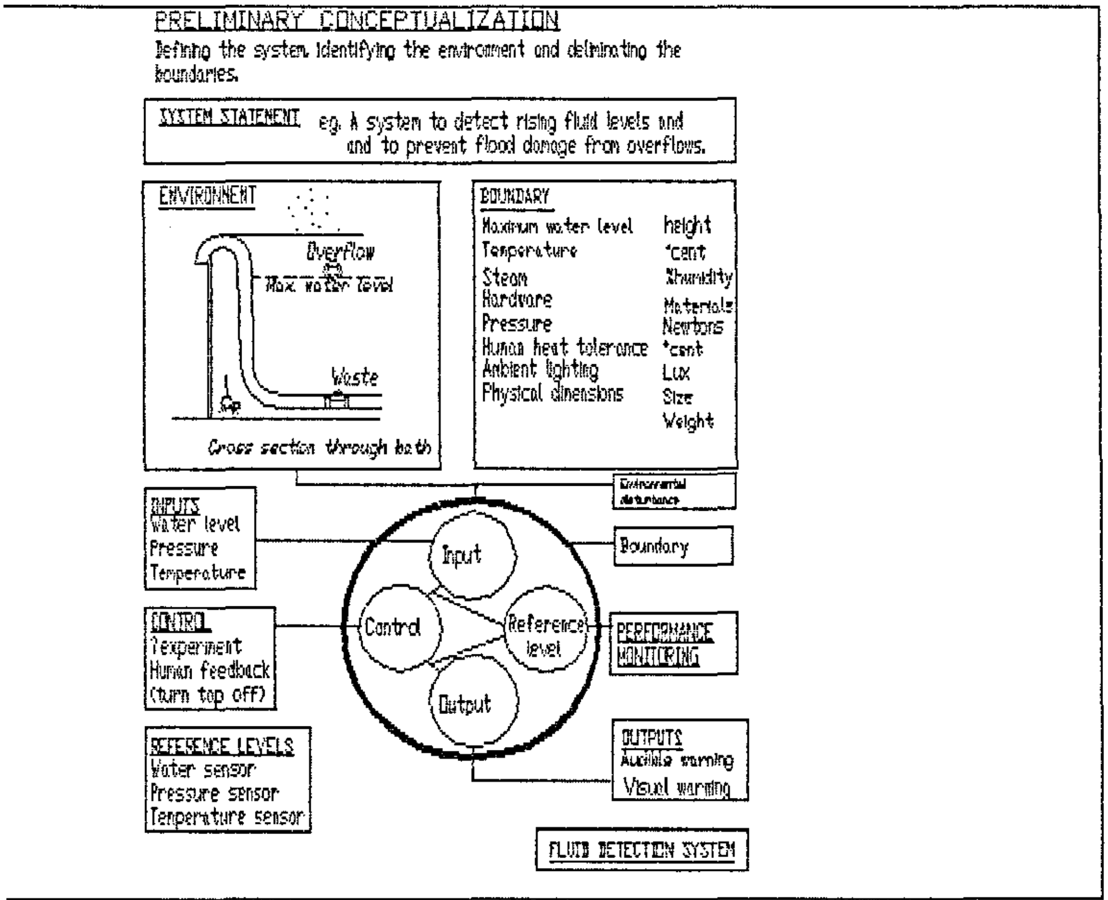



Figure 3.5

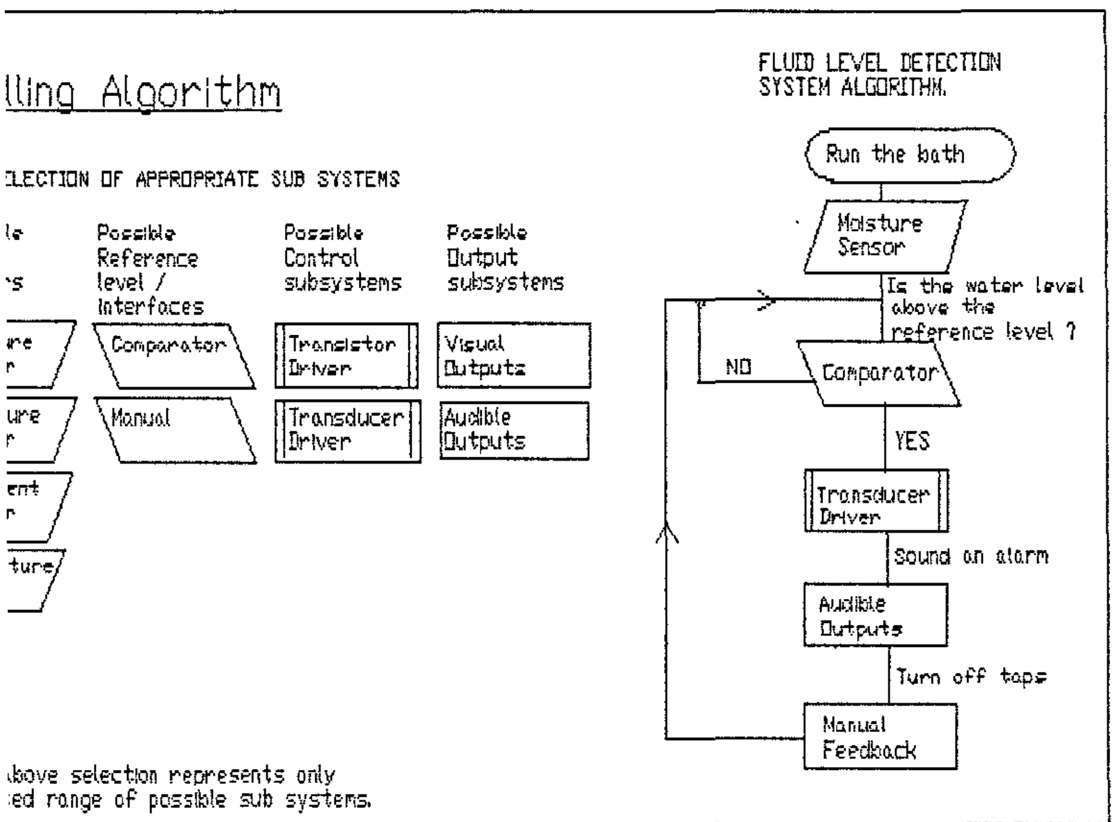
OUTPUT SUBSYSTEMS



ıre 3.6



PRELIMINARY CONCEPTUALIZATION
Defining the system, identifying the environment and delimitating the boundaries.
SYSTEM STATEMENT eg. A system to detect rising fluid levels and and to prevent flood damage from overflows.
ENVIRONMENT
Overflow
Max water level
Waste
Cross section through bath
BOUNDARY
Maximum water level height
Temperature °cent
Steam %humidity
Hardware Materials
Pressure Newtons
Human heat tolerance °cent
Ambient lighting Lux
Physical dimensions Size
Weight
INPUTS
Water level
Pressure
Temperature
Input
Control
Reference level
Output
Boundary
CONTROL
?experiment
Human feedback
(turn tap off)
PERFORMANCE MONITORING
REFERENCE LEVELS
Water sensor
Pressure sensor
Temperature sensor
OUTPUTS
Audible warning
Visual warning
FLUID DETECTION SYSTEM

lling Algorithm
ELECTION OF APPROPRIATE SUB SYSTEMS
Possible Reference level / interfaces
Possible Control subsystems
Possible Output subsystems
Comparator
Manual
Transistor Driver
Transducer Driver
Visual Outputs
Audible Outputs
bove selection represents only
ed range of possible sub systems.
FLUID LEVEL DETECTION SYSTEM ALGORITHM.
Run the bath
Moisture Sensor
Is the water level above the reference level ?
NO
Comparator
YES
Transducer Driver
Sound an alarm
Audible Outputs
Turn off taps
Manual Feedback

to describe in such a way that it goes beyond simple description, to explain the important aspects of the object of the system being modelled. The features of models which make them extend beyond pure description is the element of portraying causal relationships.

### 3.2.2 Description, explanation in electronic design analysis

The key concepts of description, explanation and design development in systems modelling are present in all modelling types ie. iconic, analogue, conceptual and symbolic. All models to a lesser or greater extent are descriptive, the degree to which they are explanatory depends on the extent to which they portray the nature and types of relationships. It follows that if it is possible to describe and explain, then the potential exists for analysis and ultimately control to be exercised. Without these two key concepts analysis is impossible. Additionally the descriptive properties of systems supports their role has communication vehicles.

When the information goes beyond the simple account of relationships between the system and its subsystems the model becomes a powerful device for explanation. If it is possible to describe, explain, analyze and communicate information about systems then the opportunity is developed to allow control to be administered. A major reason in attempting to make system models explanatory, is the desire to predict how the modelled system may be subject to control. Control of any electronic system is a fundamental concern for the modeller. Through the creation of a model and the analysis of the causal workings, progress is made towards the criterion of effective control. Control is not the purpose of a model, rather it is a consequence of it.

### 3.2.3 Heuristic devices

The value of modelling is not restricted to simple description, explanation, analysis or control. Models are also vehicles for increasing understanding and knowledge.

Modelling methodologies are heuristic tools, the process of investigating systems sufficiently well to formulate models, will necessarily result in a corresponding increase in knowledge. Heuristic or discovery aspects of modelling offer the potential for providing a better understanding of the system being modelled and also the investigations own purposes and motives. This is an important point in that the purpose of the modelled design investigation may be redefined.

### 3.2.4 Structure and modelling

Modelling helps ensure that knowledge is organized and focused in such a manner that learning is more unified into a structure. Modelling helps to interrelate and interpret observations in many fields of knowledge. Forrester (1968) contends "...that without an organizing structure, knowledge is a mere collection of observations, it is difficult learn from experience, it is difficult to use the past to educate for the future".

Bruner, "The Process of Education" (1960) supports the need for an organizing structure within which learning may take place. "Grasping the structure of a subject is understanding it in a way that permits many other things to be related to it meaningfully...good teaching that emphasizes the structure of a subject is probably more valuable to the less able student than the gifted one, for it is the former rather than the latter who is more easily thrown off". Bruner suggests that learning serves the future in two ways "...one is through its specific applicability to tasks that are highly similar to those already learned...A second way is through the transfer of principles or attitudes". He makes the significant point, applicable to modelling methodologies, that "...the continuity of learning that is produced by the second type of transfer, transfer of principles, is dependent upon the mastery of the structure of the subject matter". Bruner's three main claims, for the importance of structure, are applicable for the justification of structured models in electronic design contexts:

[1] Understanding fundamentals makes a subject more comprehensible.
[2] Unless detail is organised into a structured pattern, it is rapidly forgotten.
[3] Constantly reexamining material makes possible the narrowing of the gap between advanced and elementary knowledge.

Forrester (1968) makes the powerful claim that in the concept of system we find a common foundation that underlies and unites the two cultures of the sciences and the humanities in such a manner that the process of education is accelerated and more relevant to the needs of the wider society. The implication of Forrester's statement for systems methodologies is that throughout the organization of knowledge into a modelled structure, the social and human consequences of design decisions may be considered alongside the more technological factors associated with electronics.

### 3.2.5 Relationships between models

The four classes of model used in electronics design activities may be viewed as a continuous process rather than as separate categories. In most cases modelling is not restricted to a single model type, although in the early stages when learning the techniques of model manipulation it is probably more appropriate to teach the use of models separately. Modelling may be regarded as a continuous process, the sequence for electronic design activities being; conceptual, symbolic, analogue and iconic, each demonstrating an incline in the level of abstraction. Thus in the movement from conceptual to the iconic model, the relationship to the system being modelled becomes more obvious. If the purpose of the model is to represent appearance, then an iconic model is the most appropriate. Most typically in electronics the purpose of the model is to discover the range of possible systems suitable for the solution of a problem and to then discover alternatives methods to realize the model. When the primary purpose is to predict systems behaviour under varying environmental conditions with the intention of controlling operation, then the conceptual and symbolic models are the most useful.

3.3 Modelling compared against other approaches

3.3.1 The selection of the most appropriate modelling method will largely depend upon the degree to which it is to be used. Uses are related to the methods for dealing with complex situations and includes description, explanation, control, discovery and also the range of other methods available, and on the relative advantages and disadvantages of the respective methods. The range of methods available is best understood in terms of the degree modelling is to be used in the overall methodology. The degrees may be considered:

[1] Simulation of the system being modelled. Simulation involves investigating the behaviour of a system by firstly building a model and then experimentation to gain insights into how the system might be expected to work in different conditions.

[2] Operational Gaming. Models used in conjunction and combined with direct experimental manipulation of the system itself. Operational gaming involves some of the real life elements of the system operating in combination with some modelled elements.

[3] Experimental Optimization of the system itself with no or little use of models. Experimental optimization techniques follow on from early abstract models and help test at a practical level the validity of the modelled system.

3.3.2 Modelling approach decisions

The selection of the most appropriate modelling strategy will depend upon a number of interrelated variables. Husey et al (1971) considers the most important general criterion to be that of cost in its most general sense. The cost criterion embraces money, time, inconvenience, prestige, materials, appearance, human factors or any other yardstick of desirability or undesirability.

Simulation using models has obvious advantages for saving time and money. The use of models has many practical advantages, but it is important not to lose sight of the disadvantages. A model can never be exactly the same as the system it represents. The results of simulation are not always a reliable guide to what will happen in practice. All models represent reality with varying degrees of fidelity.

## 3.4 The process of model building

The process of modelling building may be identified to have five stages. The process is not necessarily linear, but rather is cyclical and iterative:

| | |
|---|---|
| REAL WORLD SITUATION | Observation of the state and behaviour. Establishing the environmental context of the system. |
| DERIVATION OF A SET OF ASSUMPTIONS | Statement of the systems function and procedure specification. Preliminary conceptualization. |
| DEFINING THE SYSTEM AND BOUNDARY | Ranking of the variables and establishing parameters. |
| FORMULATION OF A TENTATIVE MODEL | Simulation and operational gaming. Symbolic modelling. |
| TESTING MODEL | Experimental optimization leading to the practical realization of the system. |

Any modelling activity must include an explicit statement of the assumptions that have been made in order that a model can be derived. These assumptions may include the choice of boundary of the situation being modelled, or that certain variables be either ranked or ignored according to the nature of the investigation. The modelling process and its component elements are iterative, in which the testing of the model leads to decisions concerning the adequacy of the model. This in turn may modify the criteria by which the model is judged and through modification the initial conceptual model is reformulated.

It may occur that a single model is inadequate for a particular stage in the analysis or that a single complex model is not practical. In such circumstances the breakdown of the system into independent subsystems helps overcome complexity and aids the analysis and the solution of the design activity or problem.

## 3.5 Hierarchy of models

The problem of inadequate modelling may be overcome by the establishment of a hierarchy of models. The degree of resolution or detail that will differentiate one model from another in the hierarchy, is the degree of detail with which the elements of the model are expressed. The highest levels in the hierarchy contain broad descriptions of the situation (low resolution) while the lower levels contain increasingly more detailed descriptions of less of the system being modelled to a higher resolution.

## 3.6 Modelling approaches for electronic design contexts

A broad classification of problem types can be derived by taking the extreme ends of a continuum from "Hard" to "Soft". Brian Wilson (1984) suggests that this distinction leads to questions which are concerned with how an activity should be undertaken as opposed to what the activity is. A hard or structured problem is exclusively concerned with the "how" type of question, and typically reflects the types of design contexts that are encountered in electronics. Confronted with problems of switching a device in a range of conditions, requires decisions on how to achieve the desired state rather than why this should be necessary. Experience suggests that this is not always the case, when a major objective of design education is the establishment of rationality in students, it is necessary to justify design decisions by reference to the "why" type of question. Wilson further suggests that soft or unstructured problems are typified by being mixtures of the how and the why type of questions. In the area of production, Wilson gives the example that a manager may be faced with the problem that performance could be improved. The statement of the problem gives no guidance to what should be investigated to identify areas for potential improvement.

There is a need for a change in emphasis from the development of methodologies and techniques to solve "Problems", towards the establishment of new approaches to structure situations which lead to more diverse design opportunities. Wilson highlights the problems associated with the concept of problem. The notion that problems may be defined suggests that solutions may be found which removes the problem. This is not unreasonable at the harder end of the hard-soft continuum, but at the softer end problems may occur in a manner which makes them difficult to isolate. It is usual to find that problems are not straightforward, it is equally important to examine the problem and the situation in which the problem occurs. The ways in which problem situations are described need to be appropriate to the situation leading to the development of an appropriate modelling language. Mathematics traditionally have been applied to hard problems and have proven useful when the elements of the situation apply and behave in accordance with physical laws. Mathematics prove unsatisfactory when features of the problem include conflicting objectives, unclear or complex information flows, and people with differing perceptions and attitudes.

3.7 Chapter Review

This chapter has analysed and demonstrated the application of a systems approach to the modelling of electronic problems. Systems modelling approaches were argued to better support the design opportunities offered by electronics within a C.D.T. context, providing a powerful means by which complexity could be overcome and problems better structured. Most importantly systems approaches for electronic modelling overcomes much of the confusion and incompleteness found in verbal and written explanations and more effectively communicates design decisions. Models were demonstrated to clarify complex situations, allow the assessment of alternatives solutions and to quantify risk profile against the constraints of time, money, materials and the limitations of expertise.

Four major modelling strategies were identified and analysed; iconic, analogue, symbolic and conceptual models. Differences were examined between the essentially analytical, linear design method and the power of systems approaches to clarify thought in arriving at solutions to design problems. It was suggested that the linear sequential approach restricted the range of design response by the need to follow a tightly controlled route. Conceptual modelling using a systems approach being identified as a utilitarian tool for helping make sense of real world complexity and helping identify possible solutions. The identification of the system environment and boundary, was graphically illustrated to lead to the establishment of a conceptual system model in which the major subsystems could be identified in the context of their interactions and links of interconnectivity.

The development of the preliminary conceptual modelling stage was extended to the use of symbolic modelling tools namely; input transducers, process control elements, interface transducers, output transducers and the use of symbolic modelling algorithms. A range of possible symbols was graphically developed to demonstrate the possible application of this form of modelling. The power of this type model of model to describe, communicate and explain provided a means by which it was possible to predict how the system being modelled may be subject to control. Modelling it was argued, ensures that knowledge is organised and focused in such a manner that learning is unified into a structure and to help interrelate and interpret observations in many fields of knowledge. Modelling was regarded as a continuous process, the sequence for electronic context being; conceptual, symbolic, analogue and iconic, each demonstrating an incline in abstraction, the latter being the least abstract. When the primary purpose of the model was to predict behaviour under varying conditions with an intention of system controlling operation, then conceptual and symbolic models were the most useful. The process of model building was identified to have five major categories:

[1] Real world situation : Observation of the state and establishing the environmental context of the system.

[2] Derivation of a set of assumptions: Statement of the systems function and procedure specification. Preliminary conceptualization.

[3] Defining the system boundary: Ranking of the variables and establishing parameters.

[4] Formulation of a tentative model: Simulation and operational gaming. Symbolic modelling.

[5] Testing model: Experimental optimization leading to the practical realization of the system.

Models were demonstrated to be hierarchical in structure, those at the top of the hierarchy (conceptual models) offering low resolution of detail, whilst the lower down the modelling hierarchy the more numerous the models and the greater the degree of resolution of detail.

# Chapter Four

# SYSTEM CONTROL CONCEPTS

# Chapter Four

## SYSTEM CONTROL CONCEPTS

The establishment of an effective control vocabulary is essential in enabling the development, application and communication of system ideas and concepts. The development of such a vocabulary allows the discussion and collection of information about issues and situations relating to the use of a systems approach. Importantly, discussion on the fundamental system control concepts, enables the formulation of clear ideas about the mechanics of control situations, which may be subsequently applied to problem solving contexts.

Control is a term which describes an action which a system or subsystem applies to its own activities in order to reach and maintain a desired state. Electronic control systems may perform control over one or more processes. Control is needed to counter the various and changing influences of the system environment, on the activities of the system and the on the activities being controlled. Control systems may exist at a number of different levels of complexity. In chapter two Ackoff's classification of systems was seen to demonstrate a continuum of control complexity which is further developed within this chapter into a hierarchy.

### 4.1 Control hierarchies

Electronic control systems may be conceived in terms of hierarchies. Simple passive control systems with no direct influence on the environment being the most numerous and lying at the bottom of the hierarchy, whilst complex sophisticated systems maintaining multiple output and input control, through complex communication control loops occupy the highest levels. Control systems at the top of the hierarchy will be few in number, each with a wide environmental sphere of influence and providing outputs for subsidiary control systems below them in the hierarchy. Prestel the electronic communication and Viewdata system demonstrates the hierarchical nature of complex systems. At the highest level sophisticated mainframe computers monitor multiple inputs and outputs, whilst at the lower levels numerous terminals communicate with and make requests for information from the database system.

4.2 Open loop control Systems

Reactive (a concept developed in chapter two) or open loop systems tend to be the most simple, although the internal operation that achieves the transformation of inputs to outputs may be quite complex. Reactive systems operate on the inputs in predictable and invariant ways. Reactive systems are dependent upon their inputs and may only react or behave in a particular way when a certain threshold level is attained. Open loop systems will always react in the same way to an input. Computer printers typify open loop systems, which when correctly initialized will function predictably and invariably. Such systems do not possess any system for detecting the incorrect positioning of paper, resulting in printing output errors when the wrong starting position is given. Figure 4.1 demonstrates the model of an open loop system.

4.3 Closed loop control Systems

4.3.1 Closed loop or responsive (a concept developed in chapter two) control systems adjust their outputs to the effects of environmental changes by means of a closed loop. Their response is achieved by either feedback or feedforward control loop systems. To achieve the system goal or goals it must possess a means of comparing the present state of environment with a predetermined desired state. By comparing the present state of the environmental disturbance with the desired environment appropriate adjustments may be made to exercise control. Beishon et al (1980) suggest that a simple knowledge of the discrepancy is not sufficient in itself to exercise control. The system must use the knowledge to initiate action to reduce the discrepancy.

Figure 4.1

Open-loop control systems

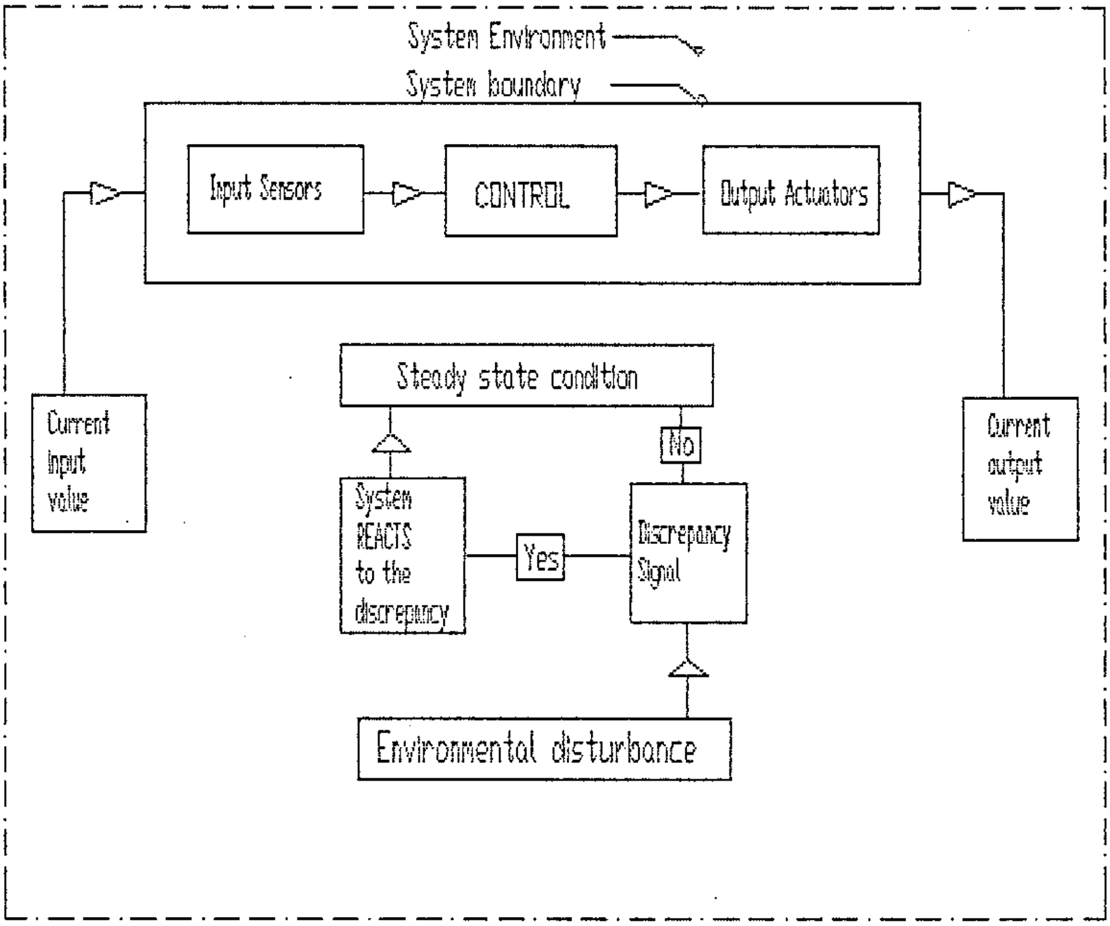
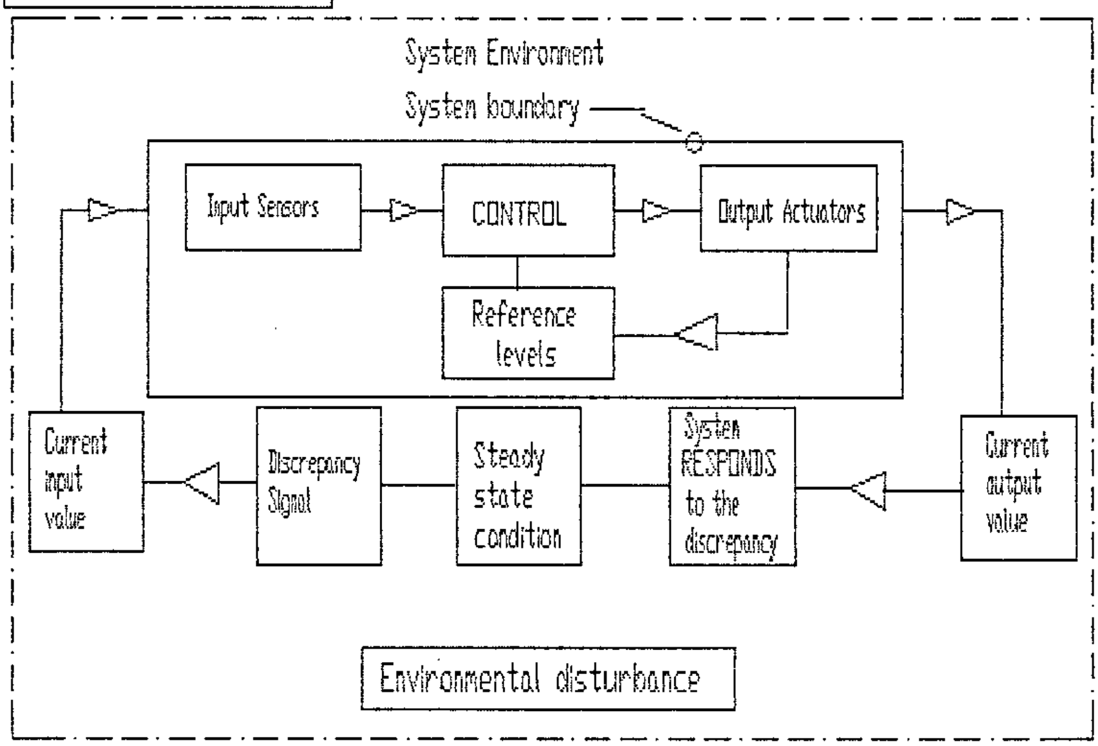



Figure 4.2

CLOSED-LOOP CONTROL SYSTEM.



The environment that influences a system consists of everything outside the system that has some effect on the system itself. Hence the control system that regulates the temperature of a Blast Furnace for its environment has the furnace interior, whilst its wider environment includes all those influences that make the furnace hotter or cooler, including oxygen and other blast gases, the fuel and the regeneration plant, coke ovens etc. Each component of the environment may provide a consequent effect on the inputs into the furnace. There are some aspects of the environment on which the control system can exercise little or no influence. These uncontrollable inputs or disturbances influence the performance of the system and in turn the systems output. To minimize environmental disturbance, optimization strategies are performed. Optimization is a primary control objective of most systems. Control systems achieve the regulation and the control of processes by a number of different techniques, most commonly by feedback and feedforward methods.

### 4.3.2 Closed loop control Systems: Feedback

The most important performance criterion of the closed loop systems is the maintenance of the system environment at a predetermined level, involving the elimination or control of environmental disturbances. The basic closed loop system operates by comparing the measured value of the current output, with the future desired output value, the information thus obtained is used to modify a range of appropriate processes, by increasing or decreasing them in order to reach and maintain the desired level.

Negative feedback: negative feedback operates at a level to reduce output discrepancy. Negative feedback systems operate on the level of the output, fedback into the process element, to move the current output towards the desired value and to then maintain this level stable around it. Such a system will respond to the disturbance in an attempt to maintain an optimum level. Central heating control systems use negative feedback to control environmental discrepancy.

Positive feedback: positive feedback systems operate on the discrepancy to increase its effect. Rather than reducing the effect it attempts to push the output level further away from the present level. The primary function of such systems is to enhance the output effect. Radio receivers use positive feedback to increase the oscillations from radio waves to enhance the effect. Figures 4.2 to 4.4 demonstrate feedback control loops and showing both negative and positive feedback control systems.

4.3.3 Closed loop control Systems: Feedforward

Feedforward control is essentially concerned with action in response to anticipated events, in an attempt to control and minimize possible disturbances. A combination of different responses may indicate future system disturbances. On the evidence of these predicted disturbances remedial action can be initiated. The role of many domestic thermostats in central heating systems is to predict rising and falling temperature and to act on the information to turn off or on the system to more closely control the environment. The thermostat turns off the heating unit prior to the optimum temperature being reached, the latent heat within the radiators continues to raise the temperature even though the heating unit is not functioning. Similarly, to avoid time lag in the heat from the heating unit reaching the radiators, the thermostat triggers the heating unit prior to the minimum temperature being reached. The important role of optimization is characteristic of all systems. In many circumstances a combination of feedback and feedforward control is applied: action in response to anticipated disturbance, combined with remedial action to reduce current disturbances to more closely regulate the process. Figure 4.6 demonstrates the feedforward control loop. Similarly to feedback systems the process of control can be to enhance or reduce the effects of the system disturbance.

Figure 4.3
Closed-loop systems : feedback control

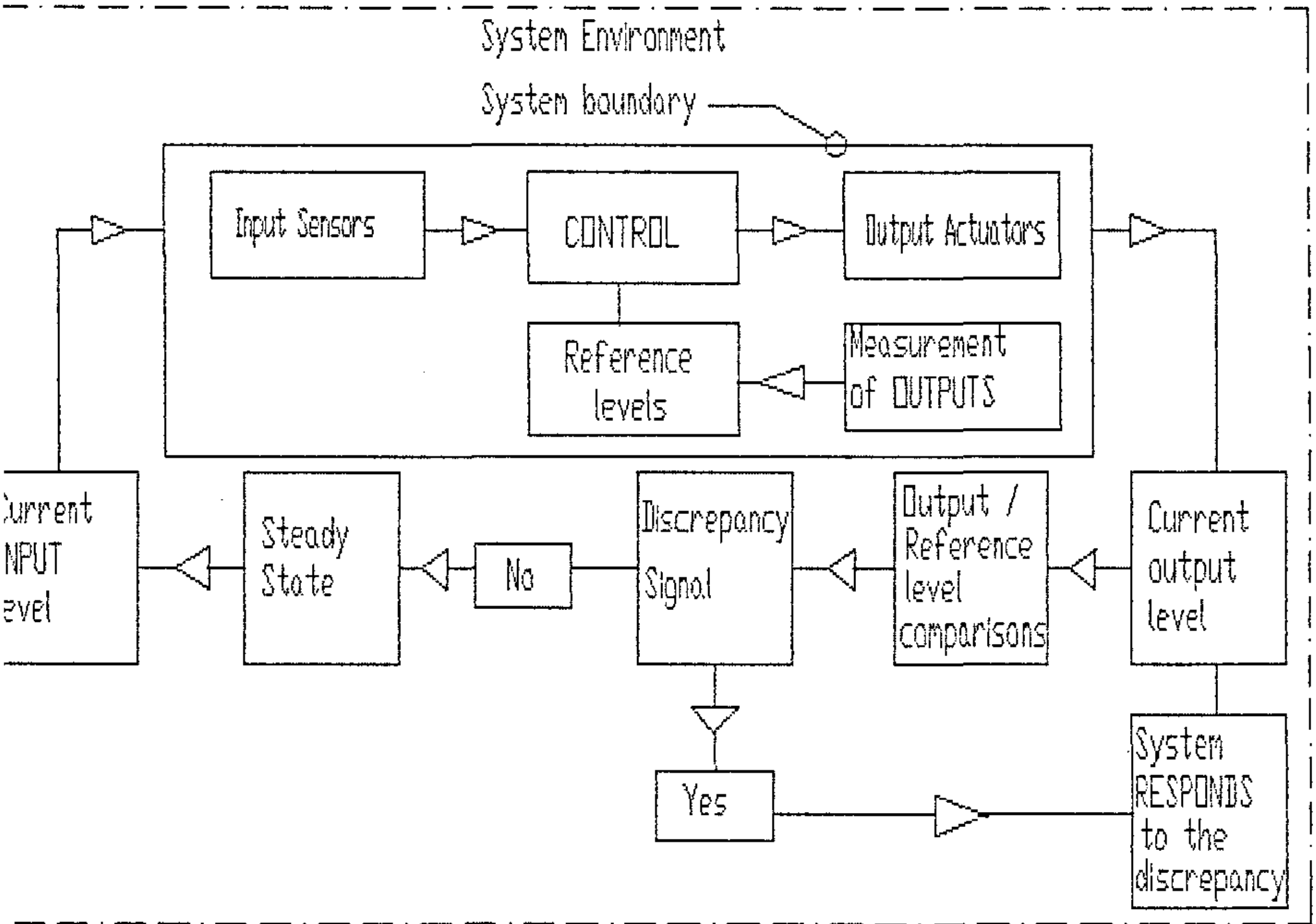



Figure 4.4
Negative feedback systems

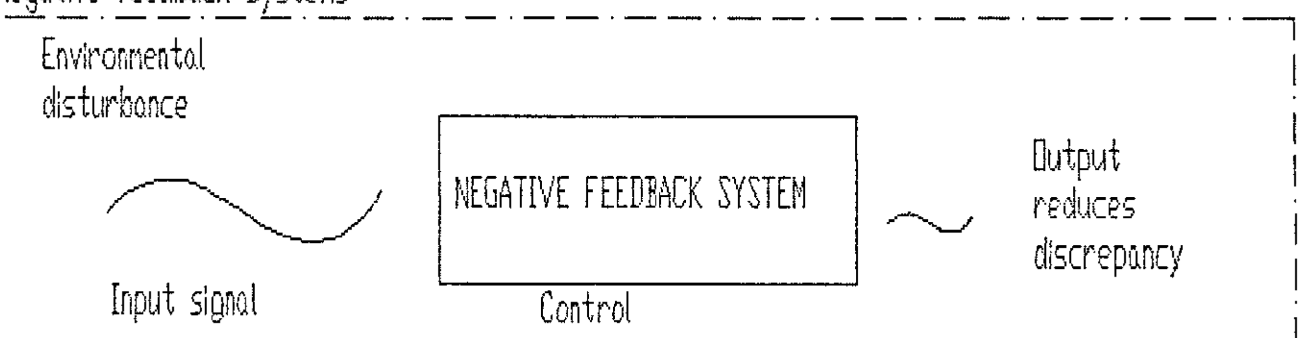
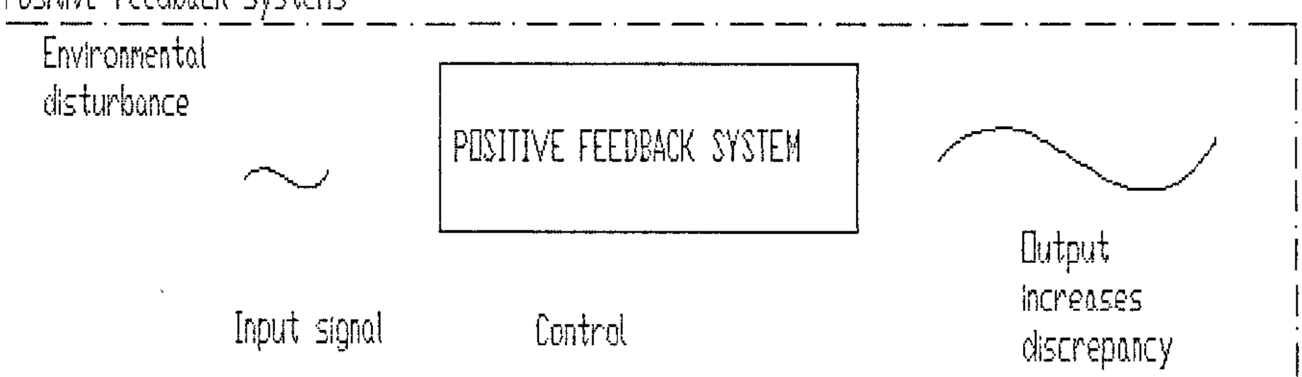
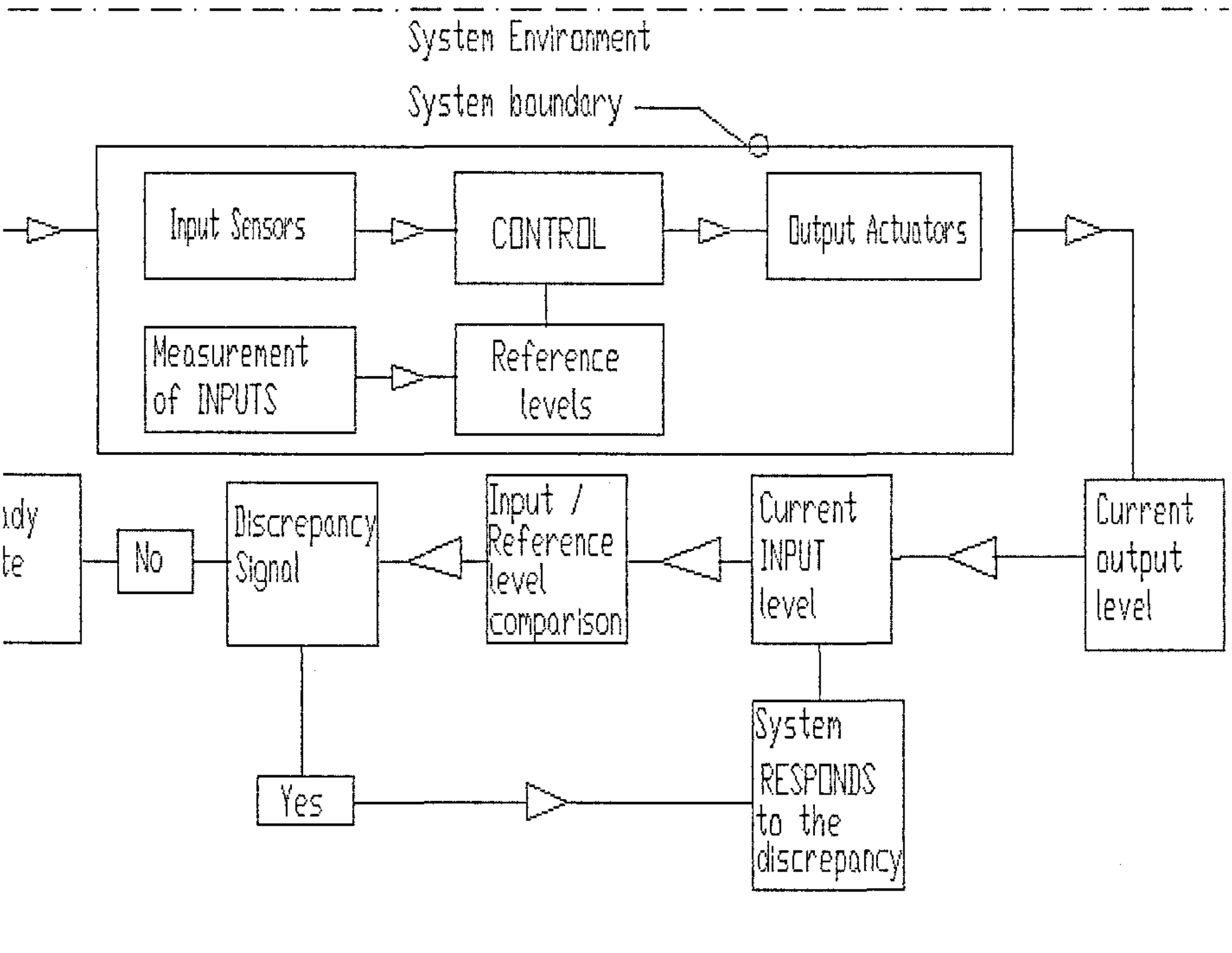



Figure 4.5
Positive feedback systems



-loop systems : feedforward control



### 4.3.4 Sequential and combinational Systems

The process which a system carries out may be either combinational or sequential. Curtis and Wilks (1982) contend that a combinational system is one where the result of the process is almost immediate and where the output is dependent on a range of inputs. A sequential process is one where the result of the process is dependent on the order or sequence of the input signals. Curtis and Wilks suggest that it is not possible for combinational systems to perform sequential processes, but that it is possible for sequential systems to perform combinational processes.

### 4.3.5 Passive Systems

Passive or monitoring control systems take cognizance of the measurable changes in both input and output, but take no remedial action. The usefulness of such systems lies in their ability to monitor and display information. A clock monitors time but cannot directly influence its passage. It does however indirectly influence the environment through the responsive action it initiates in other systems. Passive systems typically are the performance monitoring or reference level subsystems which trigger other subsystems.

### 4.3.6 Passive - automatic Systems

In the natural world plants retract their foliage in excessively bright sunlight and others close their foliage in conditions of darkness. The control systems function to protect and maximize environmental influences to their potential. Human beings similarly posses control systems, both automatic and differential. Automatic systems comprise those functions like breathing and digestion. Increased breathing rates occur automatically to increased blood oxygen level demand. Differential or noninstinctive control systems include those that are activated at random.

4.3.7 Linear and nonlinear Systems

Control systems do not take remedial action to all, changes in the system environment. Two systems of control may be identified; linear and nonlinear. In linear or analogue control systems the degree of correction is directly proportional to the deviation from the desired level. A deviation in output will result in a proportional increase or decrease in control action.

Nonlinear or digital systems respond to predetermined levels of output or input deviation. No action is taken until a discrepancy reaches a critical level when the full force of the controlling power is applied. A domestic refrigerators operating cycle turns off or on at two predetermined temperatures. It is unable to respond to variations within the intermediate "dead band". This overall cheap and reliable method of control is known as "bang-bang" control. This control technique is the most widely used of all domestic control systems.

4.4 Sampling incidence: Continuous and sampled Systems

In the majority of electrical and mechanical systems the sensing of the output is continuous. However in many systems the sampling process cannot be undertaken continuously and sampling must be of a periodic nature. It is important to comment that in most cases there are more than singular influences in terms of the environmental factors effecting the inputs and outputs. The control activity of a system in monitoring system influences and maintaining multiple outputs close to determined levels is a complex operation involving the monitoring and the integration of a number of system components and subsystems. Control may be achieved by either continuous or discrete systems. When the monitoring of outputs and processes is conducted continuously, and the control action is taken all the time a continuous control system is present. It is also possible to control processes and events by observing the state of the system environment at intervals and taking control action at particular points when the inputs or outputs digress from the control reference level. The time interval between observations will vary with the demands of the particular control process but generally must be shorter than the time it takes for the output process to change significantly. Such sampled data systems are particularly important to computer control systems. Human control systems are examples of sampled data control systems. The driver of a car does not continuously monitor the dashboard display, but rather samples the data either sequentially or at random. Sampling priorities are established, the driver may consider the reading of the speedometer to be greater importance to that of the oil gauge. If the time interval between successive readings is too great, because the driver is distracted or has too much to do, the vehicle may move into a state of disturbance.

## 4.5 Understanding the process: Control models

4.5.1 The degree of understanding required to control an environment is proportional to the complexity of the process being studied, the skill and experience of the analyst and the resources of time and effort to enable understanding to be gained. The outcome of the analysis is referred to as a control model. The control models of the processes are of two main types. Descriptive models provide a qualitive description, whilst quantitive models and prescriptive models allow the attachment of quantitive data to subsystems and the interaction links to assess optimum system performance. Chapter seven discusses the principles by which decisions may be quantified, using experimental optimization techniques. Control models therefore appear in the form of quantitive and qualitive dimensions. Quantitive models in which the system elements have numbers attached presupposes that a prior qualitive model existed.

### 4.5.2 Deterministic control models

These models derive from the idea of mechanisms where the interaction between the elements of the process can be defined precisely. The effect of varying an input can be traced in a simple manner through the change in output. The effect of adjusting the volume control determines the level of output from the loud speaker.

### 4.5.3 Stochastic or statistical control models

Stochastic control models occur where human actions form an important input to predominately physical processes. Where the number of inputs to a process is large and the complexity of the interaction extreme, only probalistic statements can be made about the possible outcomes. The response of electronic arcade games is stochastic rather than deterministic.

### 4.5.4 Steady state control models

Steady state control models are based on the average performance as compared with dynamic models which allow for fluctuations in performance.

### 4.5.5 Dynamic control models

Dynamic control models take account of the time dependence of many processes of a physical and human nature. Dynamic models take cognizance of the possible time delays between input and output; in designing such control systems the delay must be taken into account. Many electrical microwave controllers take account of the necessary time delay when cycling from the autodefrost sequence to cooking sequence.

### 4.5.6 Local control models

Local control models are useful in describing the behaviour of subsystems, as compared with global models which integrate and describe all subsystems into an overall system.

## 4.6. Transducers: Actuators and sensors

4.6.1 Transducers form an important part of any operational electronic control system. Transducers are often referred to as sensors which convert a range of inputs into electrical signals. Such a definition ignores the wider meaning of the term and restricts application to the contexts of inputs only. Transducers are normally subsystems of larger systems with one input into them and one output away from them. Transducers convert signals into a signal of a different form or magnitude.

Transducers can operate at the level of input sensors or as output actuators. A microphone is an input transducer or sensor, converting sound waves into electrical signals. A loudspeaker is an output transducer or actuator, converting an electrical signal into a sound signal. A light dependent resistor is an input transducer or sensor, converting changing light intensity into an electrical signal. A lamp is an output transducer or actuator converting electrical signals into light. Transducers additionally fulfill an important interface role in amplifying and conditioning small signals or buffering larger ones to prevent system damage. Transducers can operate at the level of linear or nonlinear control. Those that switch mode from one distinct level to another are referred to as binary transducers.

### 4.6.2 Quantisation

Curtis and Wilks (1982) refer to the control concept of quantisation, whereby analogue signals are artificially converted to digital signals. In control situations a common requirement is to quantise analogue signals to make them either on or off. The analogue signal generated by rising water temperature, heated by an immersion heater in a remote holding tank is quantised by a thermostat, switching the linearly changing temperature on and off at predetermined levels.

## 4.7 Output quantification

The assessment of a systems output performance is essential in monitoring the effectiveness of the control model. Singular outputs present few difficulties in measurement when the output is a physical entity or product. Problems occur in the following circumstances and are often compounded by the presence of human responses and attitudes.

[1] Multiple tests or measurements may need to be made on the system. The upper and lower range limits within which the outputs perform must be clearly specified.
[2] Qualitive judgments require more effective decision making techniques. Criteria related to human preference are difficult to quantify.
[3] Output from the system requires sampling for test and reference purposes. When output from the system is required for test purposes cognizance must be taken of the size and frequency of the sample and the means by which quantification will be achieved.

It is sometimes more convenient to consider system outputs in terms of the constraints and the influence they impose upon other systems and environments, rather than as outputs in their own right. The hidden outputs from a visual display unit for example may place constraints on the design and the performance of the system. Colour monitors may offer enhanced display capability but have the hidden constraints of higher radiation output than monochrome monitors. Qualitive judgments about the output display must be reconciled with the systems environmental factors. The output of the system, normally expressed in terms of behaviour is paramount in assessing the extent to which control may be exercised over it.

## 4.8 Communication

Inadequate communication within control system can lead to two types of problem, firstly when the communication fails to take place and secondly when the communication is distorted.

When the communication fails to take place and little or no information is received by the decision taking element, no logical control action is likely and the system will operate in an open loop mode. When the communication of the current state of the outputs is distorted, the control action is taken on incorrect information and the output is likely to deviate more from the desired state. Between these extremes may exist situations in which communication of the information is imperfectly transmitted back to the process controller. The effect is commonly to amplify the error introduced into the control loop, so that the output may exhibit severe random variations caused by the imperfections of the control, rather than by the system disturbance.

## 4.9 Compatibility of reference levels

Problems of effective control are compounded if the reference levels to which the process is applied are not clearly defined, stated, or else are defined or stated in such a manner that does not compare easily with what has or can be measured.

A system controlled wholly or partially by a human operator is prone to individual qualitive interpretation according to the experience, beliefs and values of the controller. Such qualitive judgments may then be inappropriately used in the process of comparison to lead to control action. The implication is that a systems response may be unpredictable and unreliable due to the shifting reference perspective of the human operator. In any physical system, in which the control variable is inaccessible to the control and sensing instruments, it is necessary to compare more accessible information and variables. These accessible variables need to have been shown by theoretical, experimental and practical tests to indicate the state of the variable to be controlled. Reference values in such circumstances have to be converted to one or more measurable values which can be controlled. Time lapse may create problems in the indirect control variables, due to changes in relationships between the accessible variables, thus reducing the effectiveness of the control loop.

4.10 Systems failures: Difficulties encountered with controlled systems in maintaining desired levels

Electronic systems have two primary objectives; to keep close to determined reference levels and to reach a desired state or return to it after the systems environment has bees disturbed. These two objectives may be used has a guide to a system stability. High stability systems may be defined has those that resist change in the system environment, but if perturbed return quickly and smoothly to the desired state. Problems which occur in control systems are of ten types:

4.10.1 Those arising from the nature of the control method.

Positive feedback systems are used to magnify rather than reduce discrepancy. The effect being to push the output further away from the input level. Oscillations in radio circuits are magnified where positive feedback produces an amplified voltage. Positive feedback instability involves the feeding in error of the signal from the output process to a controller which increases the deviation from the desired level. The system then becomes unstable and depending upon the circumstances, the process may fluctuate from one extreme to another. Positive feedback error may occur in both human and physical systems. In human systems, for example, rumours of sugar shortage may result in increased sugar sales resulting in a confirmation of the rumour and sugar shortages.

4.10.2 Specific system failures

Those of a more specific nature are related to the activities of measuring, sensing, communicating, comparing, deciding and amending.

4.10.3 Inadequate modelling

Those arising from inadequate modelling. To adequately control a process a thorough understanding of the requirements of the systems must be exist. Poor or incomplete understanding results in the development of a control model which is restricted in its ability to cope with the control required of it.

4.10.4 Loss of measuring and comparative capability

Loss of measuring and comparative capability leads to an open loop situation, or worse, one in which the controller attempts to rapidly shift the process in a direction incompatible with the true environmental disturbance.

4.10.5 Total control loss

A complete loss of control potential leading to a situation in which the controlled output assumes a value markedly different from the target value. This may result in a complete system failure or a failure of one of the system elements or subsystems.

4.10.6 Input magnitude

The level of the input from the environment may be of such a magnitude that the range of variation available is unable to cope with or to respond in such a way to counteract the disturbance.

4.10.7 Defective decision making element

The decision taking element in the controller may be defective leading to unpredictable results and responses.

4.10.8 Communication loss

Communication breakdown may occur between the measurement of the output and the decision making device, the subsystem to vary the inputs to the process, causing loss or reduction in the control loop.

4.10.9 Component level failure.

It is not uncommon for total system breakdown to occur when a single component fails.

4.10.10 Time lag instability and inertia

The resistance of systems to change is called system inertia. Inertia is a major problem in limiting the ability of large or complex physical systems to respond and change their state with the same speed has smaller systems. In systems with inertia it is inevitable that there will be delays before the effect of the changing input values can be detected and then responded to. In other systems there are intrinsic delays which are part of the process of transforming inputs to outputs. Control systems applied in these cases have to take account of the dynamics of the processes being controlled, otherwise the control signal is liable to move too far in one direction. The resultant extreme change in system state creates a condition of reversal. This extreme change in level is referred to as hunting when the cyclical swings are small and the oscillation when the swings of state are large. Damping is the process of restricting the oscillations.

## Chapter Four

### 4.11 Chapter review

This chapter has discussed the importance of establishing an effective control vocabulary in developing and communicating system concepts, ideas and importantly the realization of the conceptual model into an operational system. The formulation of clearer ideas about the key control concepts supports the development of better designed systems. After a system has been conceptualized an effective control system must be established so that the optimum design conditions can be realized.

Control is necessary because of environmental disturbance which is a feature of all systems, which cause actual performance to deviate from the predicted performance. Control is an integral part of all system designs, control requirements must therefore be identified at the earliest stages. A systems approach changes the emphasis from the practical mechanics of control loops and focuses attention to questions where control should be exercised, what level of control is needed and what resources (and subsystems) are required. Electronic analysis using systems is concerned with the "what and why" rather than the "how" type of question.

Control was defined in terms of the action systems initiate to reach and maintain control over environmental disturbance. The ways in which systems adjust to the effects of environmental disturbance was discussed in terms of open loop and closed loop control systems. The problems of open loop systems revealed an inability to respond to varying levels of input discrepancy and the invariant, reactive nature of their performance.

Closed loop systems were shown to operate in two major modes, feedforward and feedback control, relevant to the way reference levels are monitored and then acted upon. Feedback control systems operate on the measurement of the output level fed back into the control subsystem to maintain the desired level. Feedforward systems operate on the level of the measurement of the inputs to maintain the desired output level. Both forms of closed loop system operate at two levels; positive and negative. Positive systems operate on the inputs to increase or enhance the output level. Negative systems operate at a level to increase output level discrepancy. The form in which the control is exercised was discussed in terms of linear and non linear (or bang bang) operation. The difficulties of achieving effective sampling was discussed with reference to continuous and sampled, sampling systems.

The degree of understanding to exercise control is proportional to the complexity of the process and the resources (human and material) available. The control models developed were identified as either qualitive descriptive models or quantitive models which permit the attachment of numbers or values to assess system performance. Quantitive models have a number of dimensions; deterministic, stochastic, steady state, dynamic and local models.

The operational aspects of control focused on the use of input, interface and output transducers. Distinctions were drawn between sensors, binary interface transducers, linear interface transducers and actuators. The conversion of linear to digital highlighted the quantisation of analogue to digital signals, whilst the assessment of output performance suggested that problems may occur when multiple tests need to be made, qualitive judgments are to be drawn and when sampling of the output is made for reference purposes. The problems associated with system failure was discussed under ten major headings.

# Chapter Five

# QUESTIONNAIRE BASED RESEARCH DESIGN

## Chapter Five

## QUESTIONNAIRE BASED RESEARCH DESIGN

This chapter outlines the methodology of questionnaire design, the strategies for data collection, analysis and the interpretation of information relevant to the use of a systems approach to electronic teaching within C.D.T. design and make context. An outline of the statistical procedures employed is supported by the essential background to the statistical concepts and methods employed. Such information helps make clear the methods of analysis in the description of the data and also the inferences obtained from the properties of the sample. Emphasis is placed upon the validity, reliability and the ease of interpretation of the statistics encountered, with a discussion of the mathematical methodology employed.

### 5.1 The selection and adequacy of the sample

5.1.1 It must be stressed that the sample drawn from the total C.D.T. population, was not a true random sample and consequently any inferences obtained cannot be applied with any certain to the national scene. The extent to which the results were reasonably applicable to a wider local population, and the extent to which description and inferences could be obtained from their analysis, was limited by the size of the sample and the extent to which control could be exercised over the distribution of the questionnaires. It will be demonstrated however, with the appropriate statistical tests, that when inferences are drawn from the sample to wider the C.D.T. population, that the sample is representative of the local C.D.T. populations of Derbyshire, Lincolnshire and Staffordshire. In this context the inferences and the descriptions are only applicable to the local C.D.T. population.

Selkirk (1978) contends that a sample size of around 100 is satisfactory, with special statistical tests being required for samples of less than 30. The small scale (93 returns) of this research project, highlights the need for a wider and more extensive study at a national level of the C.D.T.

population. This survey, in terms of sample size, is of a satisfactory size to enable tentative description and inferences to be made. Despite limitations of sample size, design and control, the strength of this questionnaire based research lies in the valuable insights it provides, the descriptive and inferential statistics that are accented and the pointers that are offered for future research.

5.1.2 The C.D.T. population of the survey

The investigation was undertaken using the population of the C.D.T. teachers in Derbyshire, Lincolnshire and Staffordshire of whom only some were actually used in the research. Additional to this area a number of responses were obtained nationally from other local education authorities and also from the private education sector. This group referred to as the sample, provided information concerning teachers perceived views on a range of questions related to C.D.T. and more specifically electronic and associated pedagogical methods. Additionally a range of more objective questions, provided information which included aspects of initial and inservice training, school establishment and resources. The constraints of time, money and secretarial support placed restrictions on the size of the sample drawn from the total population.

The accuracy of the estimates of any population parameter depends upon the manner in which the sample is selected and the design of the questionnaire. A major criterion for the selection of the sample being the desire for the results to be applicable to a wider C.D.T. population and to a lesser extent to provide pointers for more extensive national research. The necessity to draw subjects in an unbiased way, as a sample from the local (but non the less extensive) C.D.T. population helped make possible statistical description and limited inferences of the results to the population as a whole. Every effort was made to ensure that the sample was both random and independent, although an unavoidable loss of control over the distribution of the questionnaire compromised these aims to a limited extent.

# Chapter Five

The basic criteria applied to the design of the survey were; validity, appropriateness, control, sample adequacy, reliability, replicability and feasibility. The criteria for the selection of the sample was base on the requirement of randomness and independence. In the design of the sample a key objective was to ensure that the sample was representative of the population of interest. With respect to selecting a representative sample from the C.D.T. population, practical logistical difficulties occurred in ensuring that the sample was indeed typical. Post stratification (by means of weighted questions) ensured that it was possible to categorize a range of respondents according to their range of expertise and attitude. Question 22(i) and 22(iv) enabled the division of teachers according to their preferred approach to electronics teaching. Question 10 highlighted the range of expertise, which demonstrated a normal distribution.

5.1.3 Sampling strategies

The sample drawn from the population would have been a simple random sample if all the members of the population had had an equal chance of being selected. To meet the objectives of randomness and independence, the selection of the sample was based, wherever possible on the following three criteria:

[1] Every member of the population should have an equal opportunity of being selected as a member of the sample.
[2] Where possible the sample should be by replacement.
[3] That members of the sample should be selected independently of one another.

The stated desire to achieve random sampling, in which every member of the population had an equal chance of being selected, was achieved in all but one instance, Staffordshire, where special arrangements were made by the county C.D.T. Inspector. To offset any general applicability of the results as a consequence of this, a number of statistical test were adopted to test that the sample was based on a sound statistical foundation. These tests included:

[1] Test for no association.

[2] Sign Test.

[3] Standard Error of the sample means.

Additionally the data from the three major counties was analysed separately and the results compared to check consistency. With the exception of Derbyshire, the proviso that the selection of the sample be carried out with replacement was not performed. The single distribution of questionnaires, during the period February to March 1986 was performed without any opportunity for teachers to complete a further copy. The practical difficulties of controlling the distribution of the questionnaires in Lincolnshire and Staffordshire made the proviso of replacement inappropriate. The five Derbyshire teachers who participated in the initial pilot survey were replaced in the list for the main questionnaire issue (though neither were selected for a second time).

5.1.4 C.D.T. population: geographic distribution

The division of the population into three distinct data collection regions, according to the place of employment of the C.D.T. teacher proved easier to achieve than either a regional or a national division based on place of residence. The C.D.T. population in all three local education areas were well supported by a strong advisory and inspectorial service. Within the Staffordshire L.E.A. subjects were drawn from two distinct samples. A stratum of ten schools was identified by the county inspector, Mr A. Gordon, to reflect that area of the population with some experience and expertise in electronics teaching. A further group within Staffordshire were randomly selected.

The samples from Derbyshire and Lincolnshire were of a random and independent nature. After telephone conversations with the Lincolnshire advisor, Mr A. Breckon, the offer of assistance with the random distribution of questionnaires was made and accepted. The questionnaires were distributed by internal county mail, in Lincolnshire and Staffordshire. Within Derbyshire schools were listed alphabetically and numbers allocated. Random numbers were generated by computer to select the appropriate schools. The kind assistance given by Mr Breckon and Mr Gordon saved much effort, time and financial outlay. Mr John Wooliscroft (Derbyshire) provided advise and assistance.

## 5.2 Data collection

5.2.1 Research based on the data collected from questionnaires relies heavily on high response rates for acceptable inferences and description to be drawn from the results. It therefore follows that the distribution, collection and other follow-up arrangements be crucial factors in research design. Data for this research project was collected using five distribution strategies:

[1] L.E.A. advisory and inspectorial services.
[2] National Journal (J.J.P. Goody 1986).
[3] Electronic Mail (Times Network System).
[4] Loughborough University Design and Technology Department.

Three main considerations influenced the selection of the distribution and collection methods:

[1] Personal or postal. The convenience of postal distribution was offset against the predicted higher response rates of questionnaires delivered by personal contact.
[2] Direct or indirect. The grouping of the sample on a regional L.E.A. basis made it possible to contact the sample directly using the agency of the L.E.A. administration. Loughborough University Design and

Technology Department also distributed a number of questionnaires.

[3] Nominated or chance. Samples for the questionnaire comprised 17.57% nominated and 82.43% chance subjects.

5.2.2 Distribution techniques

In practice a combination of distribution techniques were adopted: personal, postal, direct, indirect and nominated and chance. Questionnaires were distributed by L.E.A. administration and returned in prepaid envelopes. The cooperation of the C.D.T. education advisers providing the sample, proved to be a paramount factor in the selection of the sample and the distribution of research materials. The practical assistance in distributing questionnaires and also in encouraging respondents to complete and return the results, proved a major factor in the high return rate. Against this must be measured the loss of control in the selection of the sample. Questionnaires were also circulated nationally in response to a paper published in the national electronics journal "Electronic Systems News" (J.J.P. Goody 1986). Further contacts were achieved by electronic mail (T.T.N.S.). Returns were exclusively postal.

5.3 Response rate

Table 5.1

| | Distribution | Response |
|---|---|---|
| Derbyshire | 25 | 22 |
| Lincolnshire | 25 | 17 |
| Staffordshire | 25 | 22 |
| Nationally | 18 | 13 |
| Totals: | 93 | 74 |

Response rate: 79.57%

5.4 Question Construction

5.4.1 "Many personal characteristics can be measured by the use of tests made up of demands (usually but not always questions) called items" M.B. Youngman (1979). The purpose of the tests constructed (and outline below) in this project attempted to quantify differences in the C.D.T. population on the variables (quality) being measured. The tests distributed the sample along a scale that distinguished those at one end who may be said have more of the quality being measured than those at the other who have least.

The construction of the questions started with an attempt to conceptualize the quality being measured. The next step being the operationalization of the quality ie. to specify those observable responses which if present demonstrate the presence of the attribute under test. The test items (questions) were written, scrutinized, criticized, edited and rewritten into the trial version of the questionnaire in December 1985. The use of Likert scales is detailed later in this chapter. The process described is formalized under two criteria of reliability and validity (see below).

5.4.2 Piloting

The purpose of the pilot study was to remove ambiguities, clarify instructions, restructure inconsistencies and allow coding strategies to be developed. The dependence on the instrument (the questionnaire) rather than the researcher made the pilot assessment an important element of the total research project. A small scale application prior to the distribution of the main questionnaire was undertaken to evaluate instructions, the questions and the types of response. The questionnaires were administered personally to five C.D.T. teachers in the Erewash district of Derbyshire. The responses and the follow up interview made possible the modification of the questionnaire. The initial pilot questionnaire proved difficult for the subjects to respond accurately because of ambiguities and inconsistency in the use of expressions. Coding systems were trialled to ensure compatibility with computerised analysis of the data.

## 5.5 Reliability and validity

5.5.1 The reliability of a measure is the extent to which it performs consistently. K.C. Thomas (1978) proposes "...that to be acceptable as a reliable measure of attitude a scale should have a reliability coefficient of at least +0.80. Correlation coefficients for this test measured a mean of +0.86. Tests for reliability included the observation of the variances in a split-half reliability correlation The reliability of the subjects responses was further assessed by follow up interview to test the match between earlier questionnaire answers. If samples are drawn from the same population one would expect the variances to be similar in size and the F-Ratio to be close to 1. The F-ratio is found by the calculation of the variances, the value of the larger variance is divided by the smaller, producing the F-ratio. Tables giving the upper limit of F for the 5% significance level are tabulated according to the degrees of freedom for the two samples.

Table 5.2 F-Ratio: Table of F=9.60 (5% significance level)

| | |
|---|---|
| Analogue electronics | 1.19 |
| Digital electronics | 1.24 |
| Systems electronics | 1.04 |
| Instrumentation | 1.19 |
| Forces and structures | 1.22 |
| Mechanics | 1.28 |
| Materials technology | 1.09 |
| Pneumatics | 1.16 |
| Computer control | 1.12 |

As the observed value of F does not exceed the variance ratio table value for F (9.60) there is no significant difference between the variances at the 5% level. The F-ratio test confirms at the 5% significance level, that there is a 95% likelihood that the samples were drawn from the same population.

Additionally the reliability of the results were quantifiable against information elsewhere. The high level of attendance on inservice training courses was confirmed by reference to L.E.A. records.

M.D. Youngman (1978) proposes that "...the standard concepts of reliability and validity have limited relevance in questionnaire design". Although validity is assessed in terms of face validity, reliability is easier to quantify and considerable effort was made to ensure that the questionnaire results were both reliable and valid. Validity refers to the truth and the accuracy of the results. To ensure valid results each item within the questionnaire was screened to ensure the removal of any question likely to produce inconsistent results. Additionally the validity of questionnaires can be established by computing an index between two variables, expressed as a correlation coefficient. Several questions were based on Likert type scales comprising a five point attitudinal scale to assess a variety of teacher perceptions. Measures of validity were obtained by (K.C. Thomas 1978):

[1] Examining the extent to which the scale distinguishes between groups of people known to hold either extremely positive or extremely negative attitudes towards the object.
[2] By measuring the responses of the sample to scores obtained from the pilot survey and correlating their value.

5.5.2 Standard Error of the sample mean

The accuracy of the results was performed by a range of tests, one of which involved the measurement of the standard error of the sample mean (analyzed in greater detail later in this chapter). The central limit theorem provides information about the way in which sample means will tend to be distributed, which is technically known as normal. It is known that 95% of the normal distribution lies between 1.96 standard deviations from the mean and 99% of the normal distribution lies between 2.58 standard deviations from the mean. The standard error (SE) of the sample mean is calculated by division of the standard deviation (SD) by the square root of the sample size (n):

$$\text{Standard Error} = \frac{SD}{\sqrt{n}}$$

For example, question 10 provided information concerning the perceived expertise of teachers in analogue aspects of electronics, in which the mean was 2.70 and the standard deviation 1.22:

$$SE = \frac{SD}{\sqrt{n}} = \frac{1.22}{\sqrt{74}} = \frac{1.22}{8{\cdot}6} = 0.1418$$

Thus it is 95% certain that the sample mean lay between 2.70 (1.96 x 0.14) = + or - 0.27 (between 2.97 and 2.43). Or it is 99% certain that the sample mean lay between 2.70 (2.58 x 0.14) = + or - 0.34 (between 3.04 and 2.34). These results provide information about the probable range of values within which the population mean lies. The standard error provides information in allowing the approximate mean position of the local C.D.T. population to be assessed. The accuracy of the results is proportional to the square root of the sample size. Increases in the accuracy of the results can be achieved by additional sampling. Samples need to be large enough to accommodate the principle of randomization and to provide a reasonably accurate result. Selkirk (1978) suggests "... that samples of less than 30 are statistically awkward, needing special formulae, but with samples which are a good size the labour of collecting data is rarely worth the reward in increased accuracy of the results in any but the largest scale research".

5.6 Methods of data processing

5.6.1 The statistical analysis of the numeric data was undertaken at the levels of description and analysis. The processing of the data was performed by means of microcomputer. Specific statistical algorithms and equations for data processing were developed and written in BASIC. "Omnicalc2" a spreadsheet analysis program gave access to a grid structure 99 columns across and 255 rows deep. Within the cells of the worksheet a number of statistical routines were specially written and embedded into the worksheet structure. Simple equations were developed for the non scaled questions. The problem of missing data and non response was partially overcome by follow up interviews, telephoned conversations and written correspondence.

5.6.2 Methods of analysis

The major methods of statistical analysis and their appropriateness is discussed in the following sections of this chapter, supported were necessary by worked examples of the mathematical method. Additionally further comments are made in following chapters which presents and interprets the results. Discussion at this stage is restricted to the major methods of statistical analysis used and the justification for their application.

5.6.3 Measures of central tendency

The arithmetic mean was selected in preference over other methods of portraying central tendency because although one or two high or low values can seriously distort results, the mean has the advantage that all measures are used in its calculation. Additionally the mean is a readily understood measure and since a primary criterion is successful communication its selection was important.

5.6.4 Measures of dispersion and spread

Whereas measures of central tendency give an idea of central values, measures of dispersion provide information concerning the degree of consensus and demonstrate how values cluster around the mean. The main test of dispersion was performed using the standard deviation and to a lesser extent the variance. The standard deviation is an index of central tendency and provides information about the consensus or agreement between the subjects of the sample. The variances obtained in calculating the standard deviation were applied to reliability tests which were detailed earlier in the text. The standard deviation is simply the square root of the variance. The variance is used in the mathematical calculations, because it is algebraically more tactile; whilst the standard deviation is used for reporting since it shares the same units as the original data. The variances generated (see above) by this research could form part of any future research. The calculation of the F-ratio was used to confirm significant agreement or disagreement between samples drawn from similar populations. If two samples have variances S1 and S2 the value of the larger variance divided by the smaller would provide the F-ratio. If samples are drawn from the same population one would expect S1 and S2 to be similar in size and the F-ratio to be close to 1. The F-ratio is therefore a useful aid for confirming relationships between similar populations.

The standard deviation is a measure of how scores tend to be dispersed about the mean, providing an inferential and descriptive statistic. The interpretation of the standard deviation as a measure of dispersion is performed by use of the empirical rule, which describes the relationship between the mean and the standard deviation. The empirical rule is meant as a simple indicator for interpreting the standard deviation. A data set with an approximate normal "bell shaped" distribution, coupled with the standard deviation can be very descriptive. The percentages in the empirical rule holds for most data sets whose distribution is normal, and does not deviate too much from being unimodal and symmetrical. 68% of all data is within one standard deviation of the mean, 95% is within two standard deviations from the mean, and all data is within three standard deviations from the mean. The empirical rule cannot predict or indicate varying amounts of dispersion within the dispersion of the scores. The empirical rule becomes inaccurate with very skewed data sets.

### 5.6.5 Correlation

Measurements of two variables were made for the same subjects of the sample and the degree of agreement between the two variables was measured by calculating the coefficient of correlation (r). The test of connection or dependence between the variables was achieved using the product-moment linear correlation coefficient (P.M.L.C.C.) in preference to Spearmans test, which was performed at the earliest stages in the analysis of the data. The fitting of a line or curve to the data enabled the prediction of one measurement from another measurement. The value of the P.M.L.C.C. always lies between +1 and -1. The values at which the correlation is sufficiently different from zero to be significant varies according to the size of the sample and may be found by reference to an appropriate statistical table.

| | | |
|---|---|---|
| r=+0.92 | Good correlation | |
| r=-0.96 | Good correlation | |
| r=-0.12 | Poor correlation | |
| r= 0 | Poor correlation | |
| r=+0.26 | Poor correlation | (Plews 1979) |

The square of the correlation coefficient also indicates the amount of variation in the dependent variable which is understood and explained by knowing the independent variable. For example the correlation coefficient for analogue electronics (expertise and resource value) is measured at +0.88.

| | |
|---|---|
| Analogue electronics P.M.L.C.C. | +0.88 |
| P.M.L.C.C. squared | 0.77 (77%) |

That is 77% variation in the dependent variable (resource value) can be explained by knowing the independent variable (expertise in analogue forms of electronics). Caution is necessary since the actual level of teacher expertise is a subjective value involving the teachers perceived ability.

Table 5.3 P.M.L.C.C. squared

| | | |
|---|---|---|
| Analogue electronics | 0.72 | 72% |
| Digital electronics | 0.62 | 62% |
| Systems electronics | 0.37 | 37% |
| Instrumentation | 0.82 | 82% |
| Forces and structures | 0.98 | 98% |
| Mechanics | 0.94 | 94% |
| Materials technology | 0.94 | 94% |
| Pneumatics | 0.74 | 74% |
| Computer control | 0.54 | 54% |

5.7 Test for no association

5.7.1 The product-moment linear correlation coefficient may be regarded as a statistic arising from a sample of data pairs selected from a population. If the correlation coefficient had been zero, this would have indicated that the two variables were unrelated in a linear manner, that is one variable tells nothing of the other variable when the variables are not related. The test that a correlation coefficient is zero is important and indicates if the extra information that is contained in the independent variable is worth collecting and analyzing.

5.7.2 Null hypothesis

Null hypothesis: knowing a teachers perceived expertise does not provide any information about the perceived value of technological resources foe C.D.T. To find the sample statistic it is necessary to multiply the square root of the sample size (less one degree of freedom) times the correlation coefficient. The product of this has an approximate standard normal distribution when the null hypothesis is true. That is under the null hypothesis the test statistic has an approximate normal distribution with mean and standard error 1. A standard 5% normal test would:

[1] Reject the null hypothesis if the standard normal statistic exceeds 2 or is less than -2.

[2] Fail to reject the null hypothesis if the standardized statistic is between 2 and -2.

The calculation of whether a correlation coefficient is zero is straightforward, an example is shown:

Analogue electronics P.M.L.C.C. +0.88
Analogue electronics = correlation coefficient x N(-1)
= 0.85`x 0.8.54
= 7.26 > 2 reject null hypothesis

| | | |
|---|---|---|
| Analogue electronics | 0.72 | 7.26 |
| Digital electronics | 0.62 | 6.75 |
| Systems electronics | 0.37 | 5.21 |
| Instrumentation | 0.82 | 7.77 |
| Forces and structures | 0.98 | 8.45 |
| Mechanics | 0.94 | 8.28 |
| Materials technology | 0.94 | 8.28 |
| Pneumatics | 0.74 | 7.34 |
| Computer control | 0.54 | 6.32 |

In all cases the null, hypothesis is rejected, there is a strong likelihood that the variable are connected. Knowing a teachers perceived expertise can tell us something about the perceived resource value of the technological areas of the C.D.T. curriculum. Teachers with a high perceived expertise in an area of technology are more likely to regard that area as a useful resource for C.D.T. design activities.

5.8 Test for random effects: Sign Test

5.8.1 In this report project one of the objectives was to determine the effect of the independent variable of teacher expertise, on the dependent variable of the resource value of technological areas of the school curriculum. The dependent variable is likely to be influenced by random errors, many of which cannot be eliminated. Many factors affect a human subjects performance and to ensure a representative sample, their learning and other experiences would need to be equated to make possible the selection of such a sample. The list of all such random factors is large and it would be impossible to screen all random factors and errors. The solution is to choose subjects at random from the population and to perform tests to ensure that any results are not due to random factors.

5.8.2 Null hypothesis

Null hypothesis: the independent variable had no effect on the independent variable. Any correlation was due to random effects.

Questions 10 and 11. Independent variable (expertise)
Dependent variable (resource value)

| Scale: | 1 | | 2 | | 3 | | 4 | | 5 | | Mean | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ex | Rs | Ex | Rs | Ex | Rs | Ex | Rs | Ex | Rs | Ex | Rs |
| Analogue electronics | 14 | 07 | 21 | 06 | 18 | 20 | 15 | 23 | 06 | 10 | 2.70 | 6.98 |
| Digital electronics | 17 | 03 | 16 | 08 | 22 | 23 | 11 | 22 | 06 | 18 | 2.55 | 3.59 |
| Systems electronics | 16 | 04 | 17 | 06 | 16 | 19 | 13 | 19 | 05 | 26 | 2.36 | 3.77 |
| Instrumentation | 29 | 22 | 22 | 19 | 14 | 21 | 07 | 07 | 02 | 05 | 2.06 | 2.38 |
| Forces and structures | 04 | 03 | 08 | 03 | 17 | 20 | 27 | 28 | 18 | 20 | 3.63 | 3.79 |
| Mechanics | 03 | 02 | 08 | 05 | 17 | 20 | 22 | 27 | 24 | 20 | 3.75 | 3.78 |
| Materials technology | 02 | 02 | 09 | 04 | 19 | 17 | 27 | 26 | 18 | 25 | 3.17 | 3.92 |
| Pneumatics | 33 | 15 | 19 | 22 | 11 | 18 | 07 | 06 | 04 | 07 | 2.05 | 2.32 |
| Computer control | 21 | 04 | 21 | 10 | 17 | 23 | 11 | 21 | 04 | 16 | 2.40 | 3.47 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Less frequent sign | 0 | 1 | 1 | 2 | 1 | 1 |
| Total number | 9 | 9 | 9 | 9 | 9 | 9 |
| Sign test table | .004 | .04 | .04 | .18 | .04 | .004 |
| Significance level 0.5 | (Robson, 1979) | | | | | |

The level of significance is the probability of rejecting the null hypothesis ie. that the dependent variable was due to random effects. The results suggest that to a 0.5 significance level the null hypothesis may be rejected and that the independent variable had an effect on the dependent variable. The influence of perceived teacher expertise on the perceived resource value of technological areas of the C.D.T. curriculum was therefore not has a result of random errors.

5.9 Assessing attitudes

Attitudes may be considered to be those properties of an individuals personality which are more lasting than mood or motive, but less enduring than temperament. Social scientists suggest that (K.C. Thomas 1978) attitudes cannot be directly observed like many other concepts, such as intelligence, personality, traits, etc. Thomas suggests that attitudes are "conceptual inventions" or hypothetical constructs. In analyzing the C.D.T. samples attitude to systems approaches and also the attitudinal responses to competence, the following factors were considered in an attempt to quantify the information.

[1] Attitudes are learned.
[2] Attitudes consist of predispositions to respond to a given test, rather than fixed responses.
[3] Attitudes tend to be positively or negatively orientated towards the test.
[4] Attitudes persist over time. They are not immutable but substantial pressure may be necessary to effect change.
[5] Cognitive components: consisting of the knowledge a person may have about the object of the attitude.
[6] Affective components: the positive or negative feelings the person may about the object. Connotative component: the behavioural tendencies a person may have with regard to the object.

5.10 Attitude measurement techniques

5.10.1 The assessment of the differences in attitude both within and between persons, necessitated a form of reliable and valid measurement. The methods employed to assess attitude relied heavily on attitudinal scales, which provided a means of quantifying attributes or qualities. This consisted of a choice from a range of numerical values. The scales consisted of a series of statements about which the sample expressed their agreement or disagreement, or their perceived competence along a continuum. The responses were then scored and added together to indicate the attitude of the C.D.T. sample towards the object being tested. The reliability and the validity of the tests were established by computing the relationship between two variables by means of a number of tests mostly involving the correlation coefficient and the variances. These included:

[1] Test for no association.
[2] Random error test.
[3] Standard error.
[4] Square of the correlation coefficient.

The development of the questionnaire involved the drawing together of a number of statements with which individuals could identify themselves (to a lesser or greater extent). The sum of these identifications is a measure of attitude. Identifications were made on a standard five point Likert type scale.

5.10.2 Information collection

[1] To discover the perceived educational benefits of the different approaches to electronics teaching in a C.D.T. design and realization context. To discover the value of the different approaches used and how girls and boys benefit or otherwise from the various approaches adopted.

[2] To discover the main approaches adopted by teachers to introduce electronics into C.D.T. design and realization activities. To determine the factors which influence the selection of a particular approach, in terms of age, ability, resources, time allocation, funding and syllabus aims and objectives.

[3] To discover the range, extent and value of school and advisory support for teachers engaged in delivering C.D.T.

electronic problem solving schemes. Additionally to determine the extent and adequacy of inset provision and the influences on C.D.T. teaching schemes involving aspects of technology.

[4] To determine the influences of school and departmental policy on the range and scope of technology provision within C.D.T. schemes.

[5] To discover the general level of perceived competence amongst C.D.T. to teach electronics and other supporting aspects of technology. To determine the major influences effecting C.D.T. teachers in the selection of the particular teaching strategy adopted.

[6] To correlate perceived competence or expertise, against the selection of the specific teaching approaches adopted for electronics teaching.

[7] To discover the extent to which the scope of design projects is hindered by a lack of teacher technological expertise.

[8] To discover the perceived relative values as a resource for design and realization, of individual technological subject areas and how these values in turn influence the range and scope of problem solving and design activities.

[9] To discover the range, extent and type of support provision received for technology teaching within C.D.T. schemes and its respective value. To identify the major areas of support needed by C.D.T. teachers specifically for electronics teaching.

[10] To discover whether and at what stage it is considered necessary to teach any supporting electronic theory in systems regimes.

4.11 Likert's method of summated ratings

The use of Likert's scaling procedures were designed to reduce the chance of ambiguous statements and statements eliciting responses based on factors other than the attitude being examined. This involved the following techniques (K.C. Thomas, 1978).

[1] Drawing together a large pool of statements.
[2] Deciding whether each statement was either a favourable or unfavourable attitude. Neutral and ambiguous statements were discarded.
[3] The statements were then administered to a small group representative of those whose attitudes were to be measured.
[4] This allowed the preliminary estimate of other respondents attitudes.
[5] Responses to the statements were scored from one to five. Strong agreement to favourable items scored five, whilst strong disagreement scored one. Scoring was reversed for unfavourable statements.
[6] A preliminary attitude score was obtained by summing across all the subject item scores. To be retained a statement had to meet the criterion of internal consistency. This implied that the more favourable a subjects attitude the more likely they were to endorse favourable statements and the less likely to endorse unfavourable statements.
[7] A correlation between attitude score and statement endorsement constituted the criterion for inclusion of the statement. A statement met the criterion of internal consistency when the item score correlated significantly with the attitude score.
[8] Statements with the highest value correlation constituted the Likert scale.

It was possible to include other statements and also more objective tests not manifestly related to the attribute being studied as any statement that can be empirically consistent with the total score can be included. Objective assessment included questions relating to school resources, school establishment and organization, examination courses studied and staff training.

Likert type scales consist of a five point rating, ranging from a value of one indicating low, and a value of five indicating high. The numerical value indicates the weight attached to the response. The advantage of Likert scales is that the subject chooses his or her own degree of agreement to which numerical values are assigned. The total score of the subjects is the sum of the values which have been assigned to the various points of the scales.

5.12 Chapter review

The intention of this chapter has been to provide details of the questionnaire research design and the methods of analysis. This includes (F.M.E. Figueroa, 1981) "...the overall logic, the general strategy, or the basic plan of approach, and the methods used to obtain, process and analyses the information including the methods of selecting the subjects or the phenomena to be studied". The detail of methodology was included to validate the study, the results and also to enable the critical evaluation of the findings from a basis of the reader having an adequate knowledge of the procedures used. Throughout the design the methods were employed to meet the basic criteria of research methodology; validity, appropriateness, control, adequacy of the sample, reliability, replicability and feasibility. The research design was discussed under the following headings:

[1] Sampling strategies.
[2] The selection of the C.D.T. population.
[3] Data collection methods.
[4] Distribution techniques.
[5] Data collection and response rates.
[6] Piloting.
[7] Reliability and replicability:
    i, F-Ratio;

ii, Standard Error of the sample mean.

[8] Methods of processing.

[9] Methods of analysis:

i, Measurement of central tendency;

ii, Measurement of dispersion and spread;

iii, Measurement of correlation.

[10] Test for variation in the dependent variable.

[11] Test for no association.

[12] Test for random effects.

[13] Attitude assessment using Likert's method of summated ratings.

# Chapter Six

# PRESENTATION AND INTERPRETATION OF THE QUESTIONNAIRE DATA

# Chapter Six

## PRESENTATION AND INTERPRETATION OF THE QUESTIONNAIRE DATA

### 6.1 Presentation of the questionnaire data

This chapter presents the information obtained from the collection of questionnaires from 93 schools, primarily in Derbyshire (22), Lincolnshire (17) and Staffordshire (22) and also a smaller number nationally. The desire to make the information readily assimilated was effected by the application of the criteria of: clarity, succinctness, interpretability and replicability (M.B. Youngman, 1982). Where the inclusion of data would have resulted in the text becoming overloaded with detail and also where there was a danger of loss of completeness, the information of a secondary value is offered as an appendix. Computer processing software was used to present the results in both numerical and graphical forms. Throughout this chapter emphasis is placed upon the use of statistics, supported by graphical data, to consolidate the textual inferences and description where appropriate.

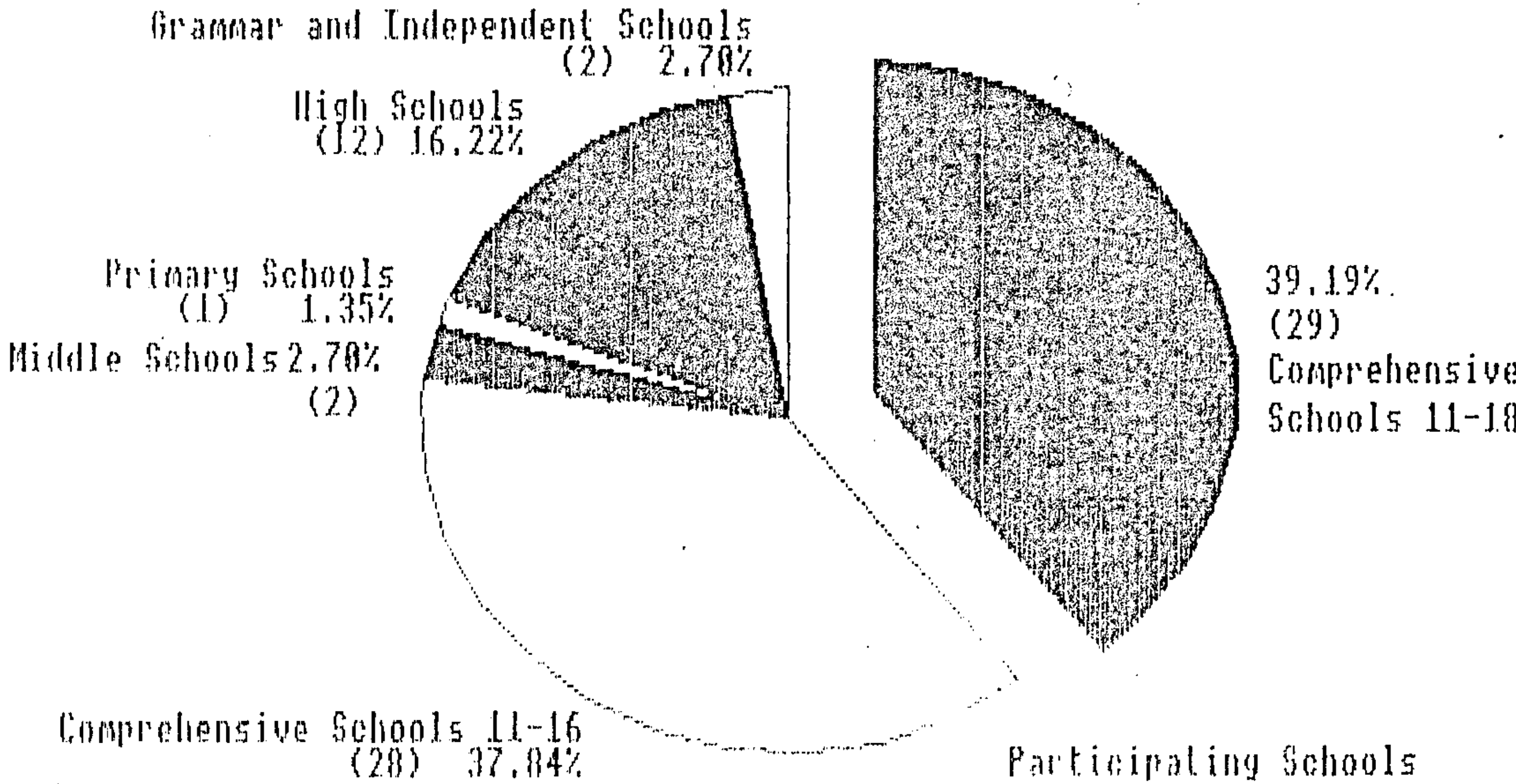
### 6.2.1 Participating establishments

Table 6.1

| School | Number | Percentage |
|---|---|---|
| Comprehensive 11-18 | 29 | 39.19 |
| Comprehensive 11-16 | 28 | 37.84 |
| High schools 13-18 | 12 | 16.22 |
| Middle Schools | 2 | 2.70 |
| Grammar/Independent | 2 | 2.7 |
| Primary | 1 | 1.35 |

Figures 6.1 and 6.2 indicate the number, size (Mean roll number 925.67) and organization of the participating establishments. Details of the breakdown by county is supplied in chapter five.

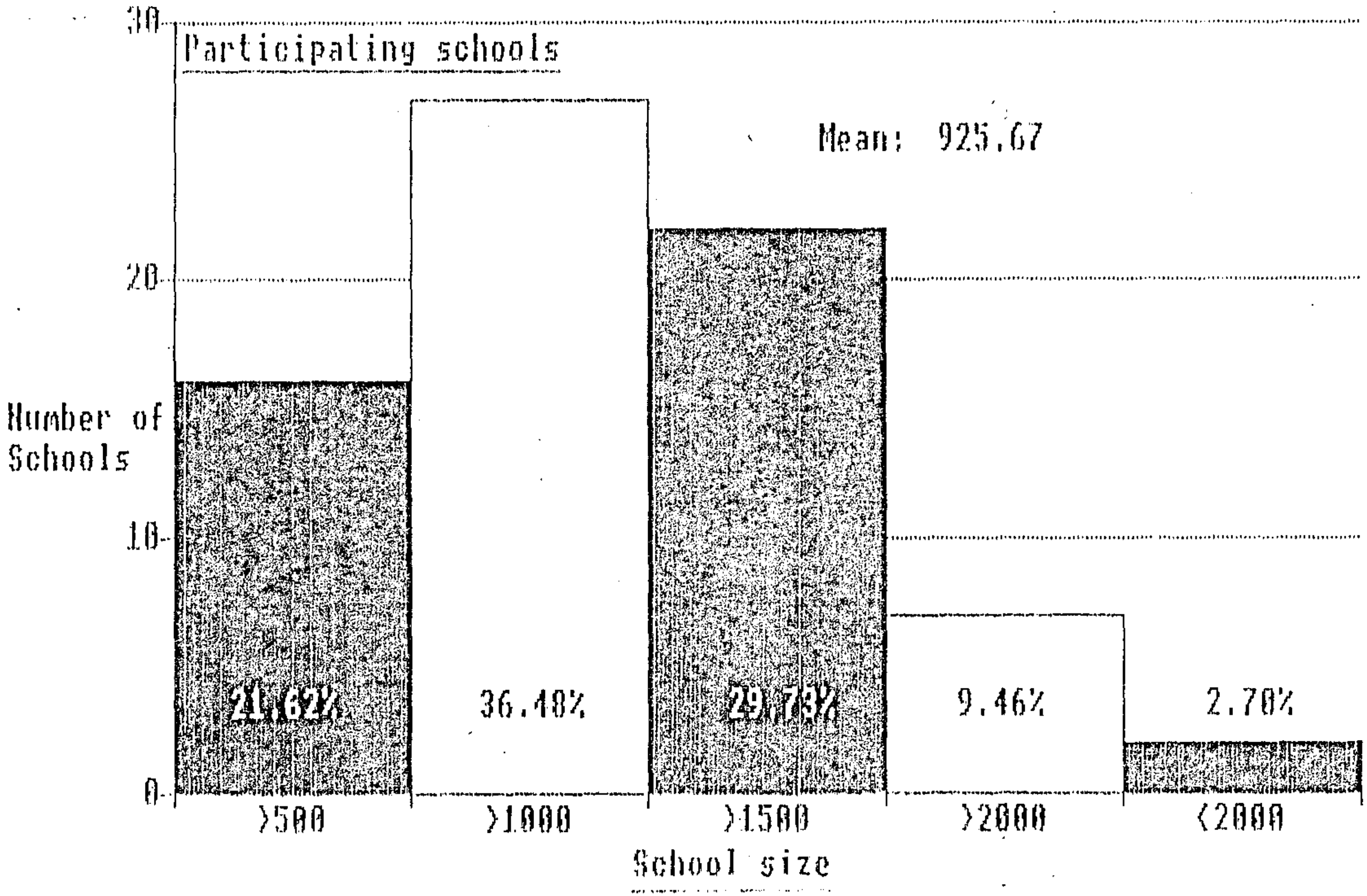
Figure 6.1




Participating Schools

Total: 74 Schools

Figure 6.2



Participating schools
Mean: 925.67
Number of Schools
30
20
10
0
21.62%
36.48%
29.73%
9.46%
2.70%
>500
>1000
>1500
>2000
<2000
School size

6.2.2 Teaching organization

Table 6.2a C.D.T. teaching organization

| | Number | Percentage |
|---|---|---|
| Mixed ability | 53 | 71.62 |
| Streamed | 21 | 28.38 |

Table 6.2b Gender groupings

| | | |
|---|---|---|
| Coeducational groups | 71 | 95.95 |
| Single sex groups | 3 | 4.05 |

Figures 6.3 and 6.4 demonstrate the extent to which the organization of C.D.T. courses provides educational opportunities to students of mixed ability and gender. In only three schools did teaching take place in single sex groups (two comprehensives 11-16 and one independent school). An additional question, concerning the percentage of girls in C.D.T. groups would have provided further insights and aided the analysis. These figures offer insights into the extent of equal opportunity provision and if mirrored nationally would reflect encouraging progress.

6.3 C.D.T. Teacher training

Table 6.3a Initial technology training

| | Number | Percentage |
|---|---|---|
| Yes | 16 | 21.62 |
| No | 58 | 78.38 |

Table 6.3b Technology inservice training

| | | |
|---|---|---|
| Yes | 58 | 78.38 |
| No | 16 | 21.62 |

Table 6.3c Confidence to technology

| | | |
|---|---|---|
| Yes | 29 | 39.19 |
| No | 45 | 60.81 |

Craft, design and technology teaching organisation

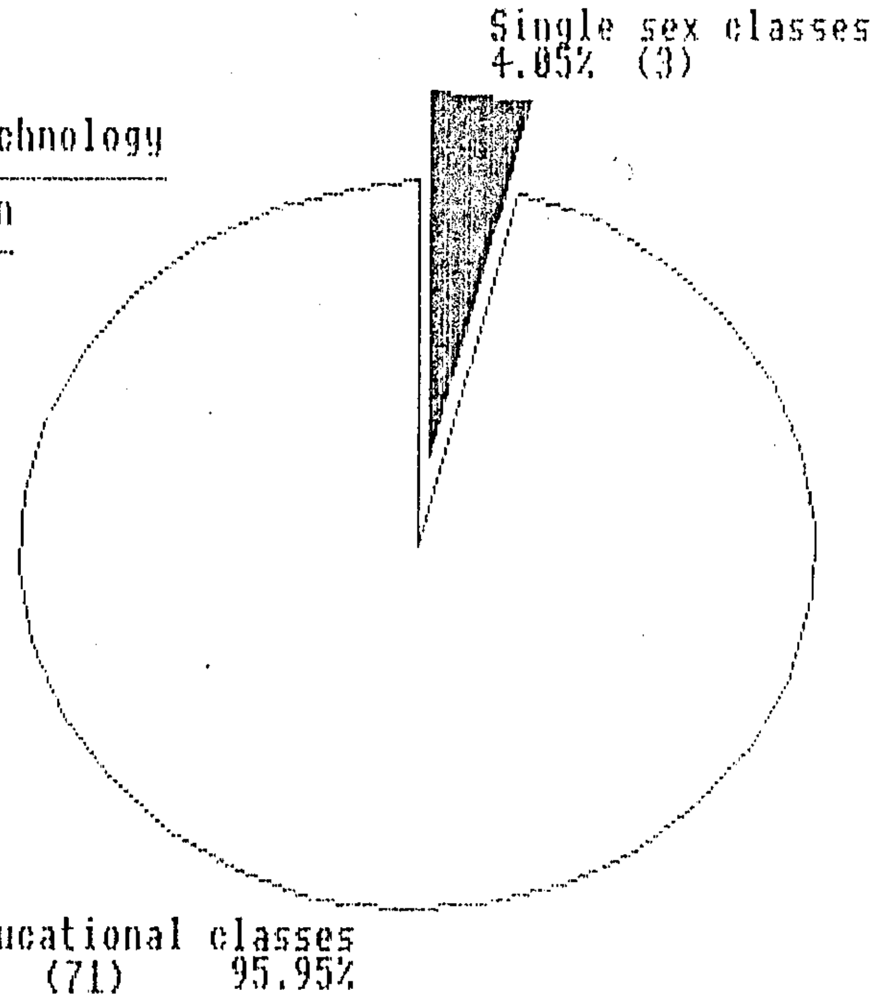



Figure 6.3

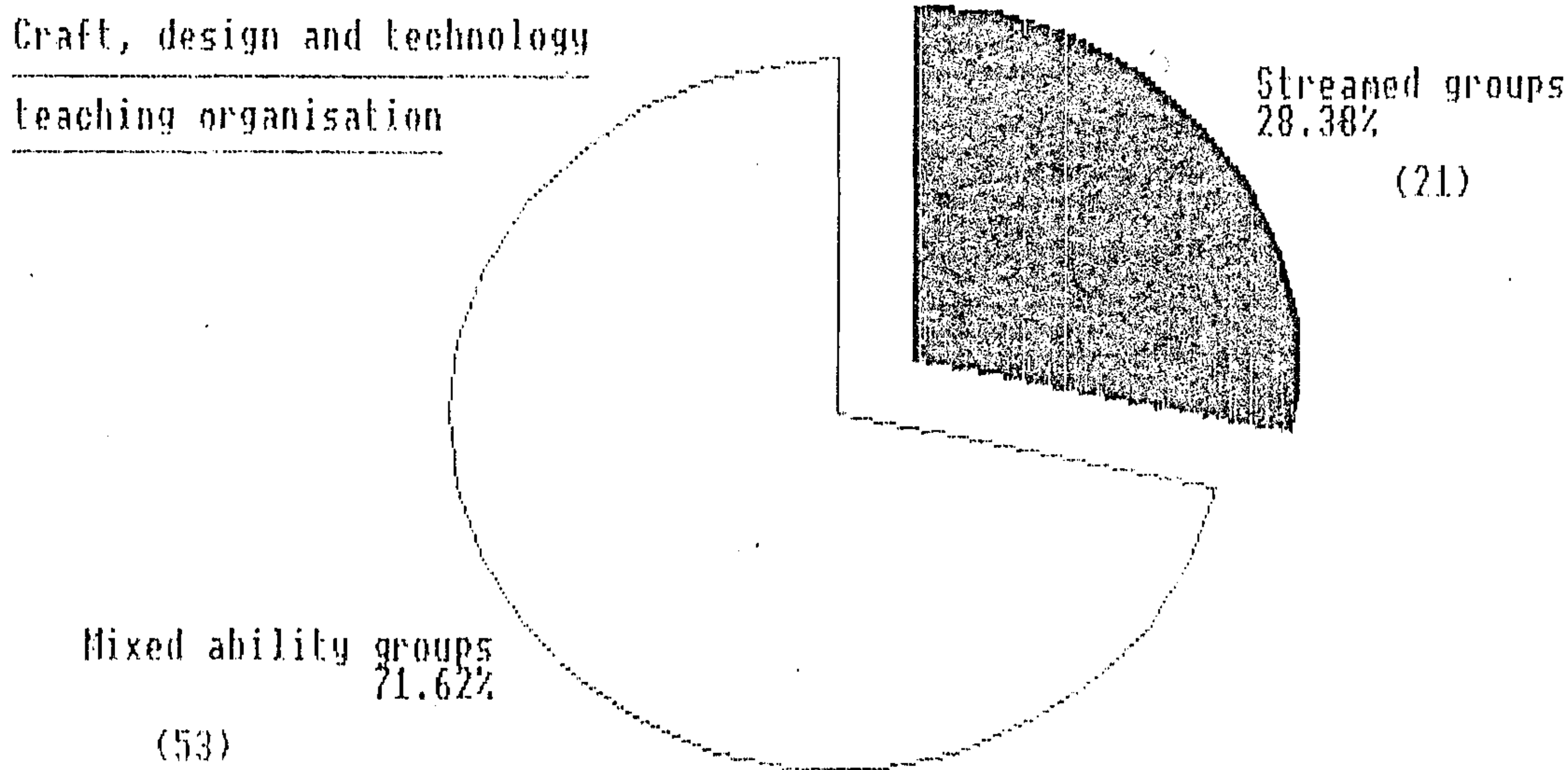

Craft, design and technology
teaching organisation
Streamed groups
28.38%
(21)
Mixed ability groups
71.62%
(53)

Figure 6.4

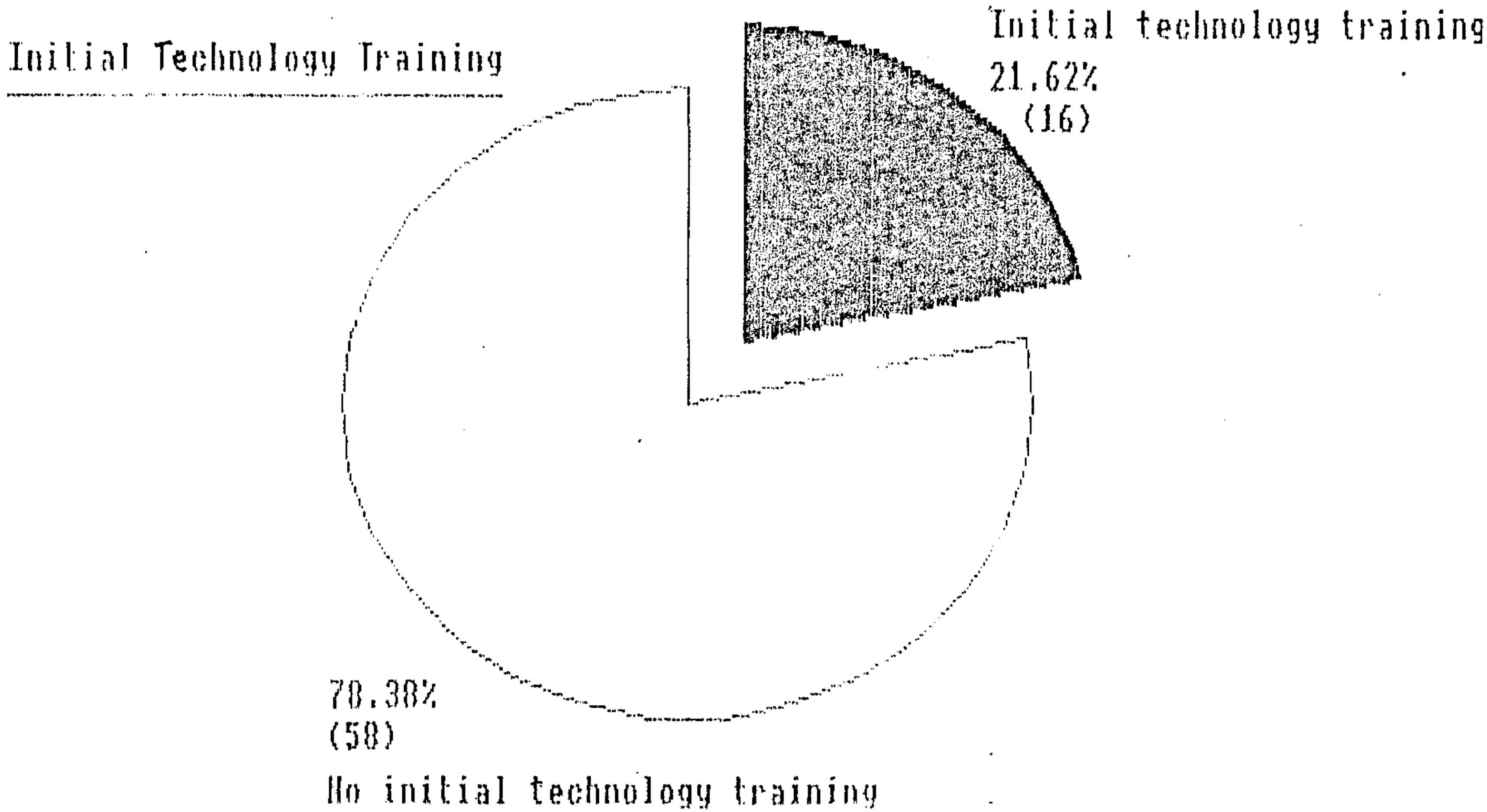
Table 6.3d Restrictions imposed on design activities by lack of technological expertise

| | | |
|---|---|---|
| Yes | 55 | 74.32 |
| No | 19 | 25.68 |

Figures 6.5 to 6.7 indicate the training of teachers in the more technological aspects of the C.D.T. curriculum. Figure 5.8 indicates the effects on the range of design activities offered. The limited provision of initial training in aspects of technology, to a minority of 21.62% of teachers has not been off-set by the extensive attendance at inservice training courses. In Staffordshire and Derbyshire the pattern of inservice training is typically of a short duration, providing intensive study sessions between four and ten weeks. Typically these are offered at a range of levels, from basic courses for beginners to courses necessary to support advanced level courses. Because of the problems L.E.A.'s experience in recruiting specialist C.D.T. supply teachers many courses are held after school. The results suggest that despite extensive inservice training provision embracing 78.38% of the C.D.T. population, a large majority of teachers lacked the confidence to cope with the full range of technological areas encountered in C.D.T. teaching. The results indicate that limitations in technological expertise have imposed restrictions on the range of design activities students are able to pursue in C.D.T. courses. Interview responses confirmed the statistical data in pointing to a general lack of confidence to respond to legitimate student demands for technological content in their design investigation.

In schools offering C.D.T. provision beyond the initial examination level of G.C.S.E., the percentage of teachers with training in aspects of technology was highest. In these schools (comprehensives 11-18 and High schools 13-18) least restrictions were place on the range and scope of problem solving activities.

Figure 6.5


Initial Technology Training
Initial technology training
21.62%
(16)
78.38%
(58)
No initial technology training

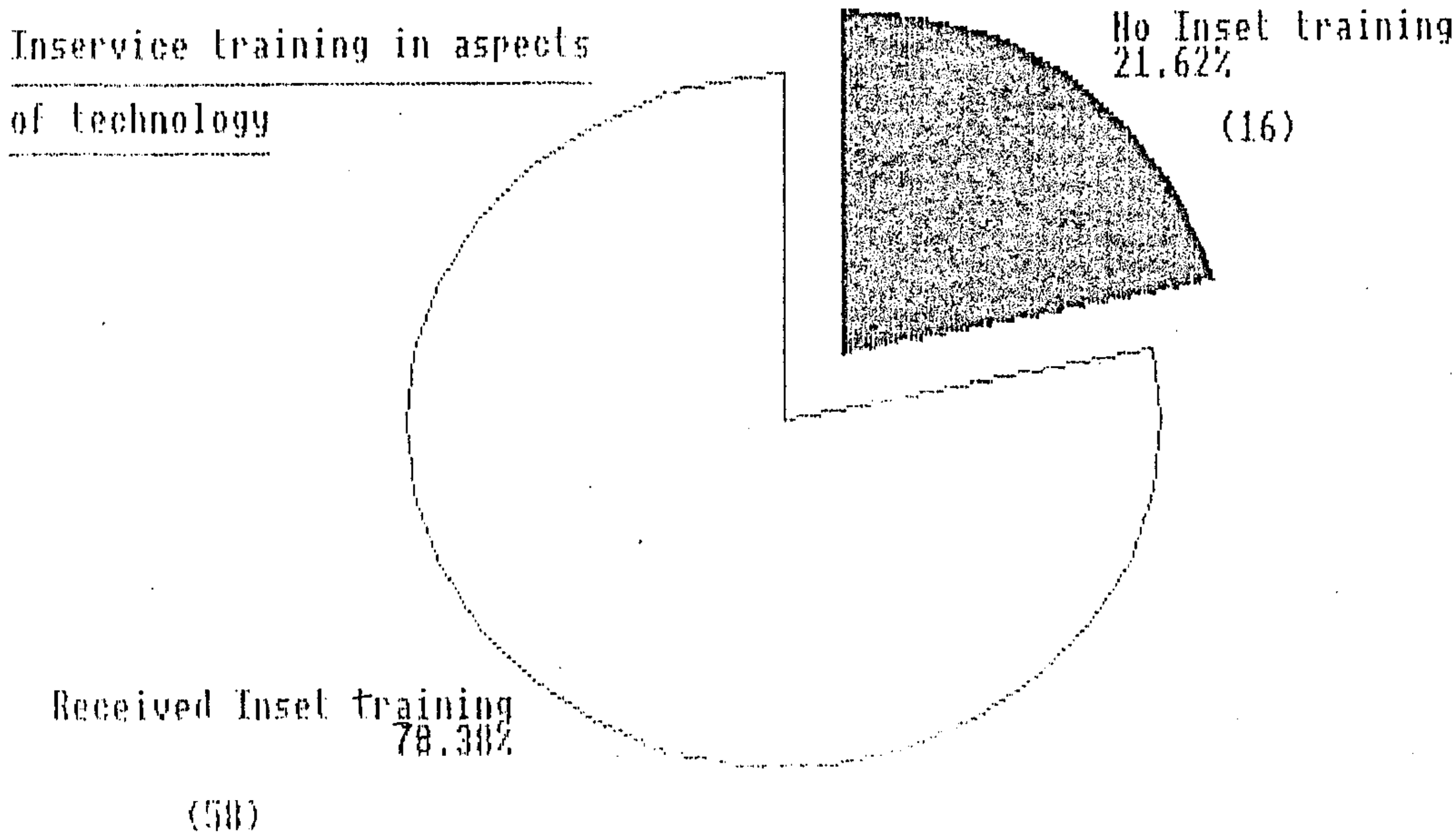

Inservice training in aspects of technology
No Inset training
21.62%
(16)
Received Inset training
78.38%
(58)

Figure 6.6

Confidence to cope with the full range of technological subjects encountered in C.D.T.

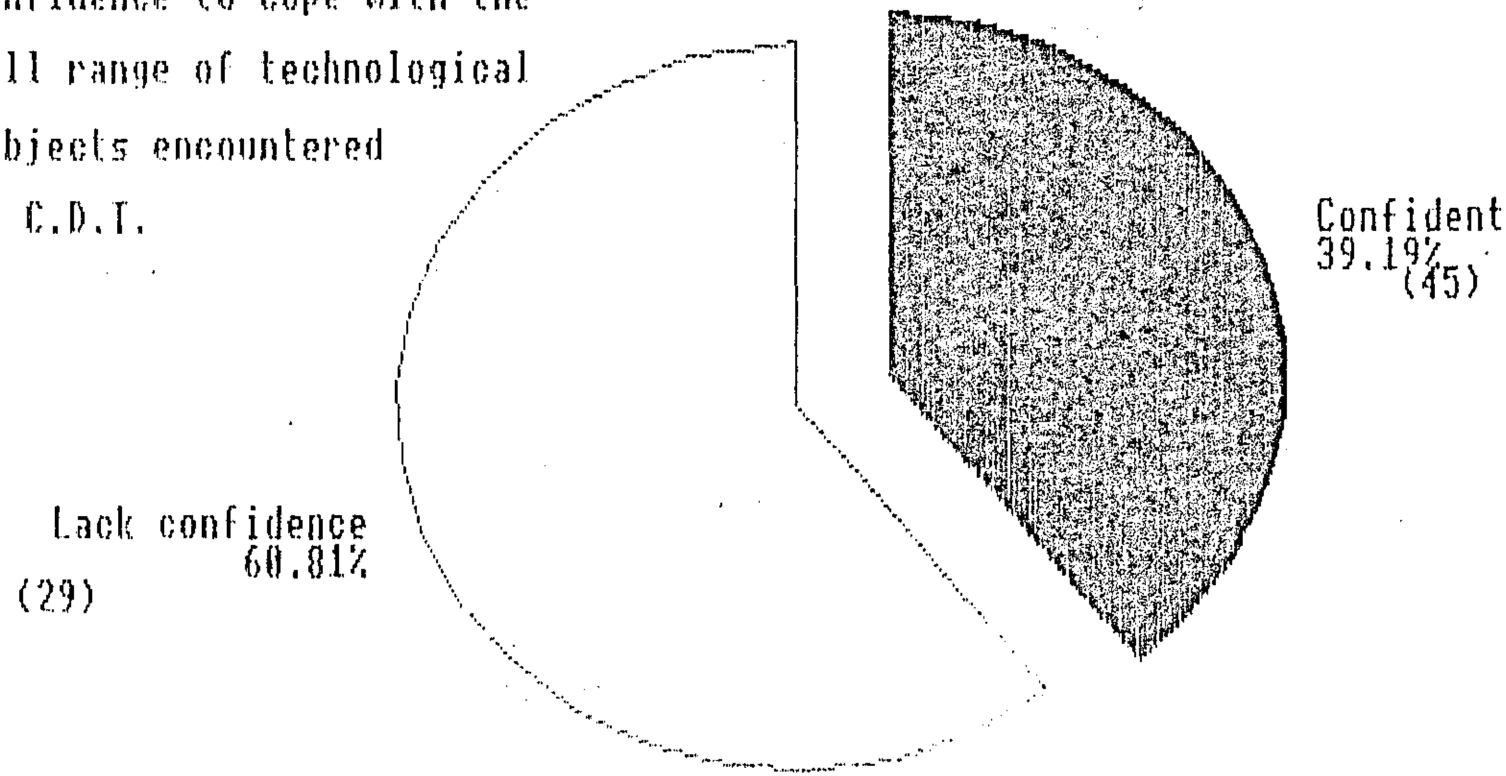
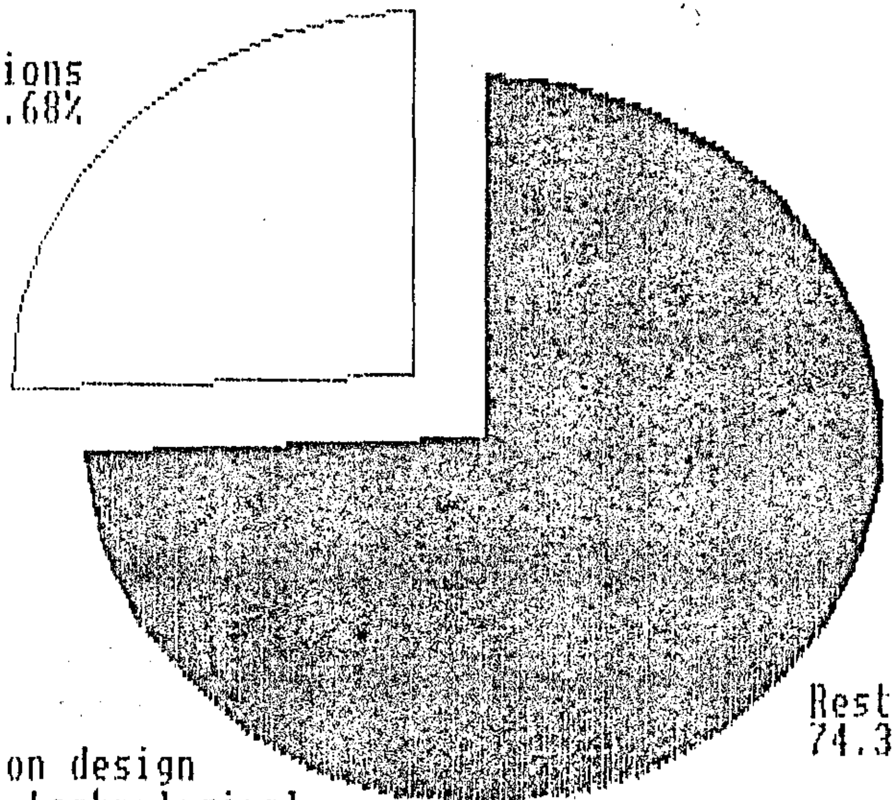



Figure 6.7

Figure 6.8




Restrictions imposed on design activities by lack of technological exepertise.

### 6.4.1 Perceived expertise and the resource value of technological areas

Question ten asked teachers to rate their perceived technological expertise on a scale ranging from five (highest) to one (lowest). Question eleven requested teachers to judge the value of particular aspects of technology in terms of the resource value for design activities. The ability to identify perceived expertise and to gain insights into those areas that teachers find most useful for C.D.T. activities makes possible the recommendation of measures to more adequately support design and realization activities. For clarity of communication the information is provided in two forms; summary tables, detailed bard charts and overlay line graphs. Each data set is displayed in a summary table and later given in greater detail with accompanying notes and fuller analysis of the information. The summary tables indicate:

[1] Perceived expertise.
[2] The perceived resource value of technological areas.
[3] The extent of consensus between teachers (S.D.).
[4] The linear relationship of the data pairs (P.M.L.C.C.) and the prediction of one measurement from another.
[5] The comparative expertise and resource value of the different technological areas of the C.D.T. curriculum.
[6] teacher responses to questions ten and eleven are scored in the range of five (high) to one (low).

Fuller data and breakdown for these questions by county is offered as an appendix.

## Chapter Six

SUMMARY TABLES

Table 6.4a Technological areas of the C.D.T. curriculum

| | Mean | SD | PMLCC | Rank Order |
|---|---|---|---|---|
| MECHANISMS | | | | |
| Perceived expertise | 3.75 | 1.14 | +0.97 | 1 |
| Resource value | 3.78 | 1.01 | | 1 |
| MATERIALS TECHNOLOGY | | | | |
| Perceived expertise | 3.66 | 1.13 | +0.97 | 2 |
| Resource value | 3.92 | 1.01 | | 1 |
| FORCES AND STRUCTURES | | | | |
| Perceived expertise | 3.63 | 1.13 | +0.99 | 3 |
| Resource value | 3.79 | 1.02 | | 3 |
| ANALOGUE ELECTRONICS | | | | |
| Perceived expertise | 2.70 | 1.22 | +0.85 | 4 |
| Resource value | 3.42 | 1.12 | | 7 |
| DIGITAL ELECTRONICS | | | | |
| Perceived expertise | 2.63 | 1.22 | +0.79 | 5 |
| Resource value | 3.59 | 1.09 | | 5 |
| COMPUTER CONTROL | | | | |
| Perceived expertise | 2.40 | 1.20 | +0.74 | 6 |
| Resource value | 3.77 | 1.17 | | 4 |
| SYSTEMS ELECTRONICS | | | | |
| Perceived expertise | 2.59 | 1.21 | +0.61 | 7 |
| Resource value | 3.77 | 1.17 | | 4 |
| PNEUMATICS | | | | |
| Perceived expertise | 2.51 | 1.18 | +0.86 | 8 |
| Resource value | 2.32 | 1.79 | | 9 |
| INSTRUMENTATION | | | | |
| Perceived expertise | 2.06 | 1.10 | +0.91 | 9 |
| Resource value | 2.38 | 1.20 | | 8 |

Table 6.4b Details by County

| | Derbyshire | | | Lincolnshire | | | Staffordshire | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | CC | Mean | SD | CC | Mean | SD | CC |
| MECHANISMS | | | | | | | | | |
| Expertise | 3.63 | 1.17 | 0.96 | 3.53 | 1.18 | 0.99 | 3.68 | 1.21 | 0.96 |
| Resource | 3.86 | 1.12 | | 3.64 | 0.99 | | 3.72 | 1.07 | |
| MATERIALS TECHNOLOGY | | | | | | | | | |
| Expertise | 3.50 | 1.10 | 0.84 | 3.64 | 0.99 | 0.98 | 3.72 | 1.12 | 0.94 |
| Resource | 4.04 | 1.09 | | 3.88 | 0.92 | | 3.86 | 0.94 | |
| FORCES AND STRUCTURES | | | | | | | | | |
| Expertise | 3.68 | 1.32 | 0.92 | 3.82 | 1.01 | 0.99 | 3.59 | 1.05 | 0.89 |
| Resource | 3.83 | 1.09 | | 3.70 | 1.10 | | 4.00 | 1.07 | |
| ANALOGUE ELECTRONICS | | | | | | | | | |
| Expertise | 2.91 | 1.19 | 0.75 | 2.59 | 1.22 | 0.86 | 2.68 | 1.25 | 0.82 |
| Resource | 3.72 | 0.93 | | 3.23 | 1.20 | | 3.41 | 1.09 | |
| DIGITAL ELECTRONICS | | | | | | | | | |
| Expertise | 2.45 | 1.10 | 0.57 | 2.35 | 1.17 | 0.62 | 2.95 | 1.17 | 0.72 |
| Resource | 3.68 | 1.04 | | 3.35 | 1.05 | | 4.0 | 0.92 | |
| COMPUTER CONTROL | | | | | | | | | |
| Expertise | 2.63 | 1.33 | 0.91 | 2.00 | 1.00 | -.05 | 2.54 | 1.14 | 0.80 |
| Resource | 3.22 | 1.11 | | 3.82 | 1.38 | | 3.54 | 1.10 | |
| SYSTEMS ELECTRONICS | | | | | | | | | |
| Expertise | 2.72 | 1.24 | 0.73 | 2.53 | 1.18 | 0.42 | 2.63 | 1.40 | 0.64 |
| Resource | 2.82 | 1.17 | | 3.70 | 1.31 | | 4.09 | 0.92 | |
| PNEUMATICS | | | | | | | | | |
| Expertise | 2.50 | 1.26 | 0.75 | 2.35 | 1.22 | 0.88 | 2.72 | 1.07 | 0.87 |
| Resource | 2.36 | 1.21 | | 2.17 | 1.33 | | 2.54 | 1.10 | |
| INSTRUMENTATION | | | | | | | | | |
| Expertise | 2.18 | 1.14 | 0.89 | 2.11 | 1.11 | 0.92 | 2.09 | 1.15 | 0.82 |
| Resource | 2.36 | 1.21 | | 2.17 | 1.33 | | 2.54 | 1.10 | |

## Chapter Six

The relationship of the characteristics of perceived expertise against the resource value of the different technological areas is of interest in that tentative prediction may be made from the data pairs. Such prediction is only applicable to the counties of Derbyshire and Lincolnshire were a more random sample was achieved. The interpretation of the correlation coefficient (being a measure of the strength of the linear relationship) is provided below.

### 6.4.2 The extent to which the P.M.L.C.C. is either positive or negative

In all but one case (Lincolnshire data pairs for computer control applications) the linear relationship was direct indicating a direct relationship between high and low scores in each data set. A high score in one being mirrored by a high in the other.

### 6.4.3 Strength of Linear relationships

The closer to +1 or -1 the stronger the linear relationship between the data pairs. If no linear relationship existed then the score would have been close to 0. Perfect linear relationship would be reflected by a score of 1. With the exception of the Systems electronics score all others in the summary tables demonstrate high positive correlation. the Systems electronics result of +0.61 suggests there is no more than a fair correlation between these variables.

### 6.4.4 Pairing of expertise and resource value of technological areas.

There is strong tendency for high perceived expertise to be paired with high perceived resource value for the corresponding technological area of the C.D.T. curriculum. Follow up teacher interviews suggests that the usefulness of technological areas is linked to the requirement of C.D.T. teachers to have an expertise in the corresponding area.

Without the prerequisite teacher expertise the area was unlikely to be viewed as being a useful resource.

The pattern of high expertise and high resource value is not found in the Systems electronics score. Despite low perceived expertise teachers identify this area as being of high resource value. Although conclusions may not be reliably drawn from such a single test, this result suggests an anomaly needing further investigation. Interviews with teachers suggests that the two variables are not connected in the same manner as the remainder. The tentative inference is that teachers may identify Systems electronics to be of a high resource value irrespective of low perceived expertise.

6.4.5 Prediction

The generally high degree of correlation enables the prediction of score on a variable, when the scores on the other variables are known. the scores suggest a strong tendency for resource value to be associated with high levels of perceived expertise. From the results it may be inferred that teachers will have an increased perception of the usefulness of a technological area with increased expertise.

6.4.6 Consensus or variability

The degree of consensus or variability between teachers responses is indicated by the Standard Deviation on a range from 1.01 to 1.79. The smaller the value of the Standard Deviation the greater the degree of teacher consensus. In those areas of technology involving electronics only a fair degree of consensus is demonstrated (ranging from 1.09 to 1.21). Table 6.4a describes the highest level of consensus in Mechanisms and Materials technology (those areas which have traditionally formed part of C.D.T., Technical Studies and Handicraft schemes).

Figures 6.9 to 6.12 indicate the perceived expertise in the electronic aspects of the C.D.T. curriculum. In all cases the vertical axis indicates the number of respondents whilst the

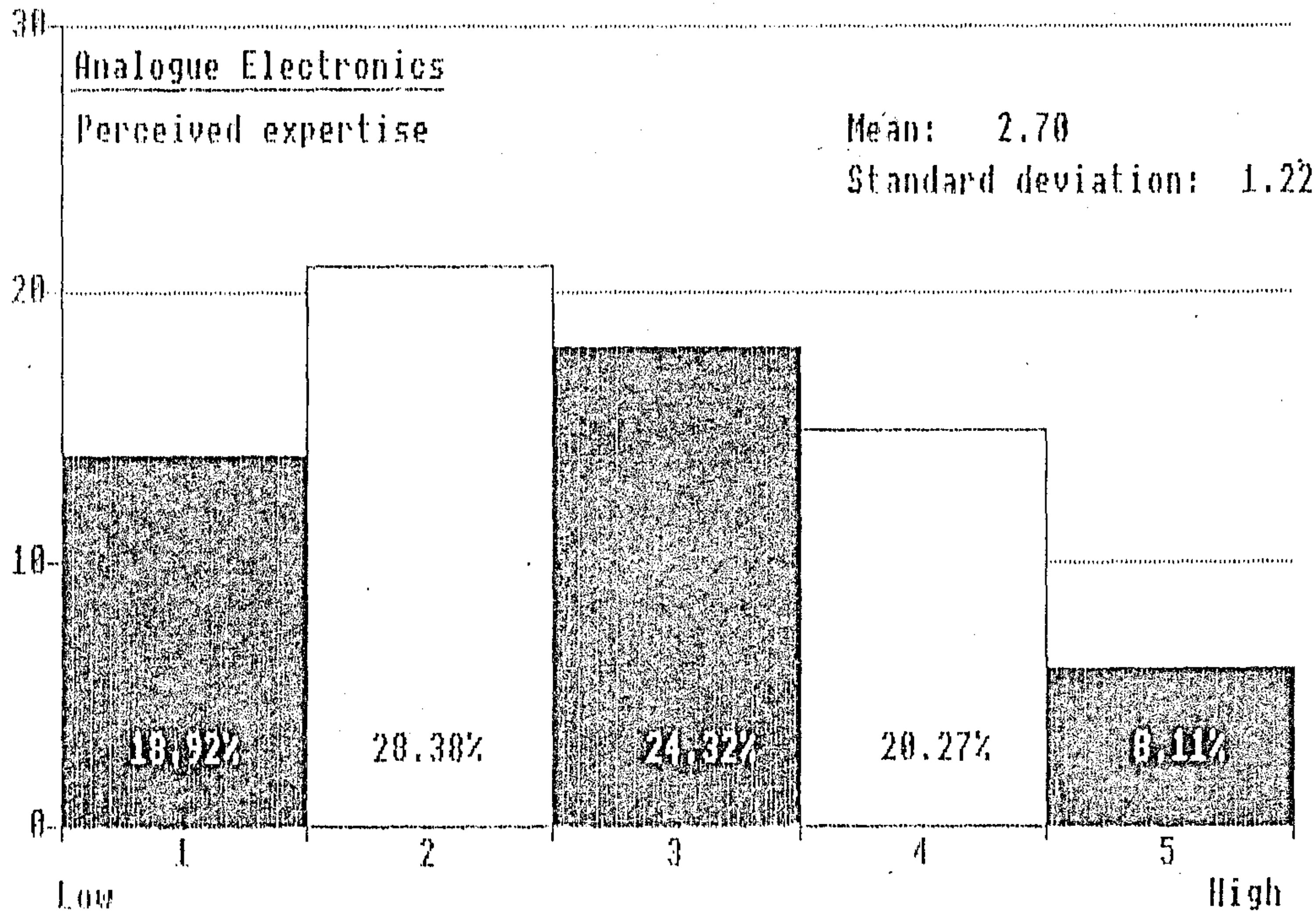

Analogue Electronics
Perceived expertise
Mean: 2.70
Standard deviation: 1.22
30
20
10
0
18.92%
28.38%
24.32%
20.27%
8.11%
1
2
3
4
5
Low
High

Figure 6.9

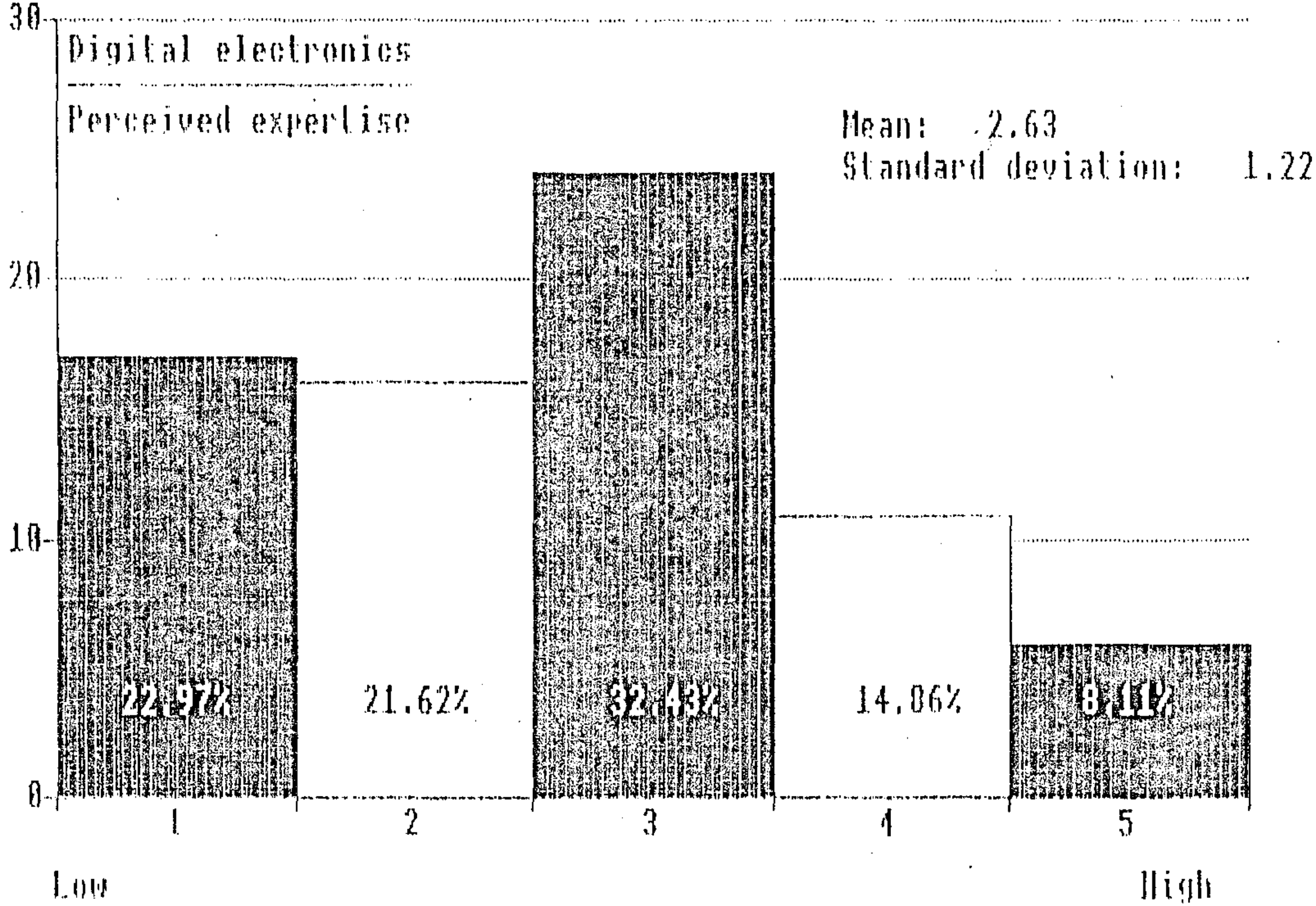

30
20
10
0
Digital electronics
Perceived expertise
Mean: 2.63
Standard deviation: 1.22
22.97%
21.62%
32.43%
14.86%
8.11%
1
2
3
4
5
Low
High

Figure 6.10

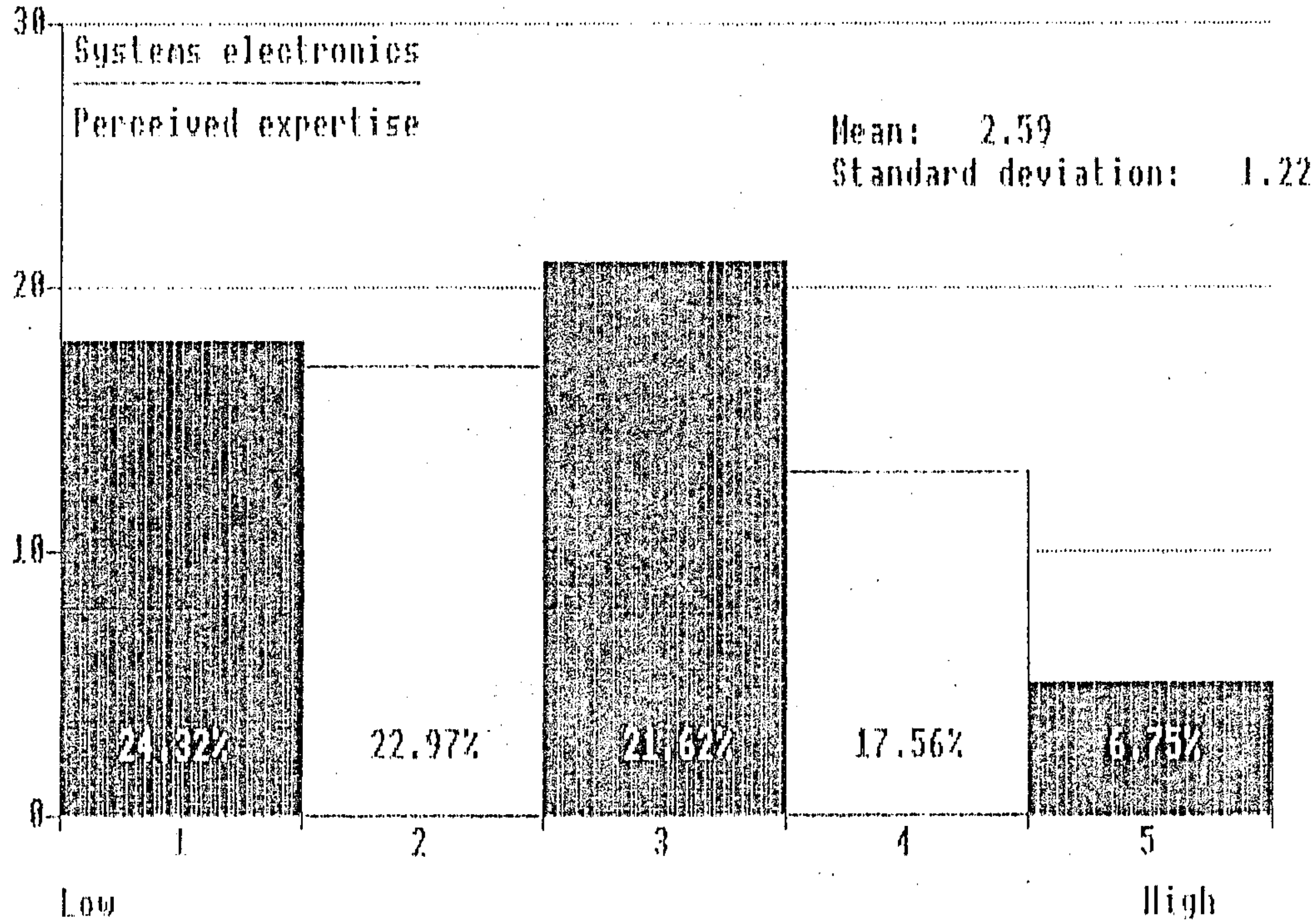

Systems electronics
Perceived expertise
Mean: 2.59
Standard deviation: 1.22
30
20
10
0
24.32%
22.97%
21.62%
17.56%
6.75%
1
2
3
4
5
Low
High

Figure 6.11

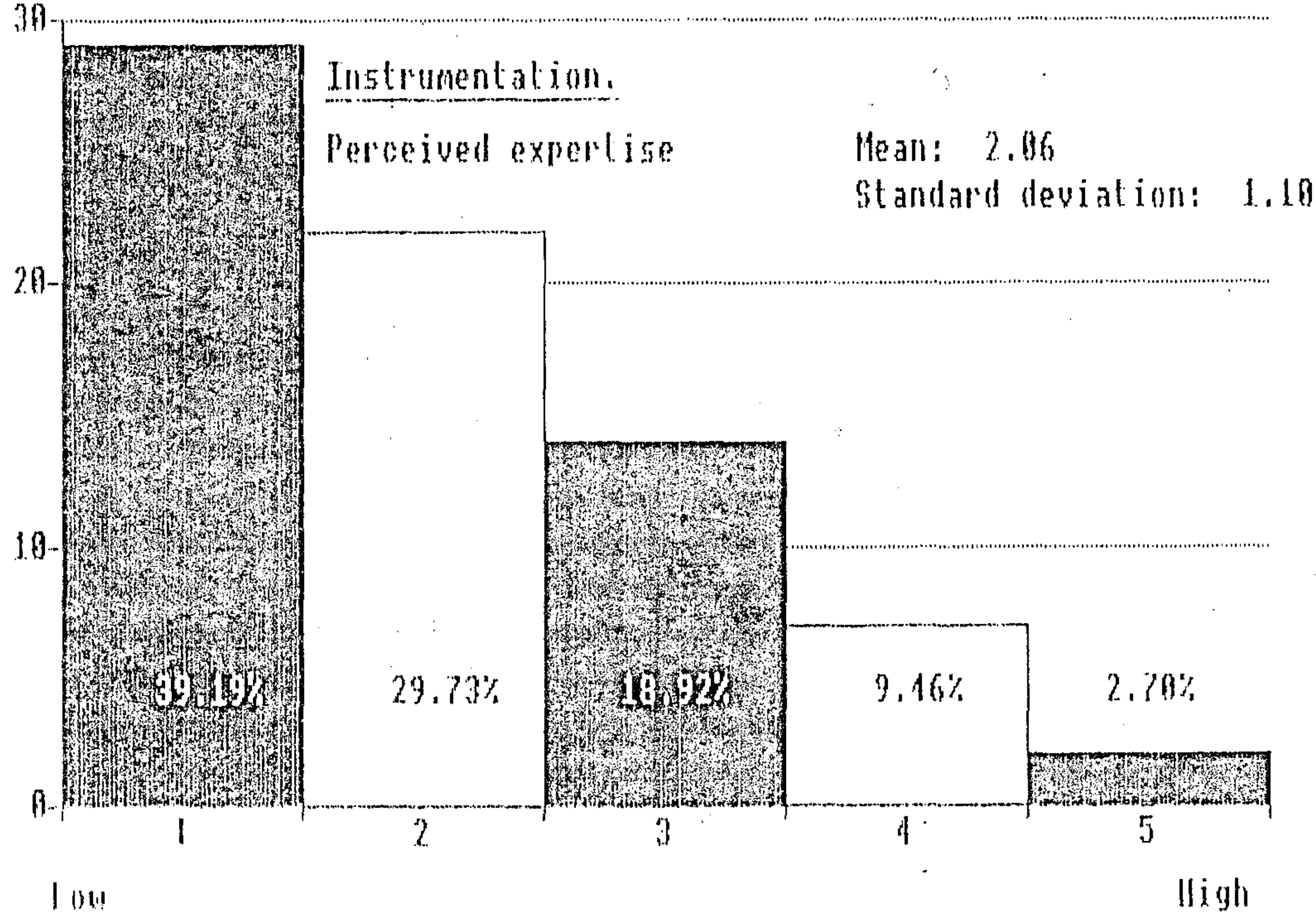

Instrumentation.
Perceived expertise
Mean: 2.06
Standard deviation: 1.10
30
20
10
0
39.19%
29.73%
18.92%
9.46%
2.70%
1
2
3
4
5
Low
High

Figure 6.12

horizontal axis indicates the value attributed, ranging from five (high) to one (low). Of the four areas, Analogue Electronic expertise is ranked highest, with Instrumentation (a strand of G.C.E. Modular Technology schemes) lowest. The degree of consensus remains close to 1.21 for Analogue, Digital and Systems Electronics, whilst the level of agreement (1.10) for low perceived expertise is higher for Instrumentation.

Figures 6.13 to 6.16 indicate the resource value of the electronic areas of the C.D.T. curriculum. The lowest valued resource is Instrumentation (Mean 2.38), Systems Electronics being ranked the highest (Mean 3.77). Figures 6.17 to 6.20 provide comparative analysis of the components of perceived expertise and perceived resource value. Tables 6a and 6b indicate the rank order of the different areas of technology within the C.D.T. curriculum.

Table 6.5a Perceived resource value

| Technological area | Rank order | Mean | S.D. |
|---|---|---|---|
| Systems Electronics | 1 | 3.77 | 1.17 |
| Digital Electronics | 2 | 3.59 | 1.09 |
| Analogue Electronics | 3 | 3.42 | 1.12 |
| Instrumentation | 4 | 2.38 | 1.20 |

Table 6.5b Perceived expertise

| Technological area | Rank order | Mean | S.D. |
|---|---|---|---|
| Analogue Electronics | 1 | 2.70 | 1.22 |
| Digital Electronics | 2 | 2.63 | 1.22 |
| Systems Electronics | 3 | 2.59 | 1.22 |
| Instrumentation | 4 | 2.06 | 1.10 |

## 6.5 Teaching approaches adopted to introduce technological content into Design activities

The primary objective of the questions relating to technological approaches in design activities was to gain insights into the preferred teaching approaches in aspects of

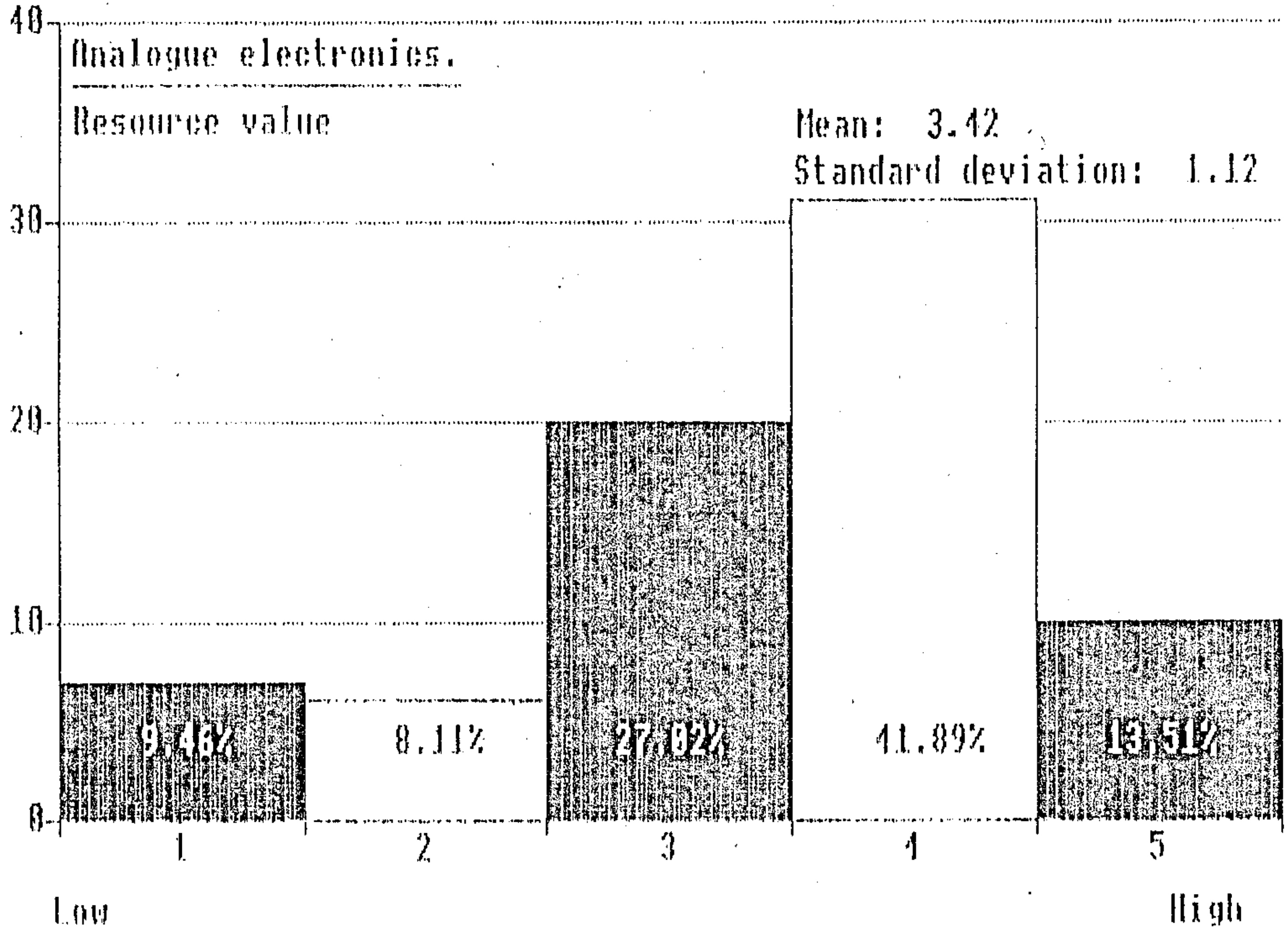
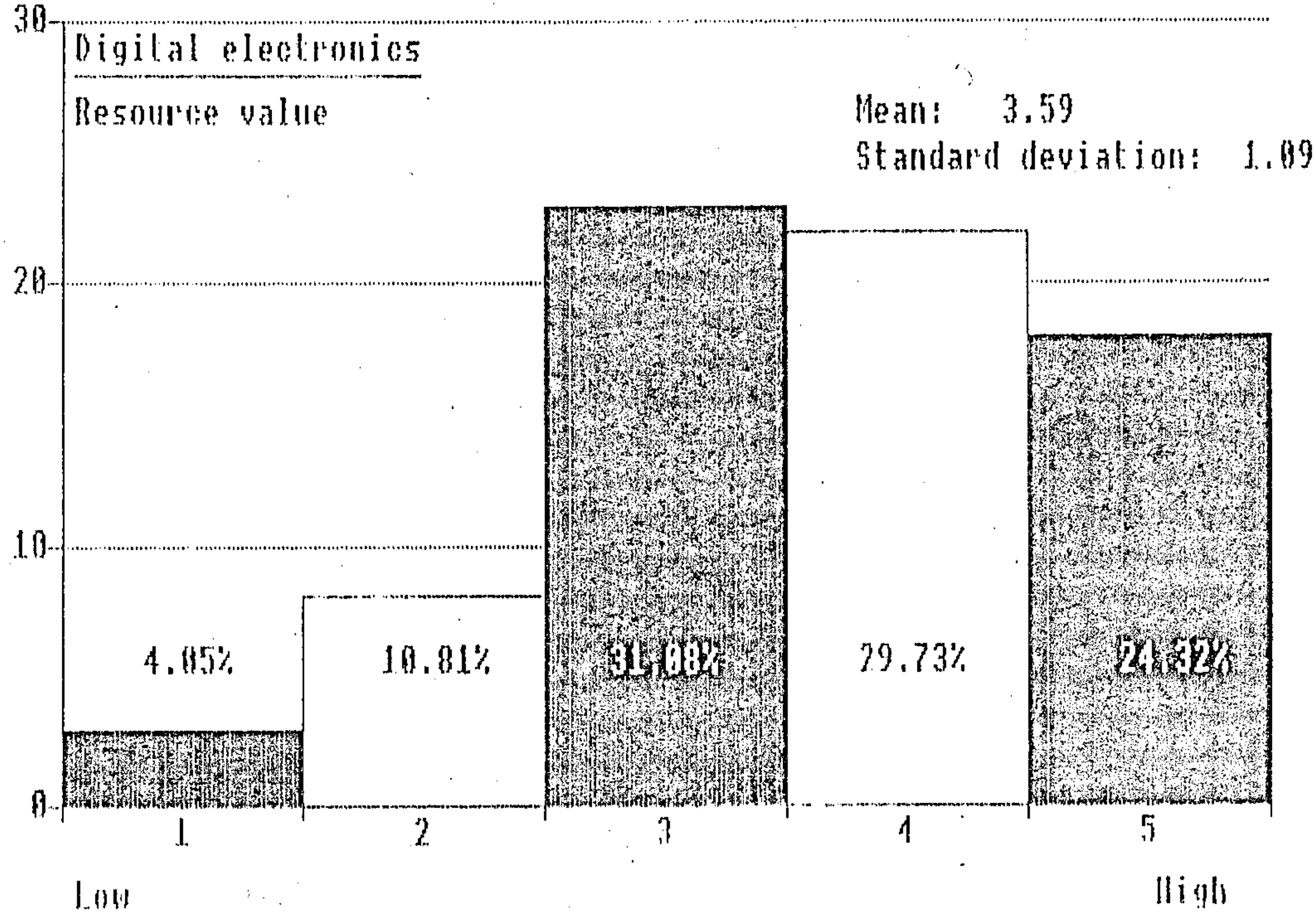

Analogue electronics.
Resource value
Mean: 3.42
Standard deviation: 1.12
40
30
20
10
0
9.46%
8.11%
27.02%
41.89%
13.51%
1
2
3
4
5
Low
High

Figure 6.13

Figure 6.14


Digital electronics
Resource value
Mean: 3.59
Standard deviation: 1.09
30
20
10
0
4.05%
10.81%
31.08%
29.73%
24.32%
1
2
3
4
5
Low
High

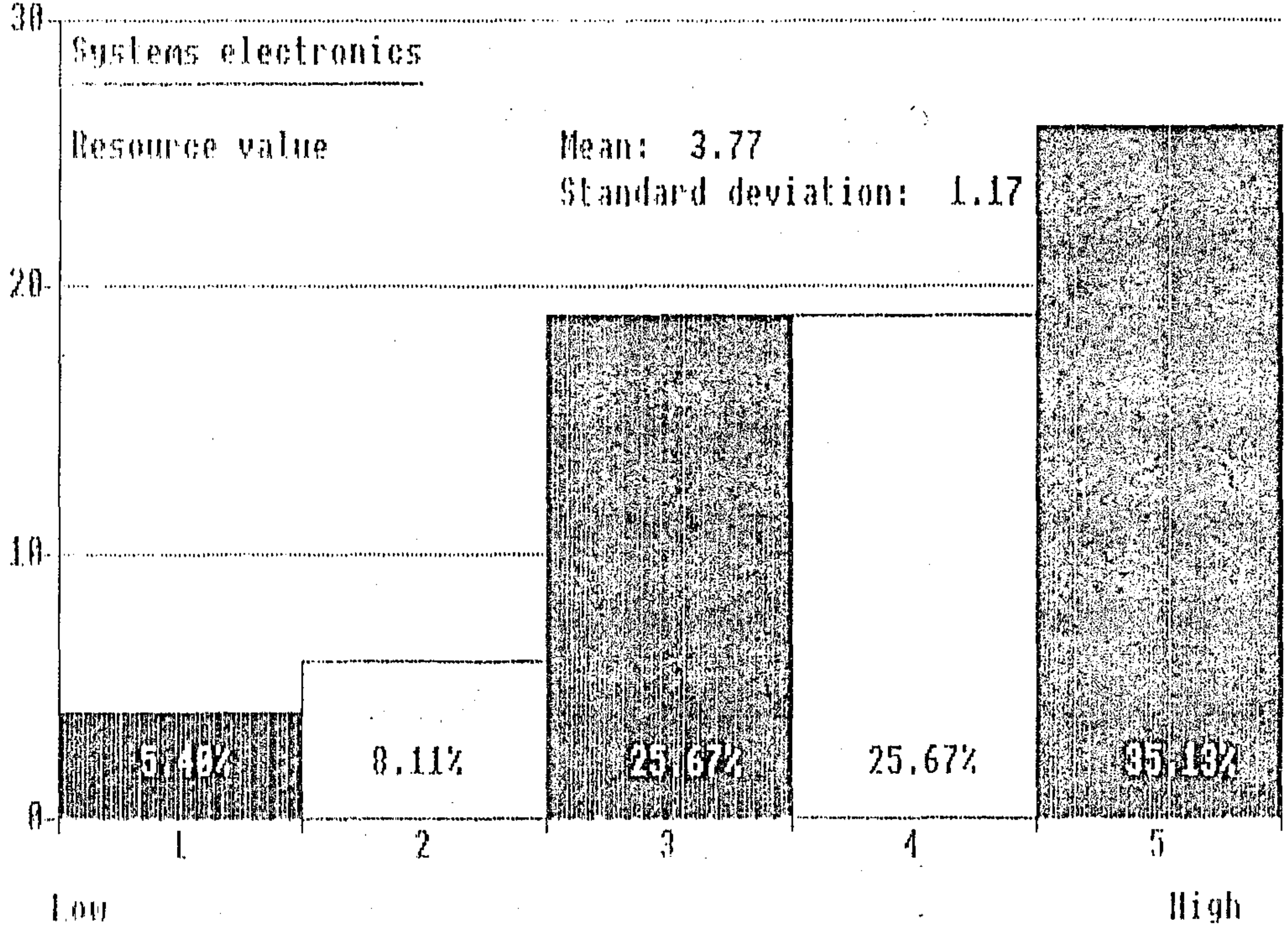
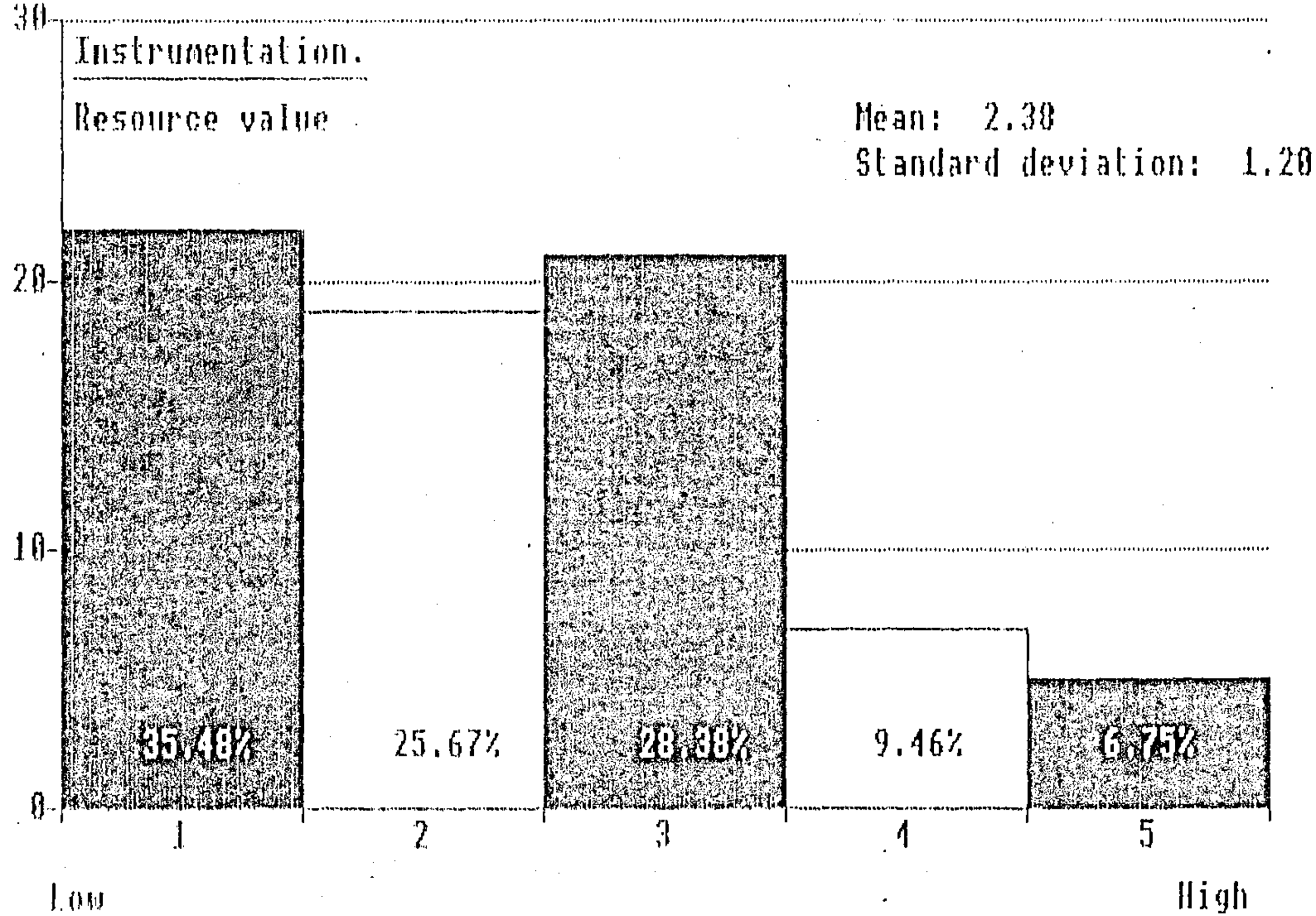

Systems electronics
Resource value
Mean: 3.77
Standard deviation: 1.17
30
20
10
0
5.40%
8.11%
25.67%
25.67%
35.13%
1
2
3
4
5
Low
High

Figure 6.15



Instrumentation.
Resource value
Mean: 2.30
Standard deviation: 1.20
30
20
10
0
35.48%
25.67%
28.38%
9.46%
6.75%
1
2
3
4
5
Low
High


Figure 6.16

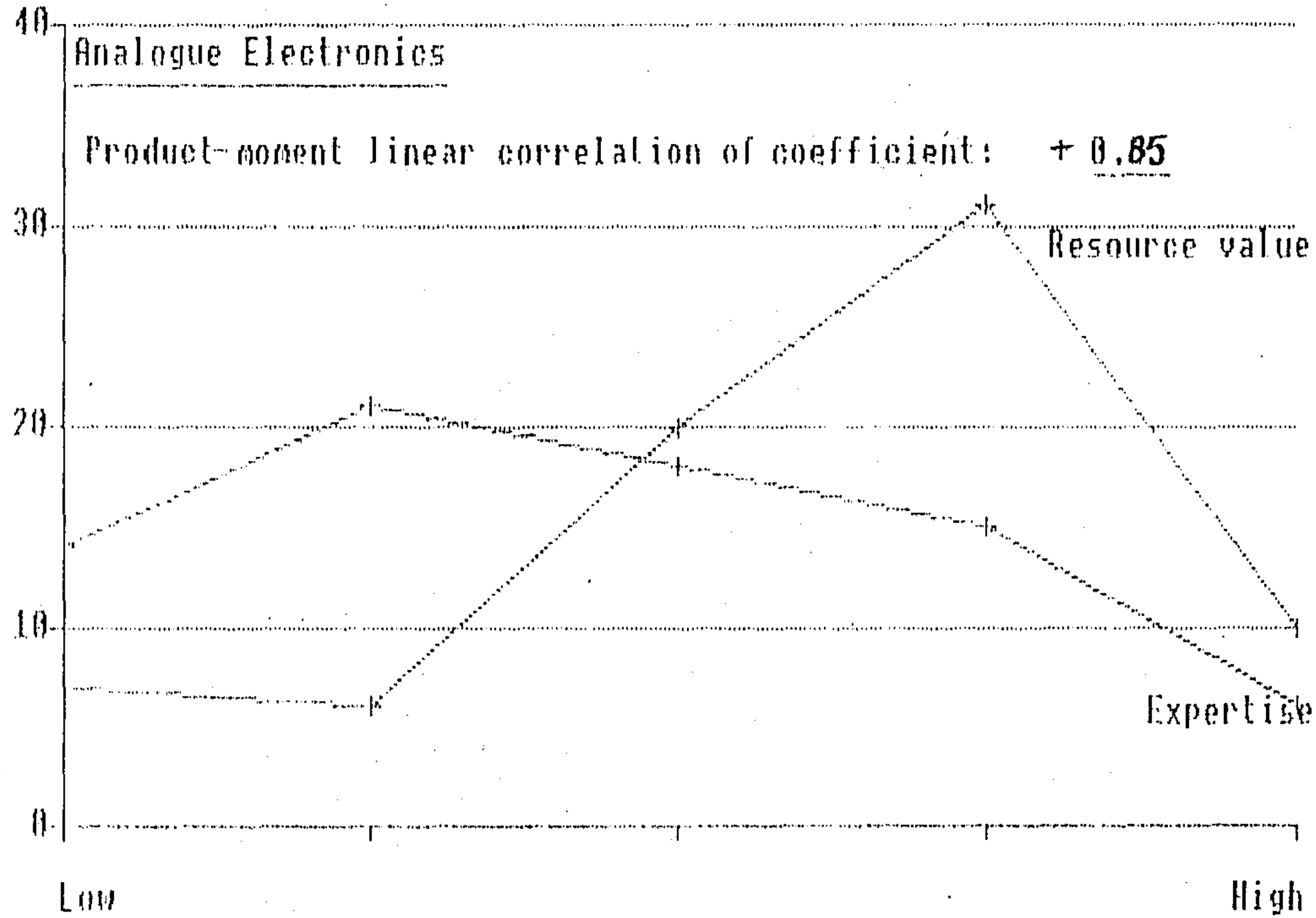

Analogue Electronics
Product-moment linear correlation of coefficient: + 0.85
40
30
20
10
0
Resource value
Expertise
Low
High

Figure 6.17

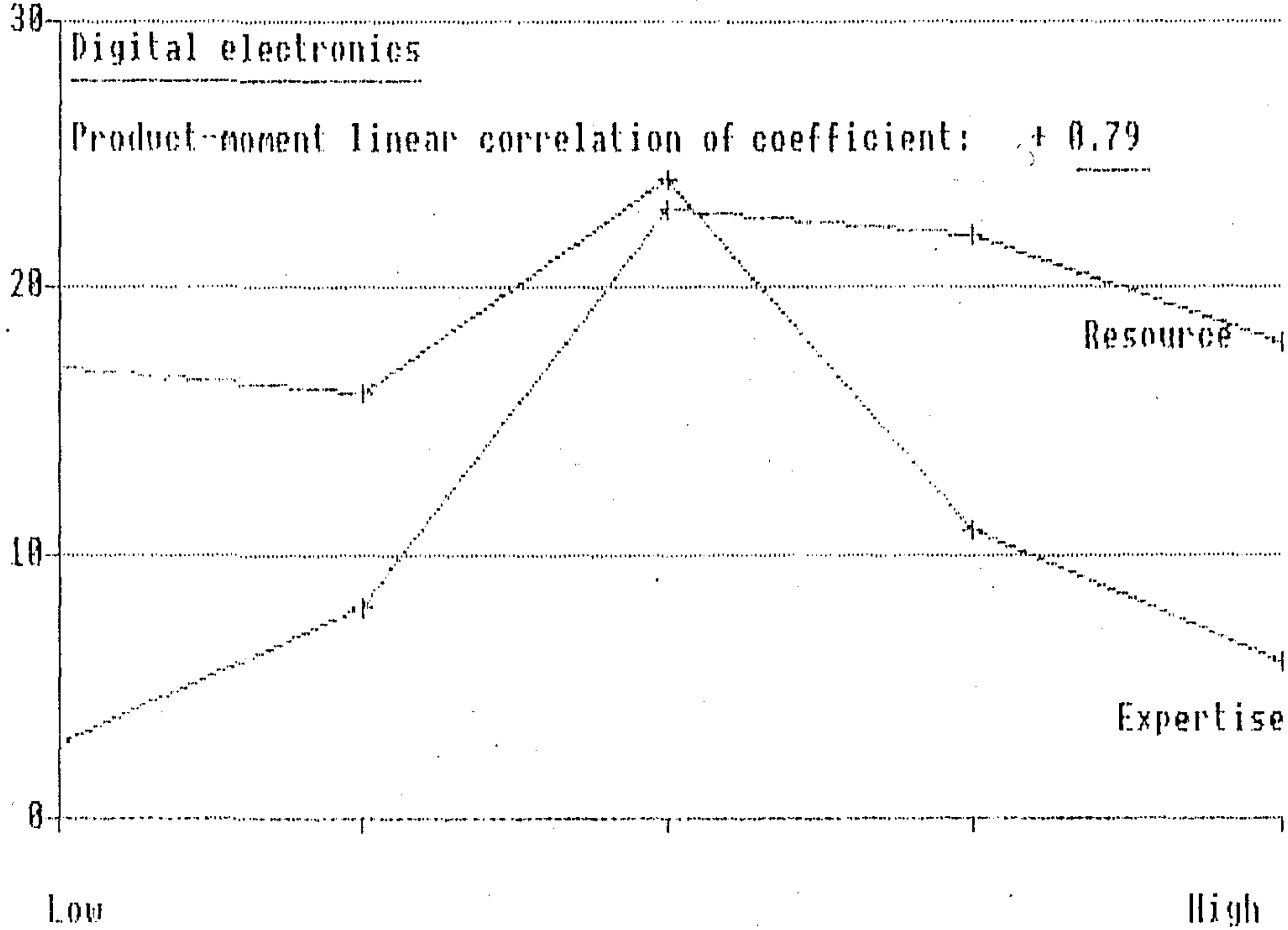
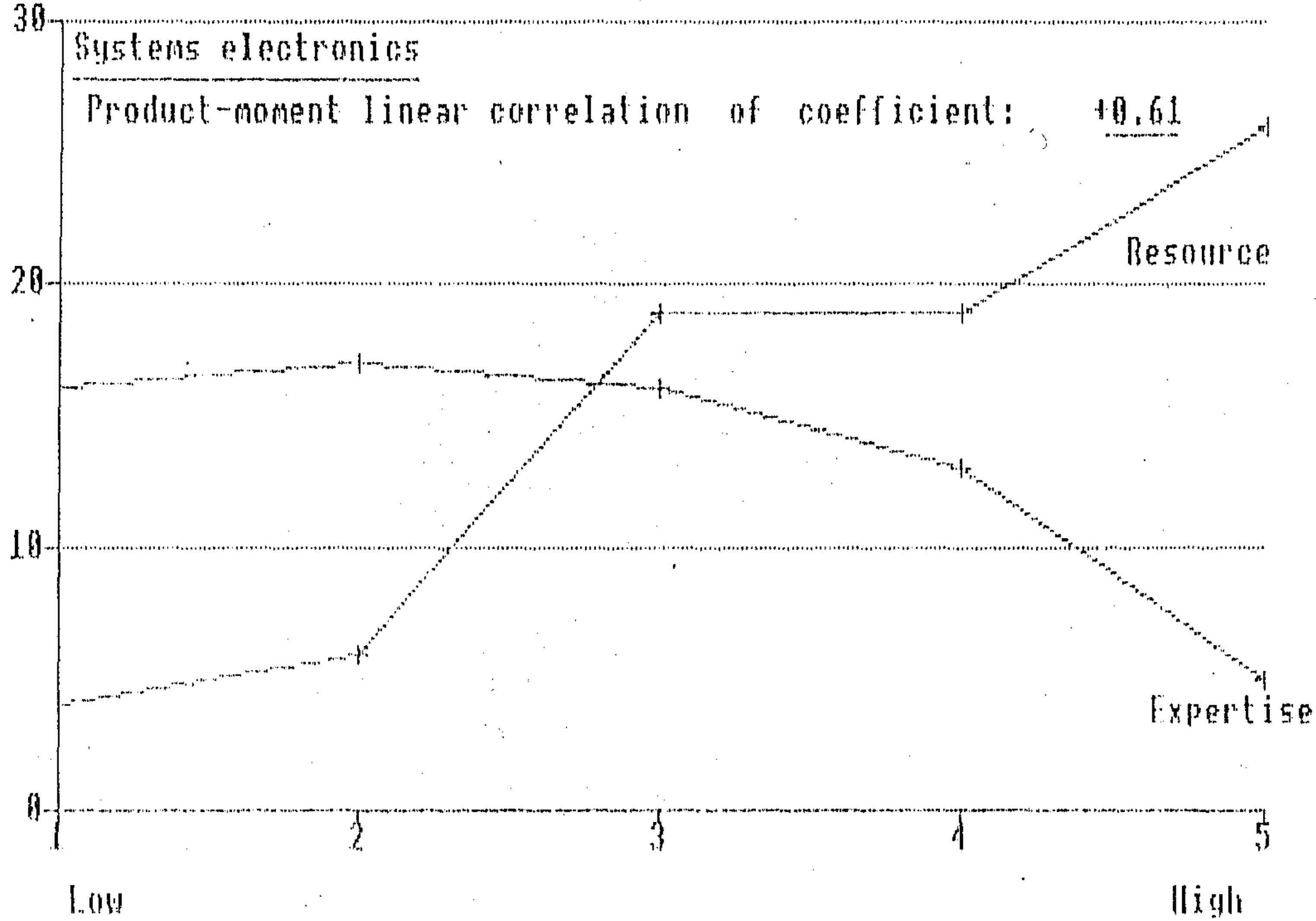
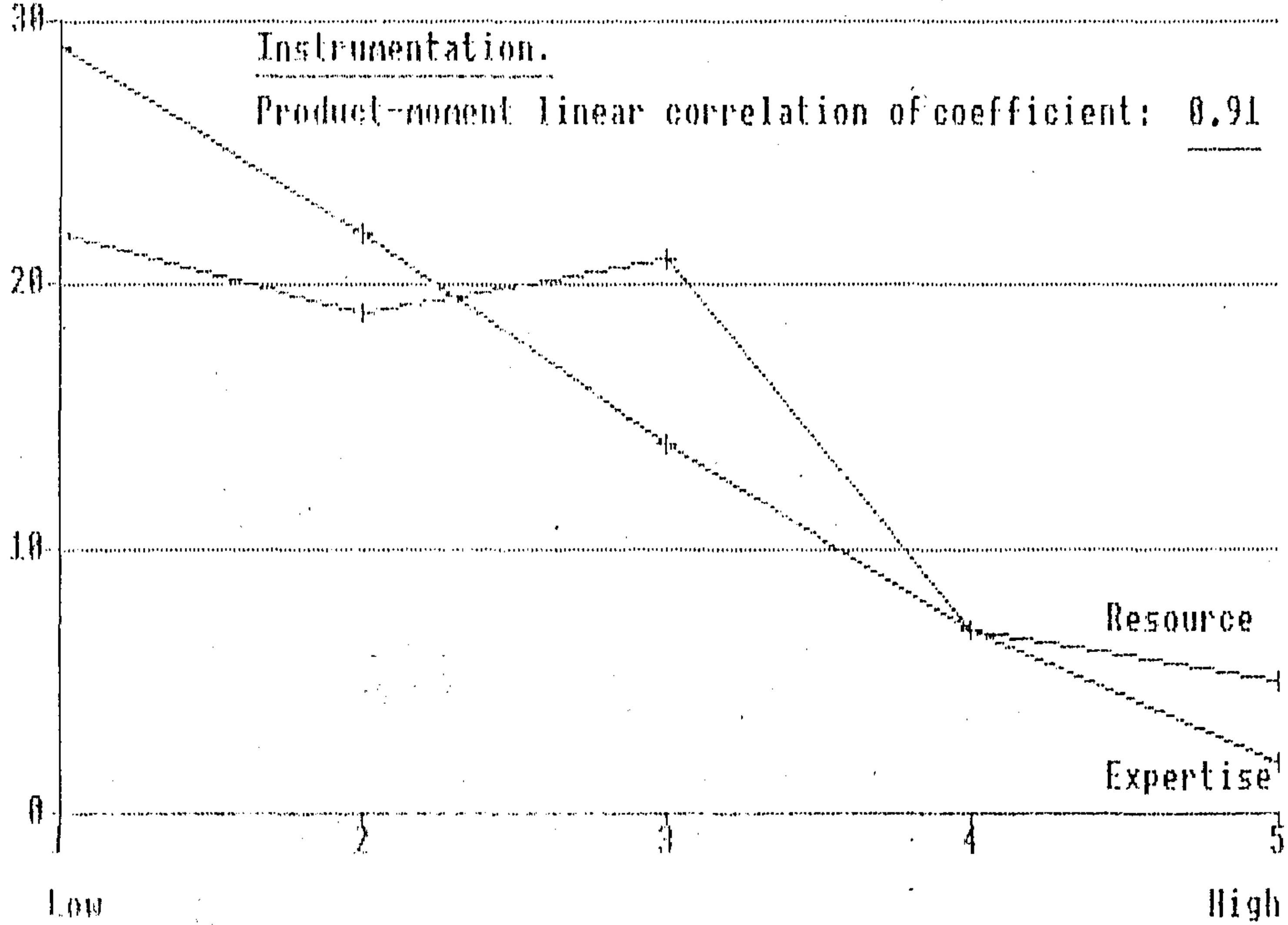

Digital electronics
Product-moment linear correlation of coefficient: + 0.79
30
20
10
0
Resource
Expertise
Low
High

Figure 6.18



Systems electronics
Product-moment linear correlation of coefficient: +0.61
Resource
Expertise
30
20
10
0
1
2
3
4
5
Low
High


Figure 6.19



Instrumentation.
Product-moment linear correlation of coefficient: 0.91
30
20
10
0
1
2
3
4
5
Low
High
Resource
Expertise


Figure 6.20

electronics. Responses provided the necessary insights but conclusions were difficult to draw due to the limitations caused by the construction of some of the questions. Questions 12, 13 and 14 indicate the manner in which technological content is introduced into problem solving activities, responses indicate whether:

[1] Technological aspects are taught in in isolation of each other.
[2] Design briefs lead into specific aspects of technology.
[3] Open-ended design briefs lead into various aspects of technology.

Figures 6.21, 6.22 and 6.23 suggest that design activities are more likely to be of an open-ended nature, leading towards a study specific aspects of technology, rather than an approach that teaches technological subjects in isolation of each other.

6.6 Electronics in Craft, Design and Technology

Figures 6.24 to 6.28 illustrate the responses to questions 15 to 19, indicating the extent to which electronics feature in the C.D.T. curriculum and also the particular approach adopted from the Systems - Analysis continuum.

Table 6.6a The extent to which electronics feature in the C.D.T. curriculum.

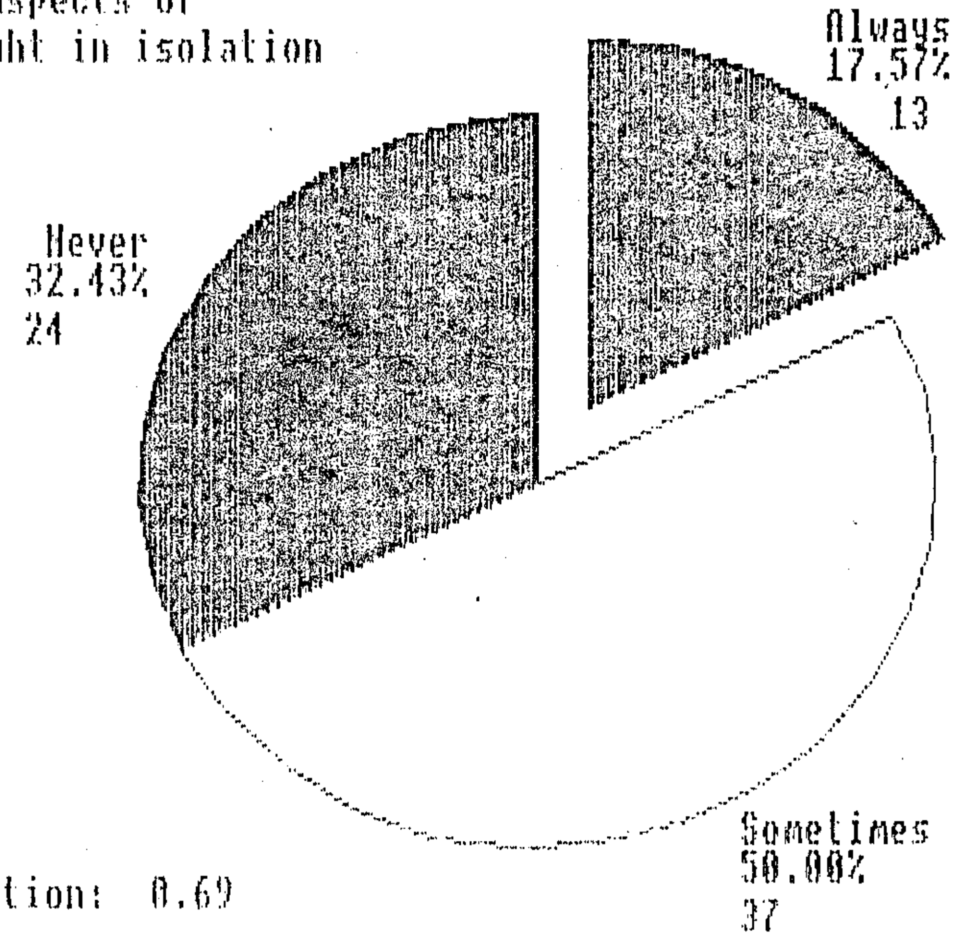
| | | | |
|---|---|---|---|
| Always | 40.54% | Mean 2.21 | S.D. 0.74 |
| Sometimes | 40.54% | | |
| Never | 18.92% | | |

Table 6.6b The extent to which electronics are taught separately in C.D.T. schemes.

| | | | |
|---|---|---|---|
| Always | 29.73% | Mean 2.11 | S.D. 0.69 |
| Sometimes | 51.35% | | |
| Never | 18.92% | | |

Figure 6.21

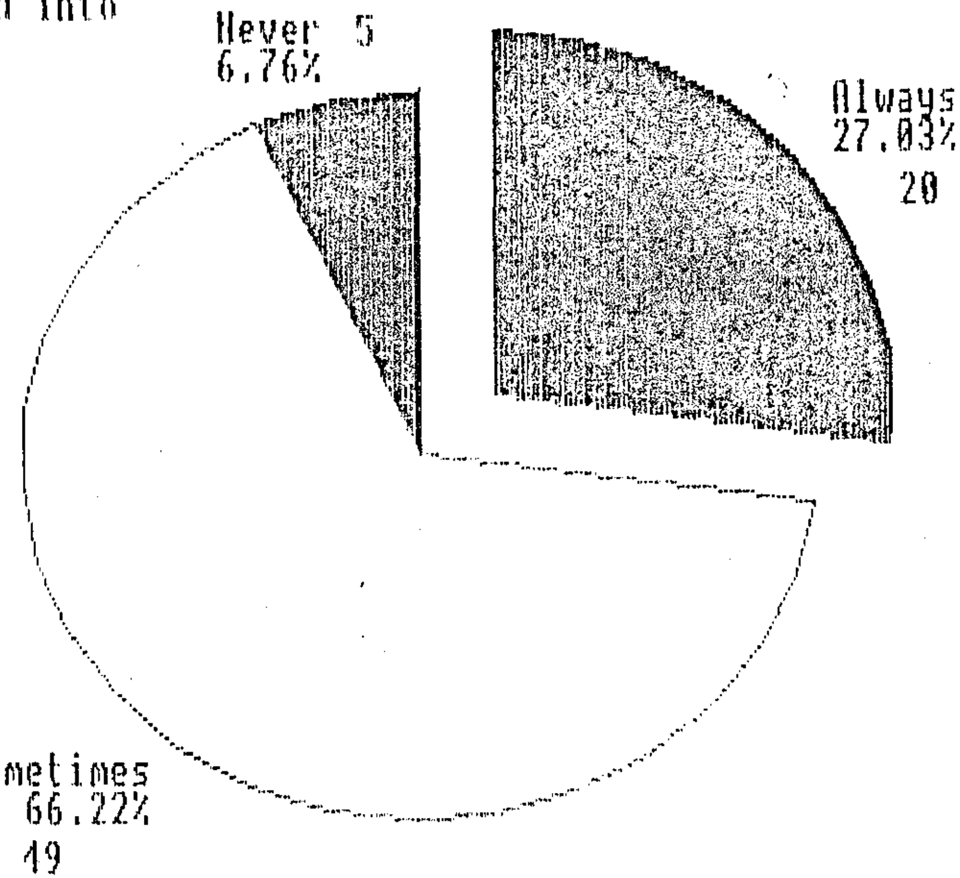
Are different aspects of technology taught in isolation of each other?




Mean: 1.85
Standard deviation: 0.69

Figure 6.22

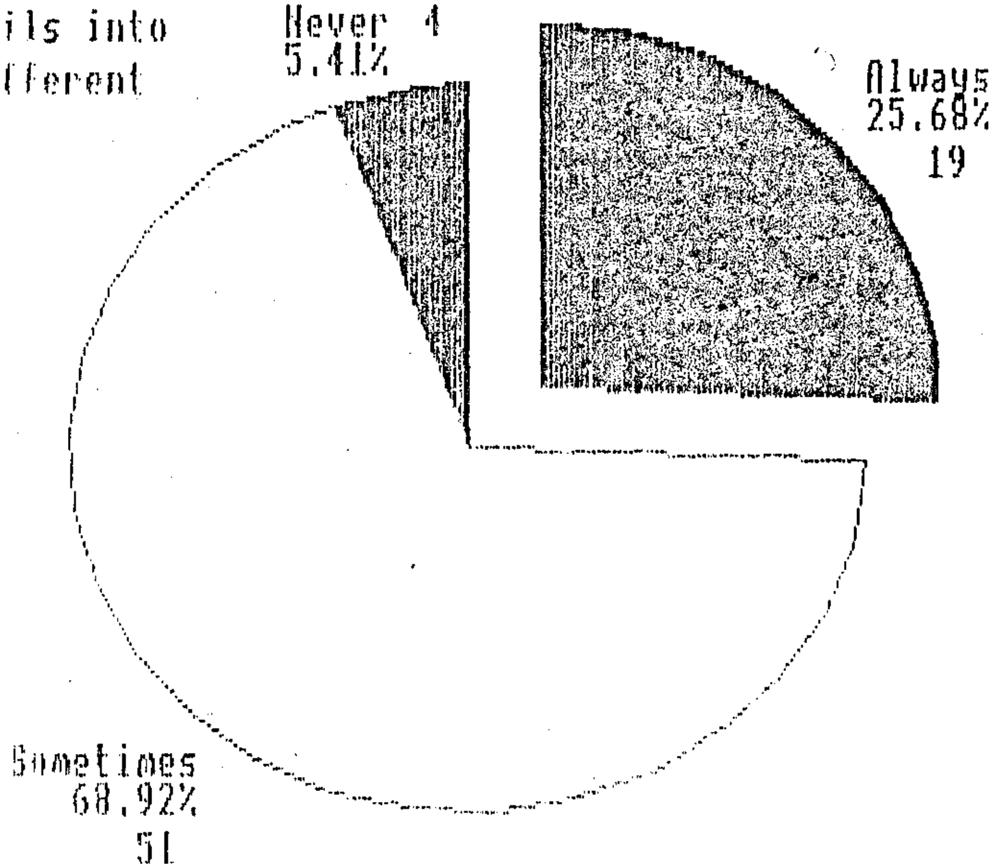
Do design briefs lead into an application of a particular aspect of technology?




Mean: 2.20
Standard deviation: 0.55

Figure 6.23

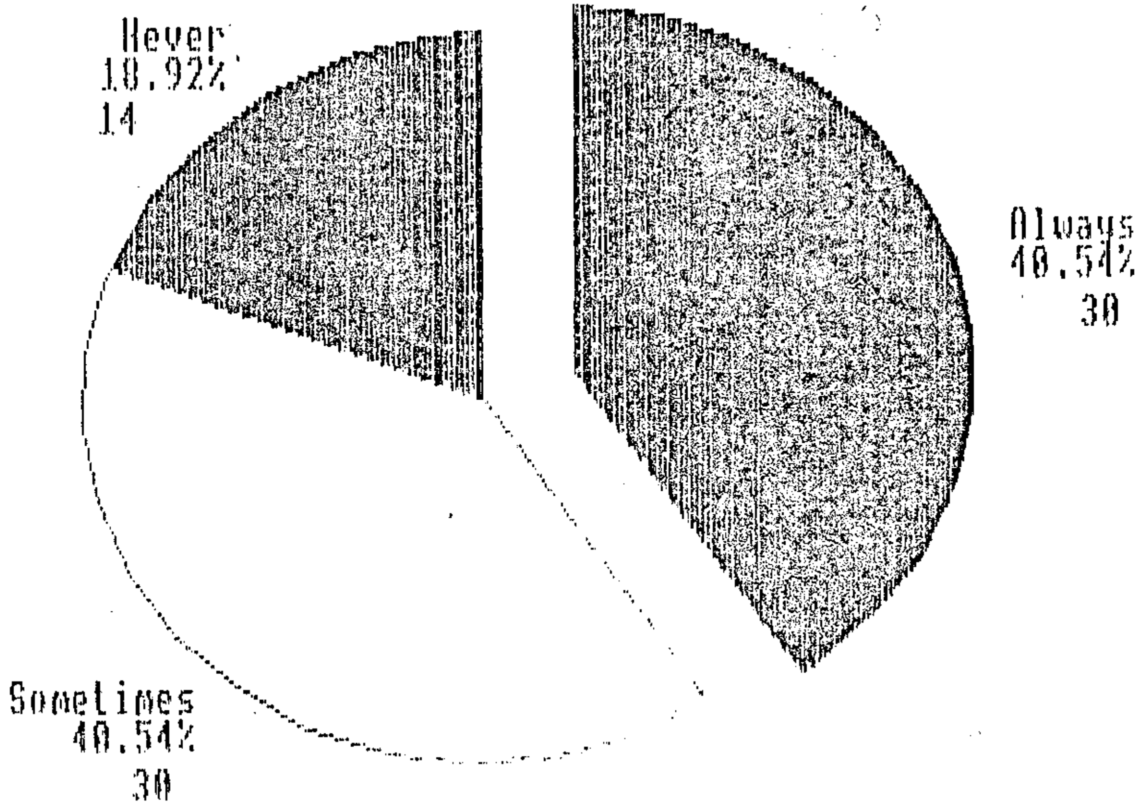
Are open design briefs set which may lead pupils into to a variety of different investigations?




Mean: 2.20

Standard deviation: 0.27

Do electronics feature in your CDT curriculum?



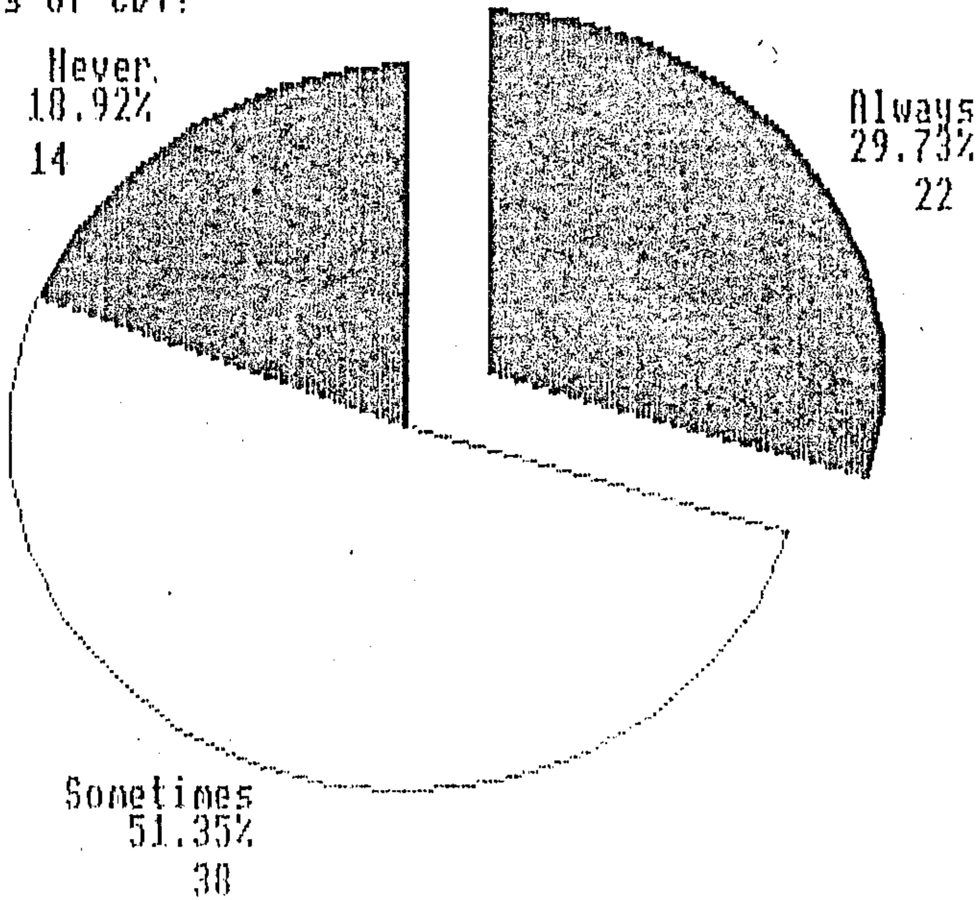

Mean: 2.21

Standard deviation: 0.74

Figure 6.24

Figure 6.25

Are electronics taught separately from the other aspects of CDT?

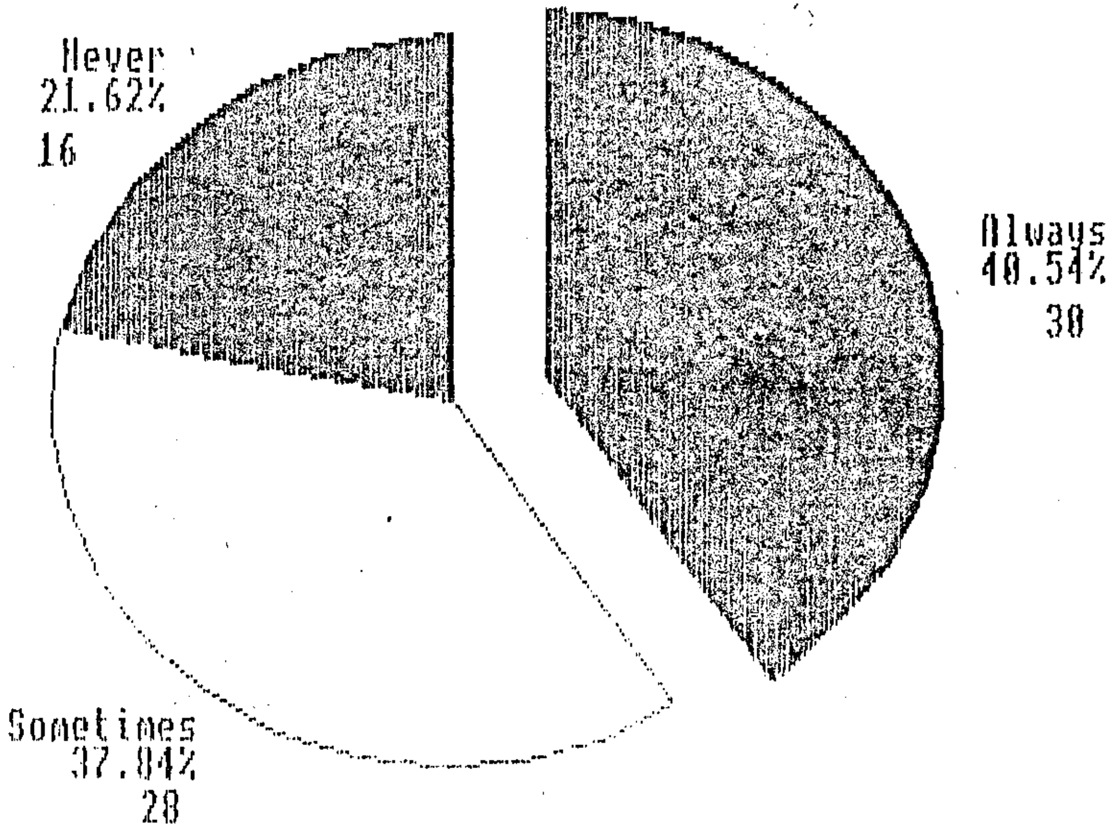



Mean: 2.11

Standard deviation: 0.69

Figure 6.26

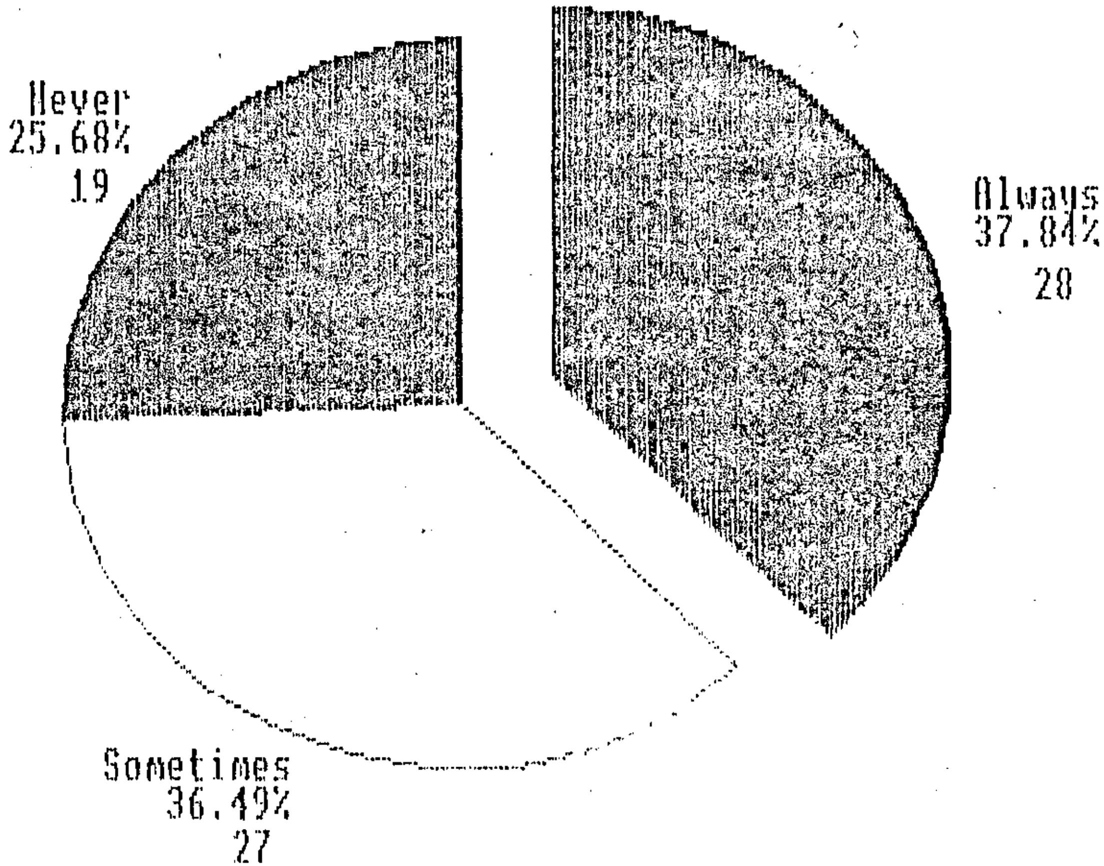
Is there a policy to promote a particular approach to the teaching of electronics?




Mean: 2.19
Standard deviation: 0.77

Figure 6.27

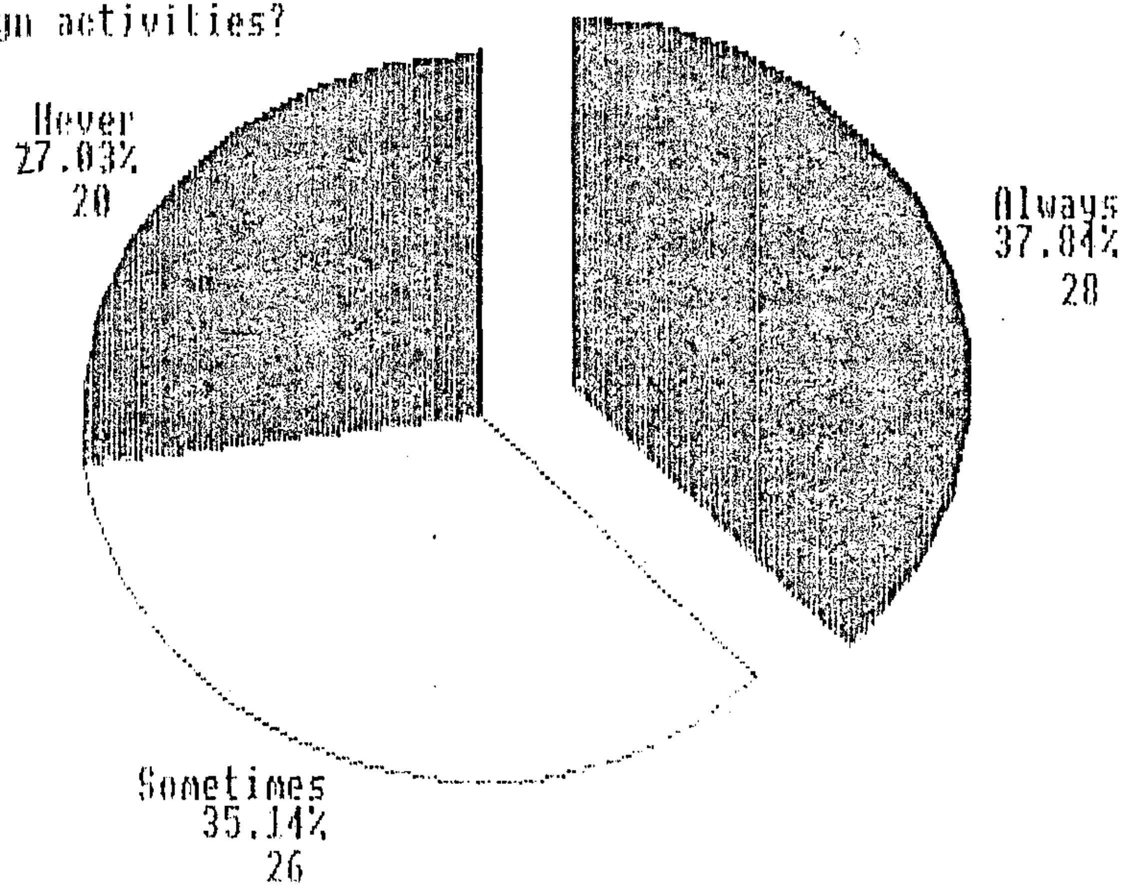
Is emphasis placed on a knowledge
of the properties of components?




Mean: 2.12
Standard deviation: 0.79

Figure 6.28

Are systems approaches employed to solve the electronic problems pupils encounter in their CDT design activities?




Mean: 2.11
Standard deviation: 0.80

Table 6.6c The extent to which a departmental policy to promote electronics exists.

| | | | |
|---|---|---|---|
| Always | 40.54% | Mean 2.19 | S.D. 0.77 |
| Sometimes | 37.83% | | |
| Never | 21.62% | | |

Table 6.6d The extent to which emphasis is placed on a knowledge of the properties of components in electronic circuits.

| | | | |
|---|---|---|---|
| Always | 37.83% | Mean 2.12 | S.D. 0.79 |
| Sometimes | 36.48% | | |
| Never | 25.67% | | |

Table 6.6e The extent to which Systems approaches are used in electronic design activities.

| | | | |
|---|---|---|---|
| Always | 37.83% | Mean 2.11 | S.D. 0.80 |
| Sometimes | 35.13% | | |
| Never | 27.02% | | |

The data generated by this question was processed by allocating a score of 3 for Always, 2 for Sometimes and 1 for Never. The higher the value of the Mean the greater the bias towards Always. the degree of consensus is shown by the Standard Deviation. The lower the Standard Deviation the greater the level of agreement between respondents.

The results would indicate that electronics feature in 81.08% of all schools researched. Of these schools 40.54% regularly incorporate electronics into their teaching schemes. The greatest bias in this group showed a Mean of 2.21 towards Always. The highest degree of agreement is shown in question 16, which highlighted the extent to which electronics is taught separately from the other aspects of the C.D.T. curriculum. A Mean of 2.11 reflected a bias towards the separate teaching of electronics in C.D.T. schemes.

Question 17 attempted to measure the extent to which schools adopt policies towards electronics teaching. The results strongly suggests that schools generate policies (40.54% Always). This question poses further questions relating to the exact nature of these policies. The original intention was to achieve an understanding of these policies from the responses to questions 18 and 19. Although in a limited way this this was achieved, it would have assisted the interpretation of the results if this question had been posed in a more straight forward way.

## 6.7 Approaches to electronics teaching

Responses to questions 18 and 19 indicate the extent to which C.D.T. teachers adopt a Systems or a Component Centred approach to electronics teaching. Within this section of the questionnaire there is an almost equal split between those who always use a Systems approach and those who always use an analytical or component centred approach. The least consensus within this section was found in the responses to the Systems questions. Conclusions to these questions (posed to ascertain the extent and approach adopted towards electronics teaching) suggest that policies exist to promote electronics teaching, and that the particular teaching approach is split along the Systems - Analysis continuum.

## 6.8 Teaching electronic theory in Systems approaches

Question 20 appeared to cause confusion to several of the participants in the survey. Respondents were requested to indicate the stage or stages during which the essential electronic theory should be taught in Systems approaches; before the investigation, during the investigation, during the realization, after construction or not at all. Some respondents restricted their response to a single stage whilst others referred to the complete range of stages during which it could be taught. The result of this confusion has meant that responses are in the range of 65 to 55 out of a maximum of 74.

When should the underpinning electronic be taught in Systems approaches?

Table 7a Before setting the problem

| | | | |
|---|---|---|---|
| Always | 7.93% | Mean 1.47 | S.D. 0.59 |
| Sometimes | 31.75% | | |
| Never | 60.30% | | |

Table 7b During the investigation

| | | | |
|---|---|---|---|
| Always | 33.84% | Mean 2.26 | S.D. 0.55 |
| Sometimes | 58.46% | | |
| Never | 7.69% | | |

Table 7c During the assembly

| | | | |
|---|---|---|---|
| Always | 39.68% | Mean 2.20 | S.D. 0.68 |
| Sometimes | 41.27% | | |
| Never | 19.05% | | |

Table 7d After the realization of the system

| | | | |
|---|---|---|---|
| Always | 35.59% | Mean 2.23 | S.D. 0.58 |
| Sometimes | 52.54% | | |
| Never | 11.86% | | |

Table 7e Not at all

| | | | |
|---|---|---|---|
| Always | 14.54% | Mean 1.65 | S.D. 0.62 |
| Sometimes | 36.36% | | |
| Never | 49.09% | | |

Table 8 Teaching electronics in Systems approaches

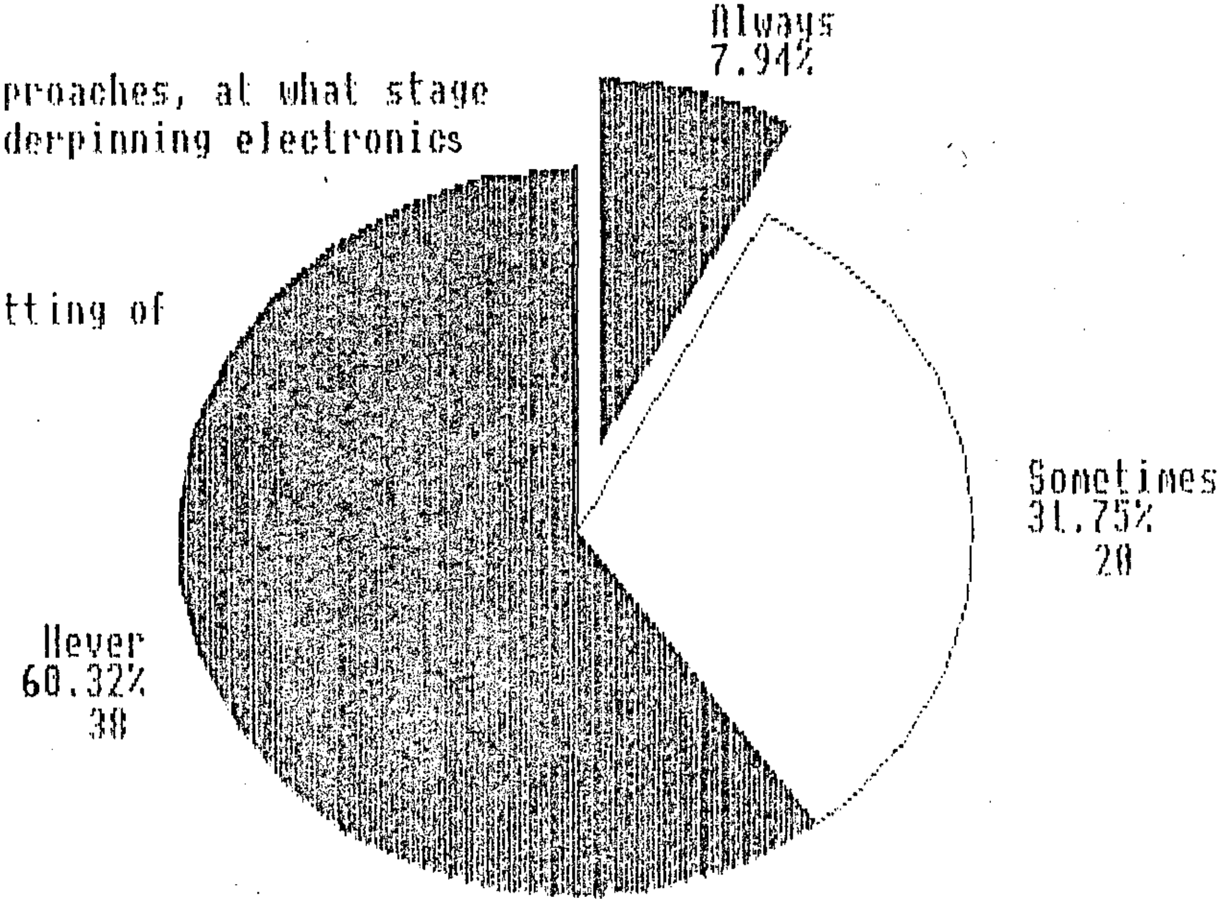
| Rank order summary | Mean | Rank | S.D. |
|---|---|---|---|
| During investigation | 2.26 | 1 | 0.55 |
| After realization | 2.23 | 2 | 0.58 |
| During realization | 2.20 | 3 | 0.68 |
| Not at All | 1.65 | 4 | 0.62 |
| Before the set problem | 1.47 | 5 | 0.59 |

Figures 6.29 to 6.33 show the responses to questions 20, which refer to the stages during which the supporting electronic theory may be taught in systems approaches. The

Figure 6.29

In systems approaches, at what stage should the underpinning electronics be taught?

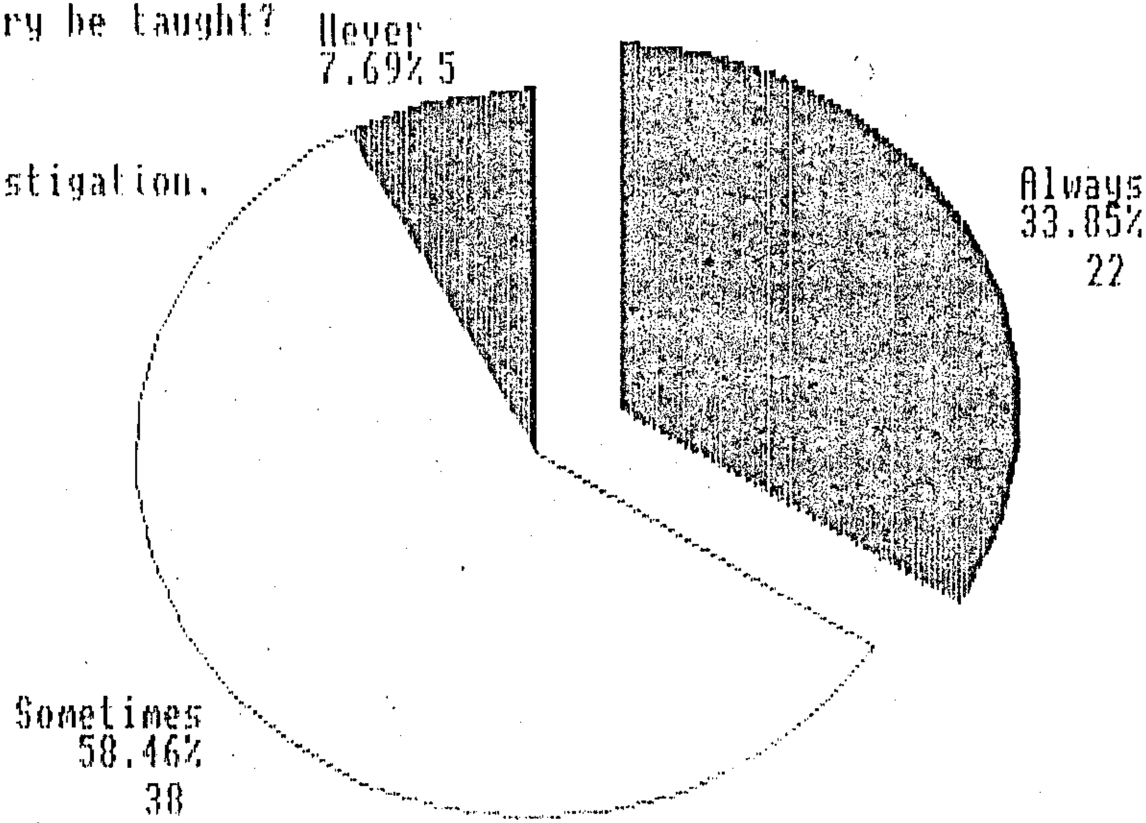
Before the setting of the problem.




Mean: 1.47
Standard deviation: 0.59

In systems approaches, at what stage should the underpinning electronic theory be taught?

During the investigation.




Mean: 2.26

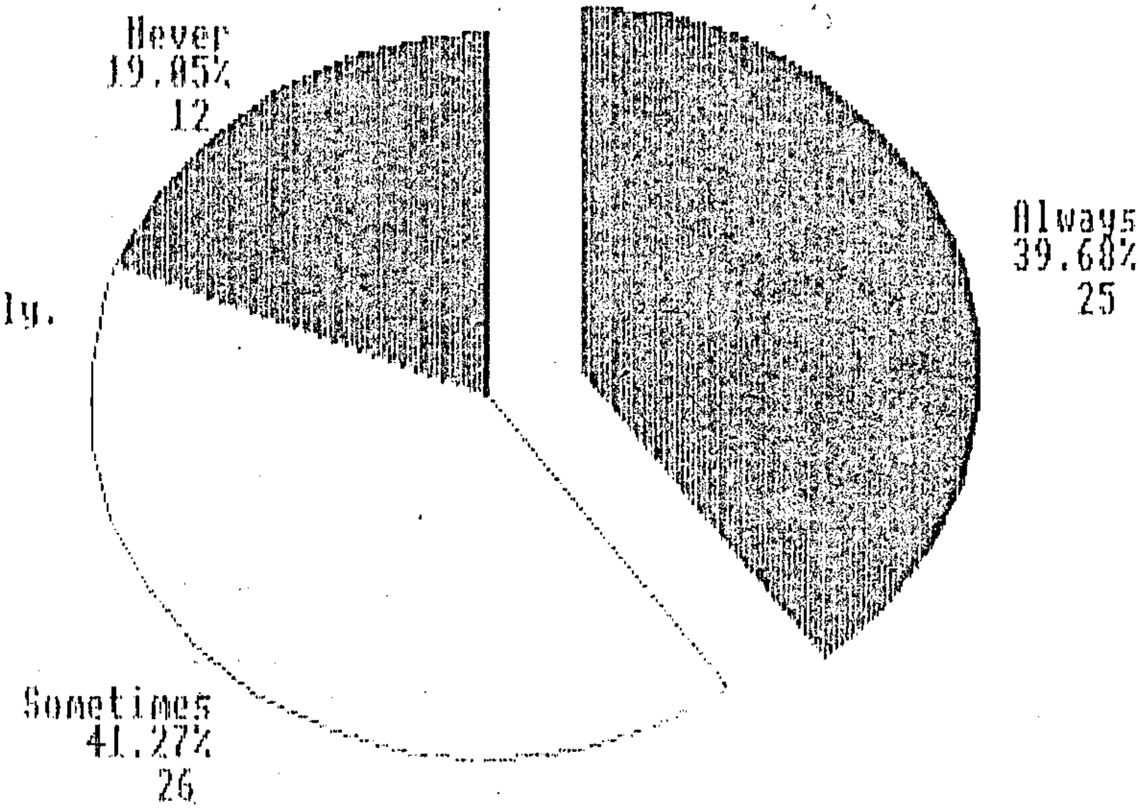
Standard deviation: 0.55

Figure 6.30

Figure 6.31

In systems approaches, at what stage should the underpinning electronic theory be taught?

During the assembly.



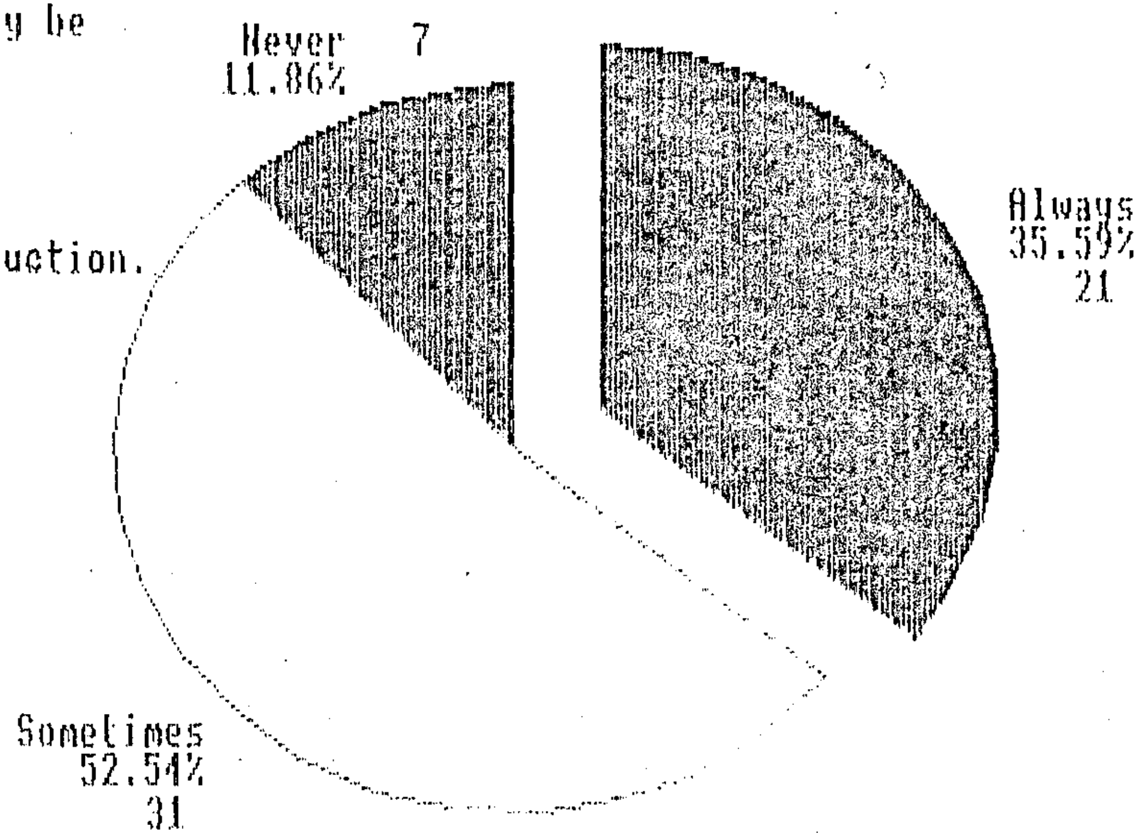

Mean: 2.20

Standard deviation: 0.68

Figure 6.32

In systems approaches, at what stage should the underpinning electronic theory be taught?

After the construction.

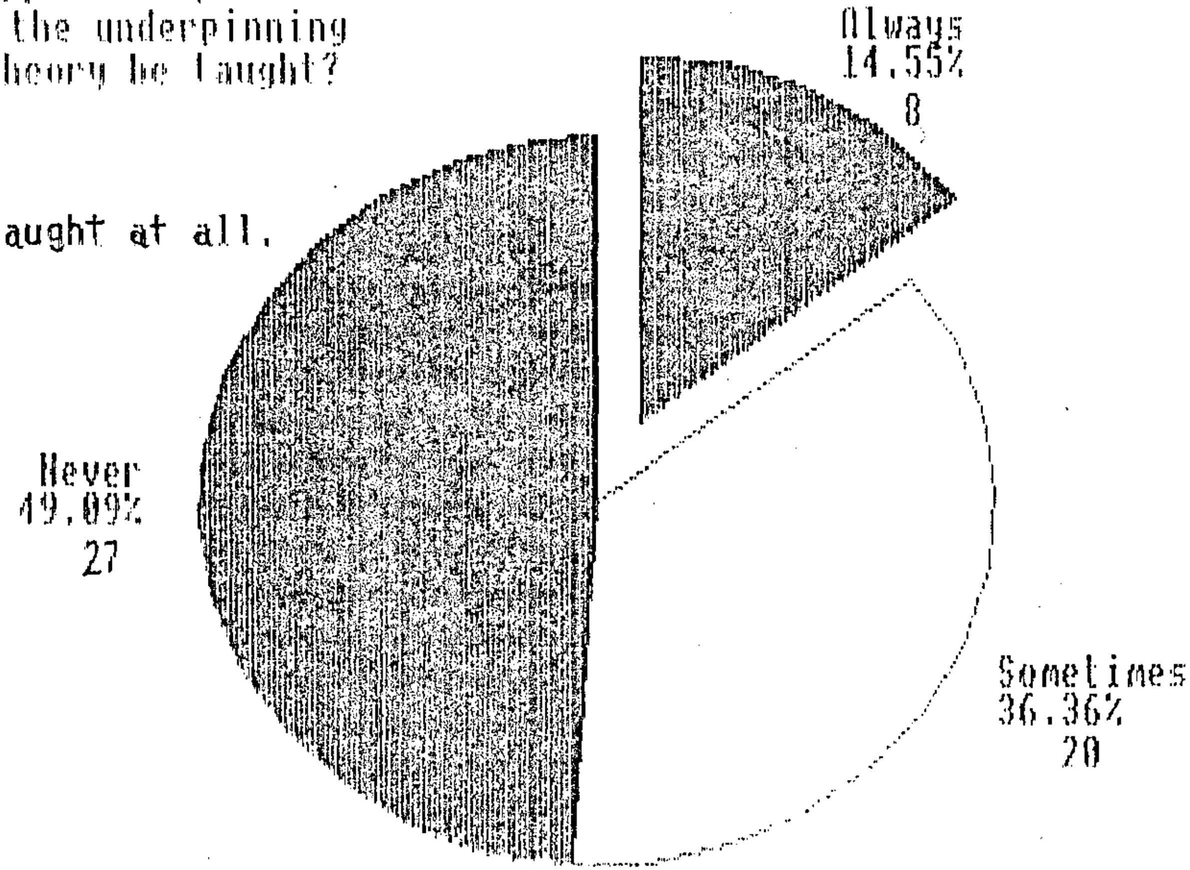



Mean: 2.23
Standard deviation: 0.58

Figure 6.33

In systems approaches, at what stage should the underpinning electronic theory be taught?

Theory not taught at all.




Mean: 1.65

Standard deviation: 0.62

interpretation of the above data, further supported by interview responses, suggests that students may participate in electronic design activities without a prerequisite knowledge of electronic theory. Only 6.84% of all teachers thought it essential to always teach the underpinning electronic theory prior to design activity. No one group differed from another in this respect and the distribution of the responses was similar for all types of school and for levels of teacher expertise. The results suggest that the most appropriate period to teach the theoretical aspects of the design activity is during the investigation stage.

Both the highest level of agreement indicated by the standard deviation and the highest mean score were present in the "..during the investigation stage". Interviews confirmed that the preference is to offer explanation of the function of individually designed systems during the investigation stage of the design process and to a lesser extent during the assembly or realization stage of the product. Personal experience supports the notion that to offer an explanation prior to the presentation of the design context is to limit the perspective on the ways of arriving at a solution. Such restrictions may limit the breath of the design ideas generated.

6.9 Major factors influencing the use of electronics in C.D.T. design activities

Table 6.9 Influences

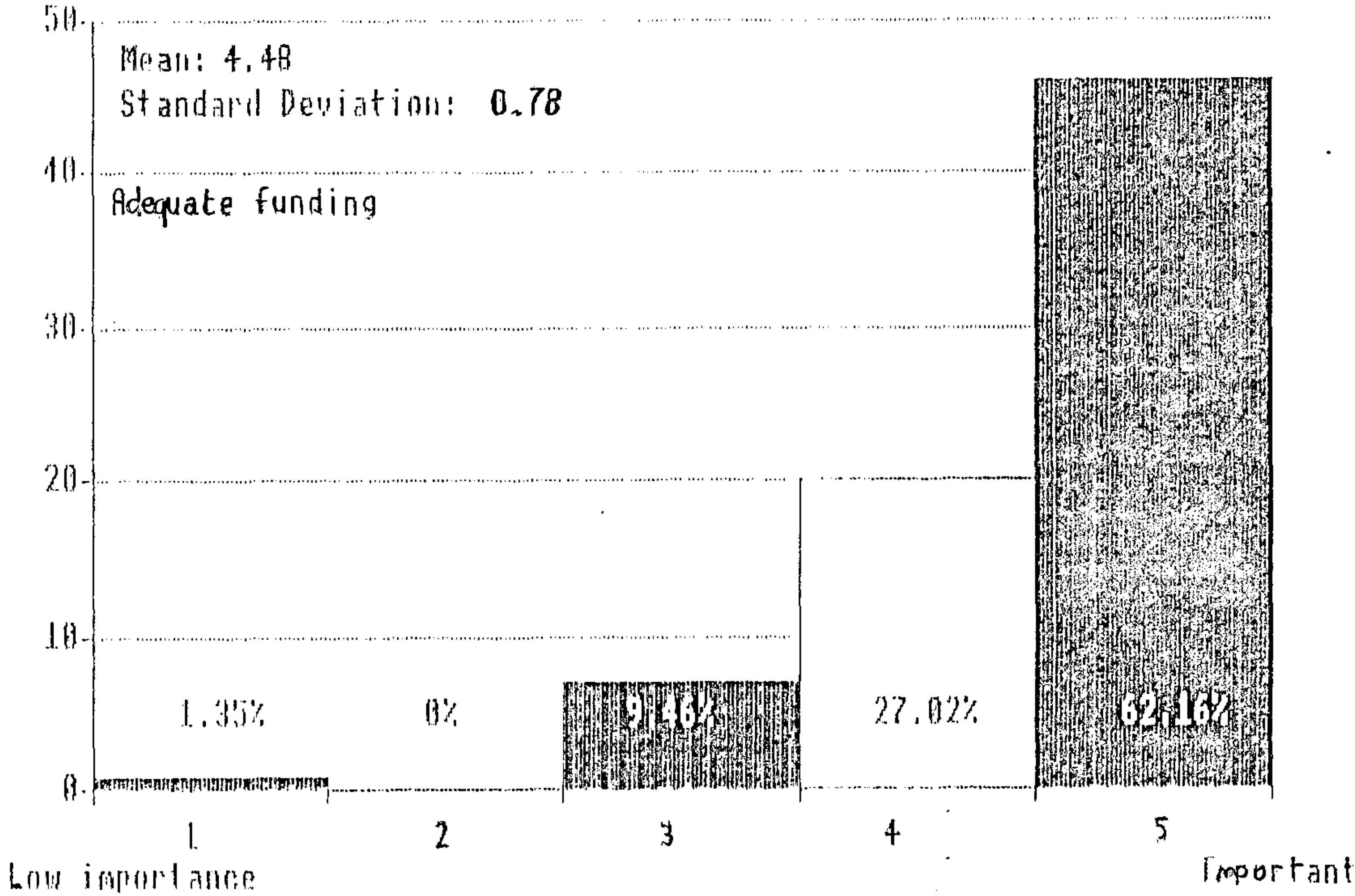
| | Mean | S.D. | Rank |
|---|---|---|---|
| Adequate funding | 4.48 | 0.78 | 1 |
| Teacher enthusiasm | 4.35 | 0.78 | 2 |
| Materials and equipment | 4.11 | 1.01 | 3 |
| Teacher expertise | 4.08 | 1.04 | 4 |
| Inservice training | 3.88 | 1.18 | 5 |
| Time allocation | 3.82 | 1.22 | 6 |
| Management support | 3.40 | 1.22 | 7 |
| Student pressure | 3.23 | 1.07 | 8 |
| Advisory support | 3.23 | 1.29 | 9 |
| H.M. Inspectorate | 2.05 | 1.21 | 10 |

The results suggest that electronics cannot be taught without adequate student and teacher support. Support is necessary in a range of different forms, from materials and equipment to moral support and encouragement. With the exception of H.M.I. all influences were considered important with particular emphasis on adequate funding and teacher enthusiasm. Figures 6.34 to 6.45 demonstrate the factors which influence teachers in introducing electronics into C.D.T. schemes. A recurring comment made during interviews was that of inadequate funding and lack of confidence. Providing that funding was present and that the necessary enthusiasm existed electronics were likely to be included irrespective of the level of expertise. Several of C.D.T. departments visited were under considerable financial pressure to maintain the most rudimentary design courses. Financial resources being unavailable to fund additional elements into the C.D.T. curriculum. Interview responses further suggest that teachers require rapid follow up support, particularly in the early stages when teacher confidence is being established and when any lack of expertise may cause problems in responding to student design demands.

### 6.10 The appropriateness of Systems electronics approaches in C.D.T. schemes

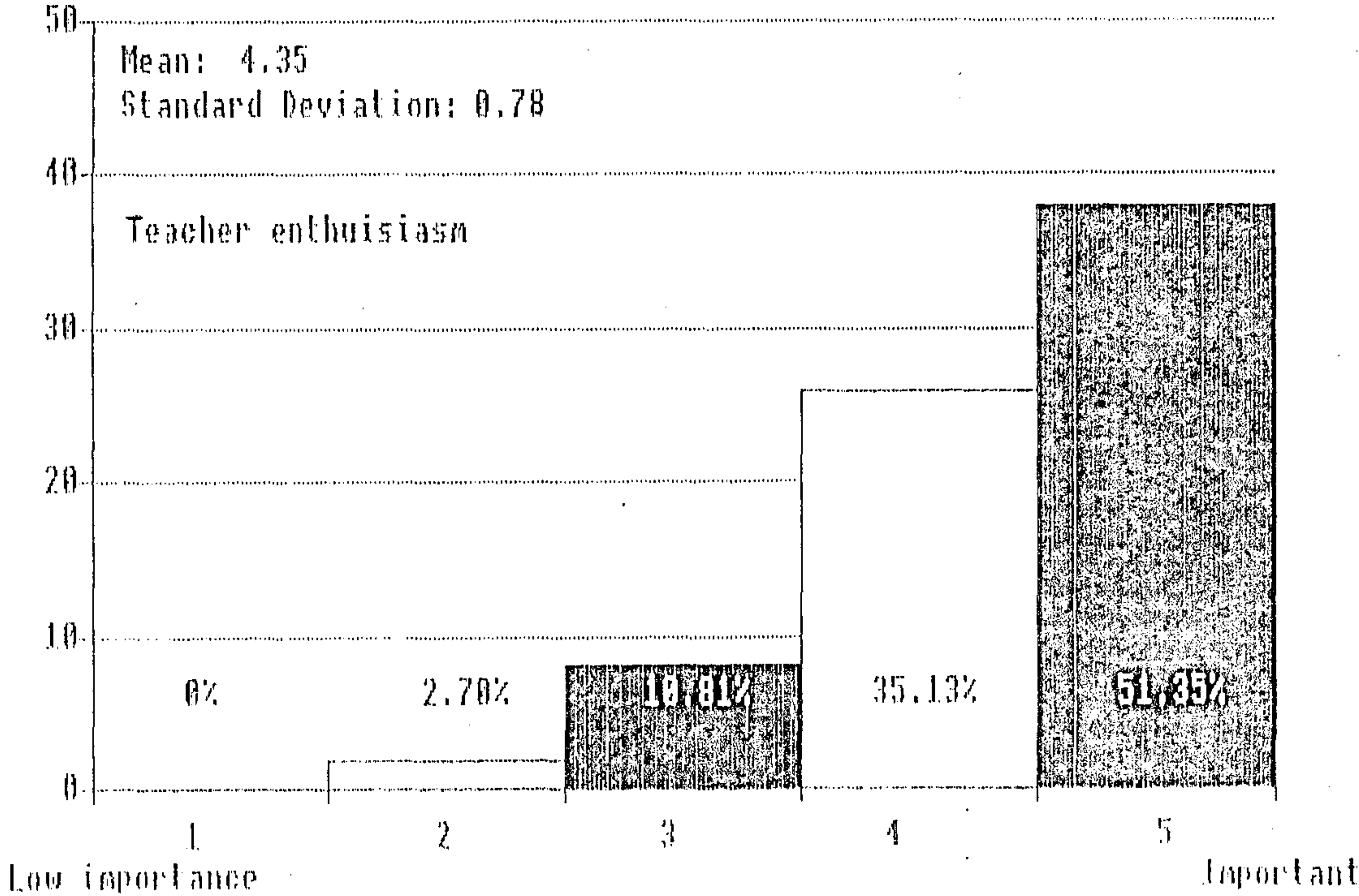
Question 22 presented a number of statements which were designed to indicate the perceptions of the appropriateness of Systems approaches for C.D.T. design activities. Participants were required to indicate the extent to which they agreed or disagreed with the statements, a score of five indicating strong agreement, a score of 0 indicating strong disagreement. A mean score in excess of 3 indicates a bias towards agreement. The lower the S.D. the greater the degree of consensus. These questions provide a guide to teacher opinion of the value of Systems approaches. Responses are provided in figures 6.46 to 6.50.

Figure 6.34

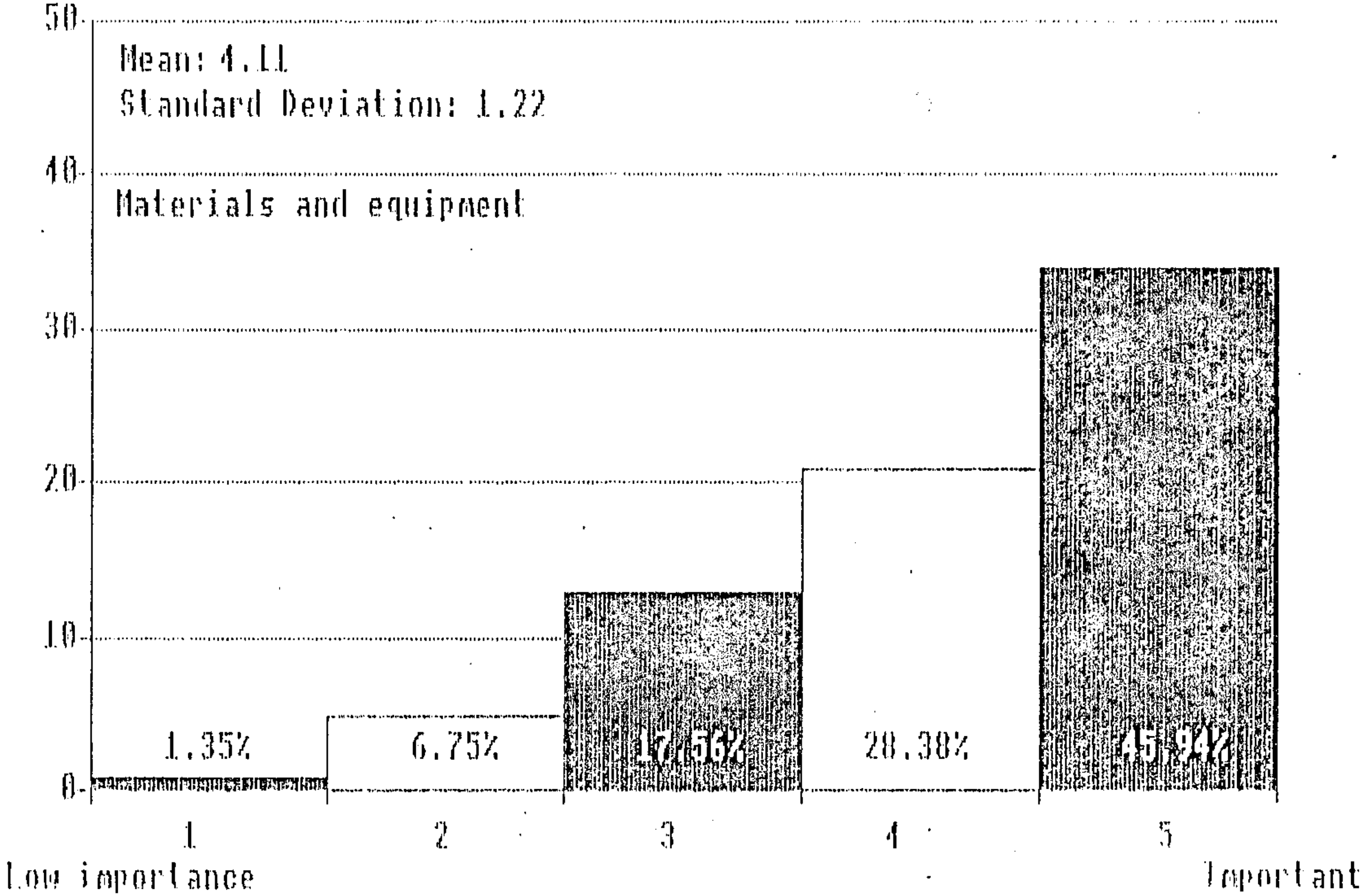


Mean: 4.48
Standard Deviation: 0.78
Adequate funding
50
40
30
20
10
0
1.35%
0%
9.46%
27.02%
62.16%
1
2
3
4
5
Low importance
Important

Figure 6.35

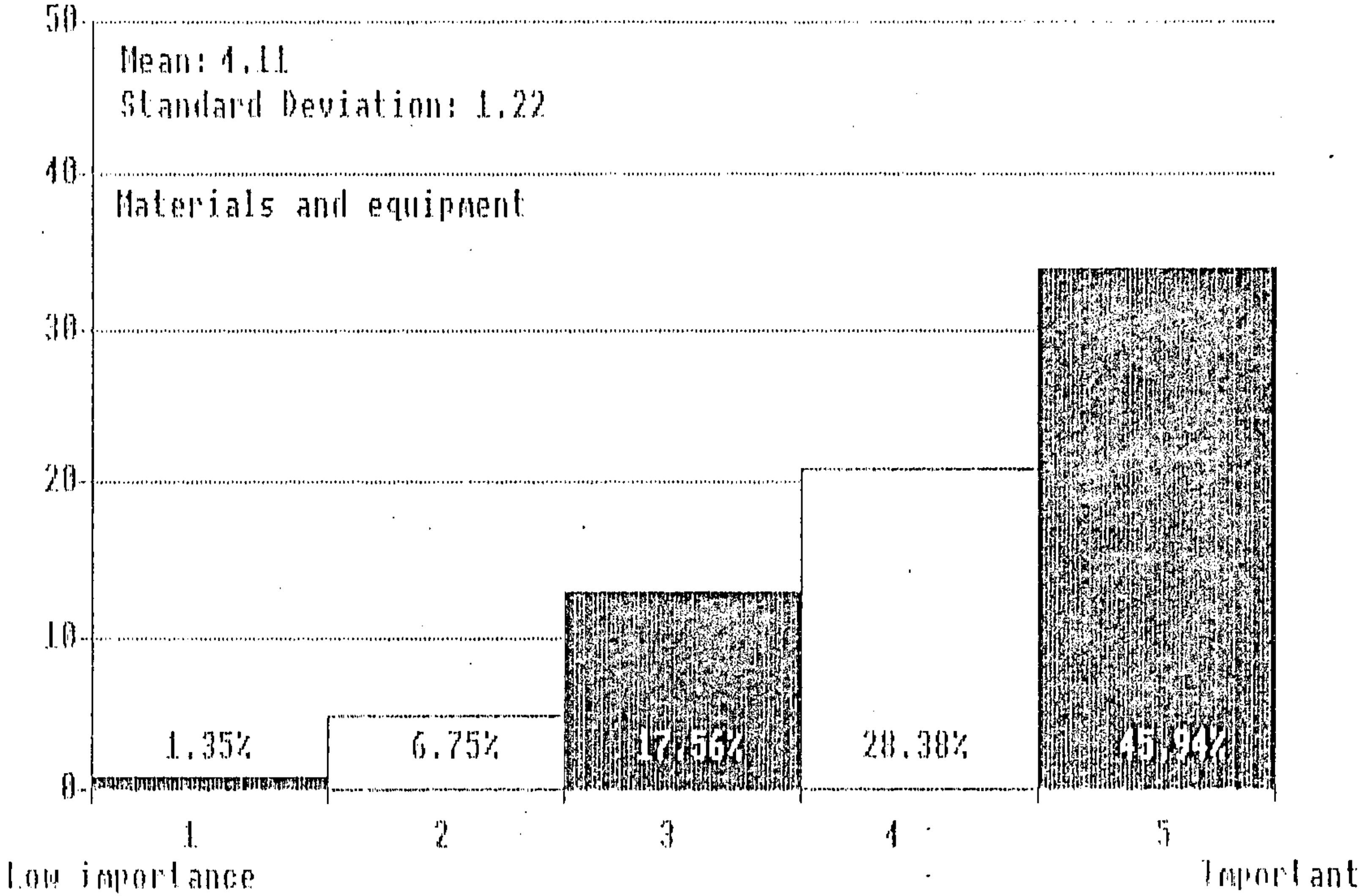


Mean: 4.35
Standard Deviation: 0.78
Teacher enthuisiasm
50
40
30
20
10
0
0%
2.70%
10.81%
35.13%
51.35%
1
2
3
4
5
Low importance
Important



Mean: 4.11
Standard Deviation: 1.22
Materials and equipment
50
40
30
20
10
0
1.35%
6.75%
17.56%
28.38%
45.94%
1
2
3
4
5
Low importance
Important

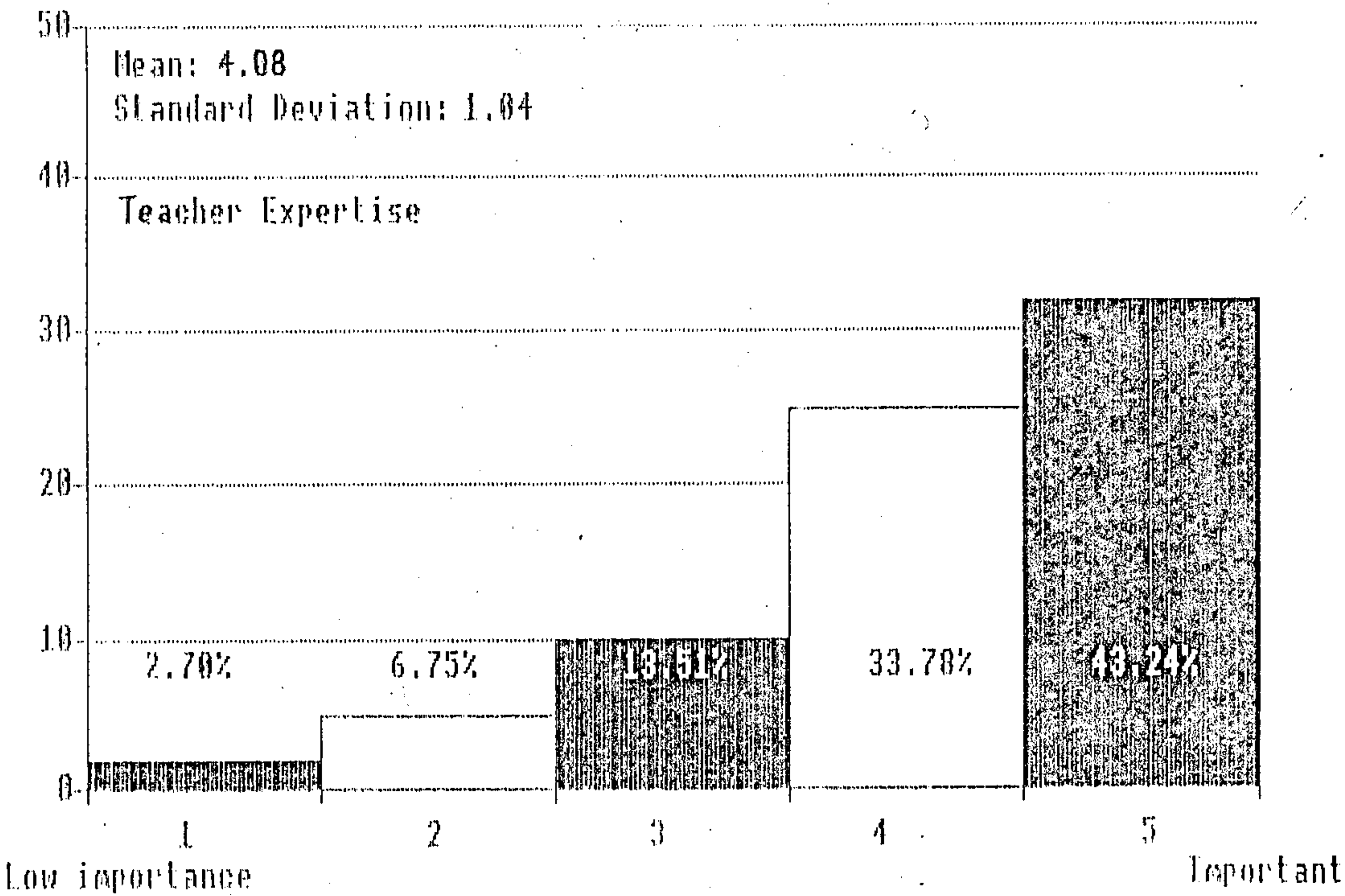

Figure 6.36



Mean: 4.11
Standard Deviation: 1.22
Materials and equipment
50
40
30
20
10
0
1.35%
6.75%
17.56%
28.38%
45.94%
1
2
3
4
5
Low importance
Important


Figure 6.36

igure 6.37



Mean: 4.08
Standard Deviation: 1.04
Teacher Expertise
50
40
30
20
10
0
2.70%
6.75%
13.51%
33.78%
43.24%
1
2
3
4
5
Low importance
Important

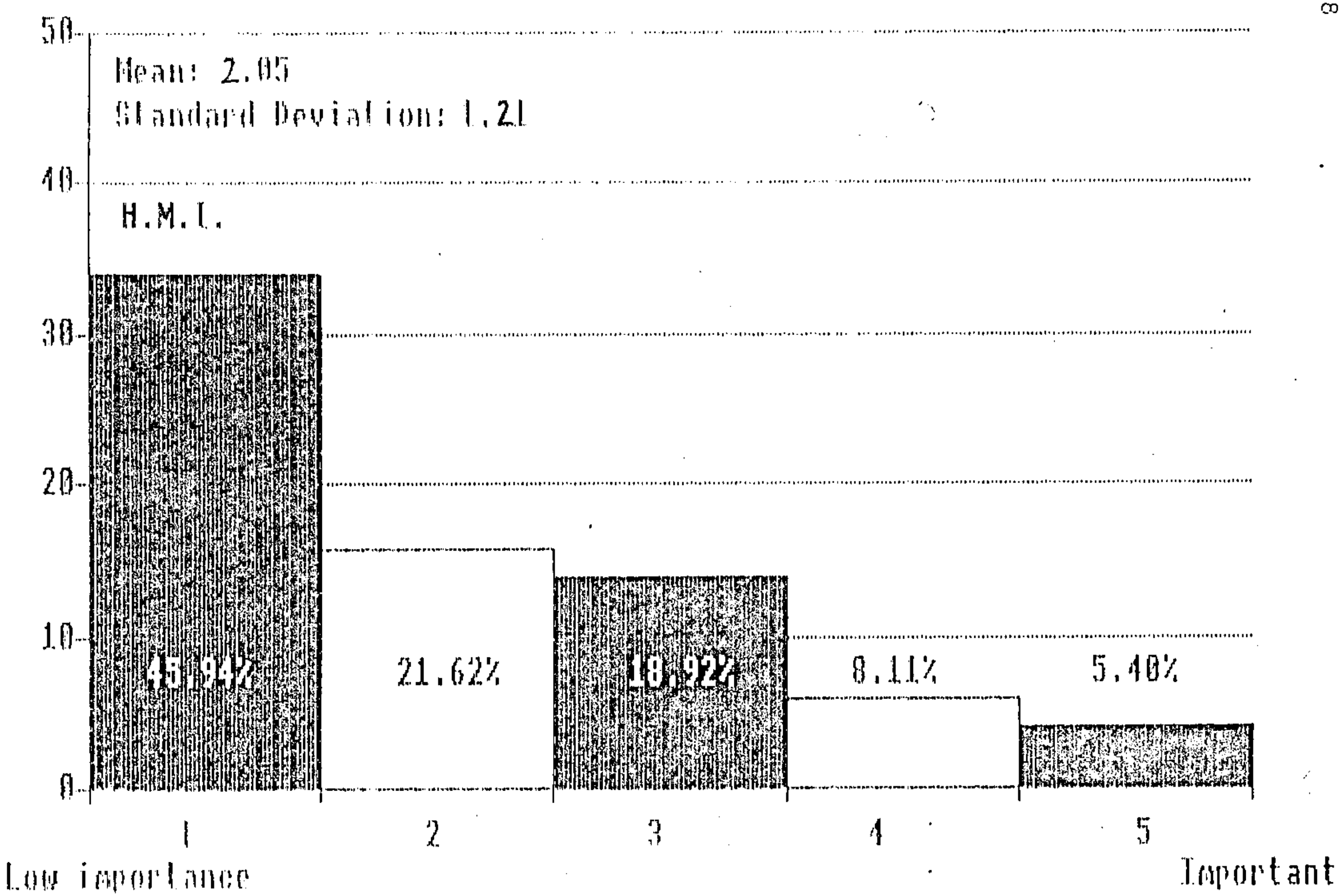

Mean: 2.05
Standard Deviation: 1.21
H.M.I.
50
40
30
20
10
0
45.94%
21.62%
18.92%
8.11%
5.40%
1
2
3
4
5
Low importance
Important

Figure 6.38

Figure 6.39

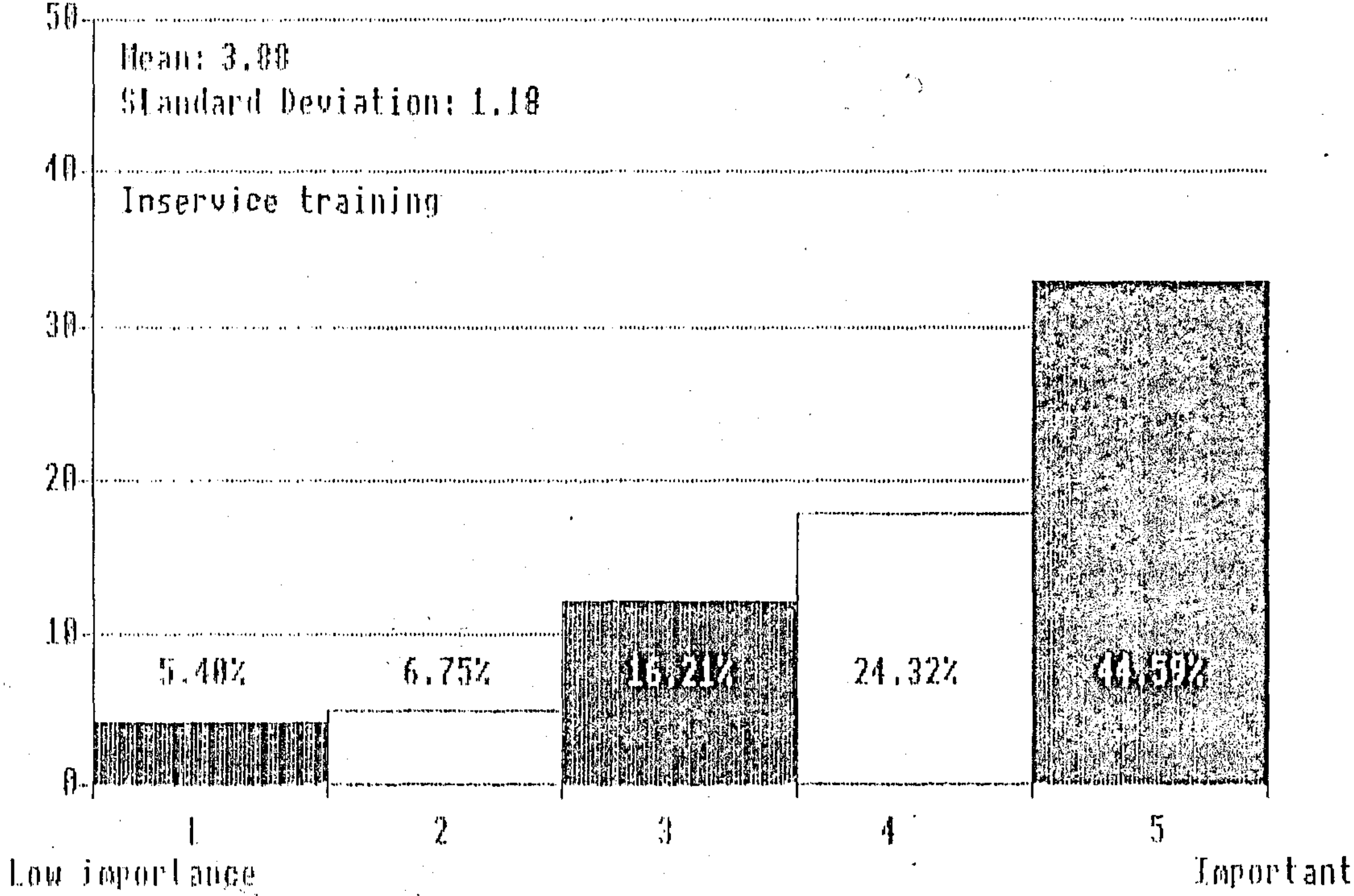
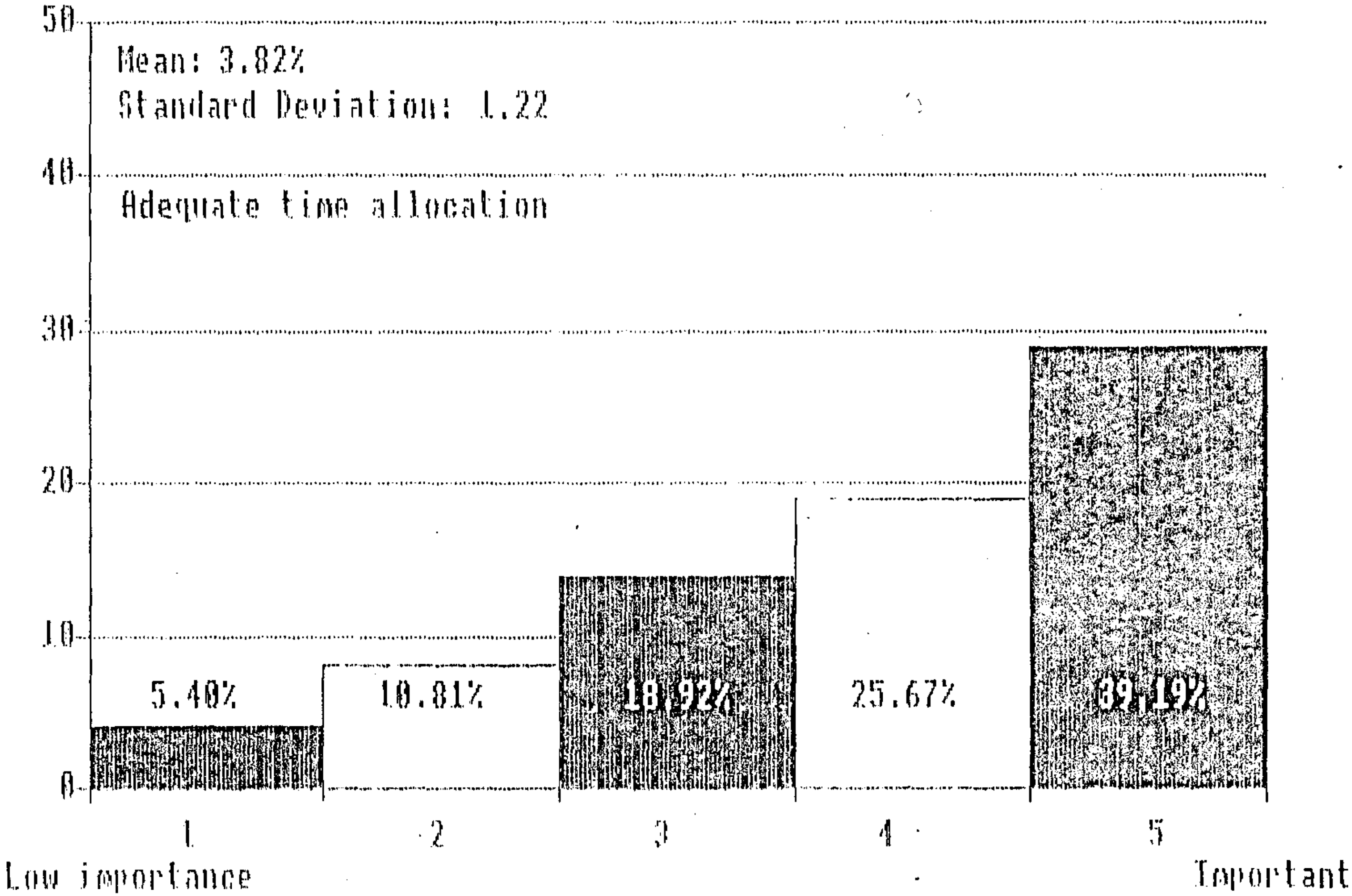
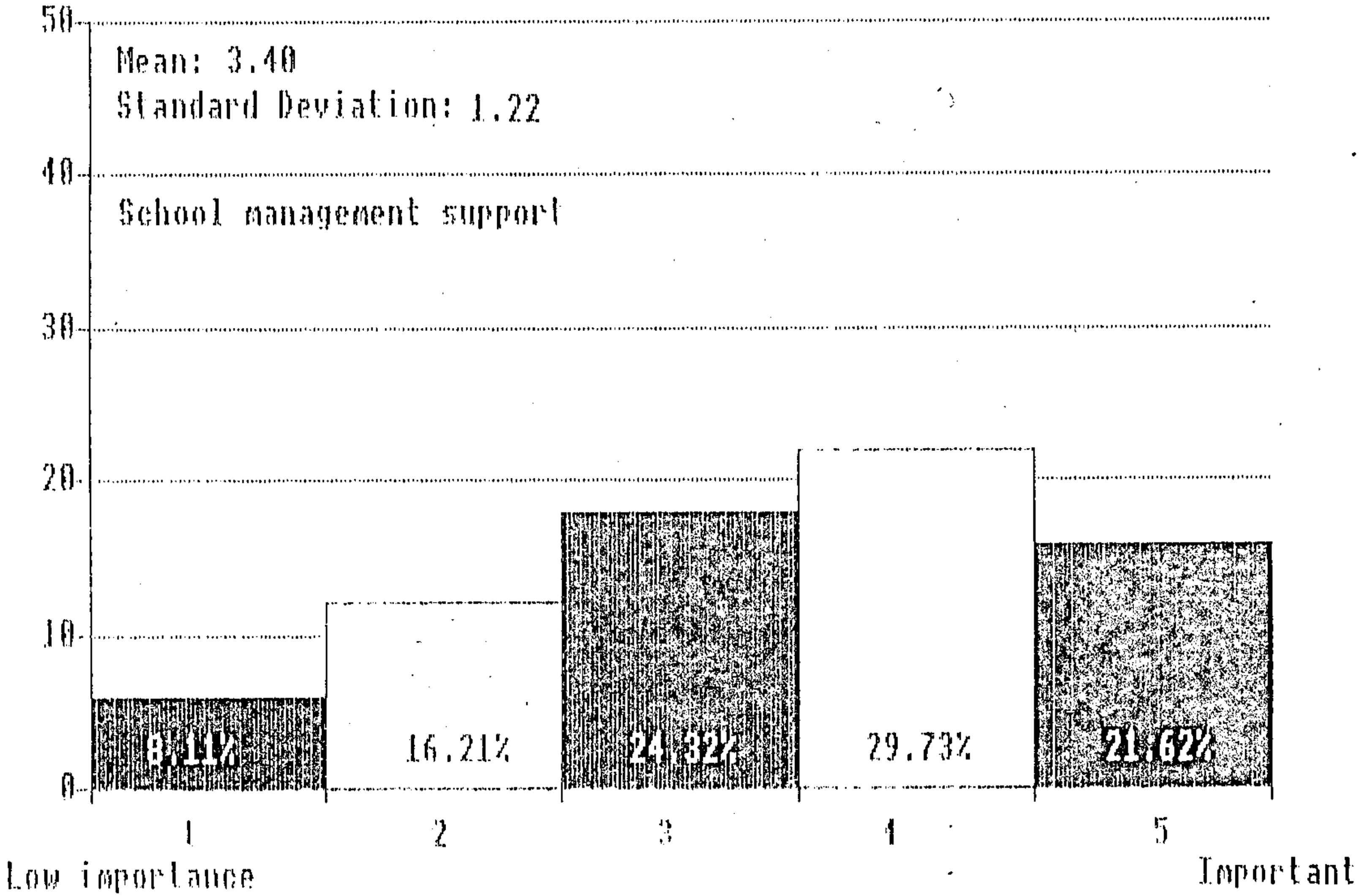

Mean: 3.88
Standard Deviation: 1.18
Inservice training
50
40
30
20
10
0
5.40%
6.75%
16.21%
24.32%
44.59%
1
2
3
4
5
Low importance
Important

Figure 6.40



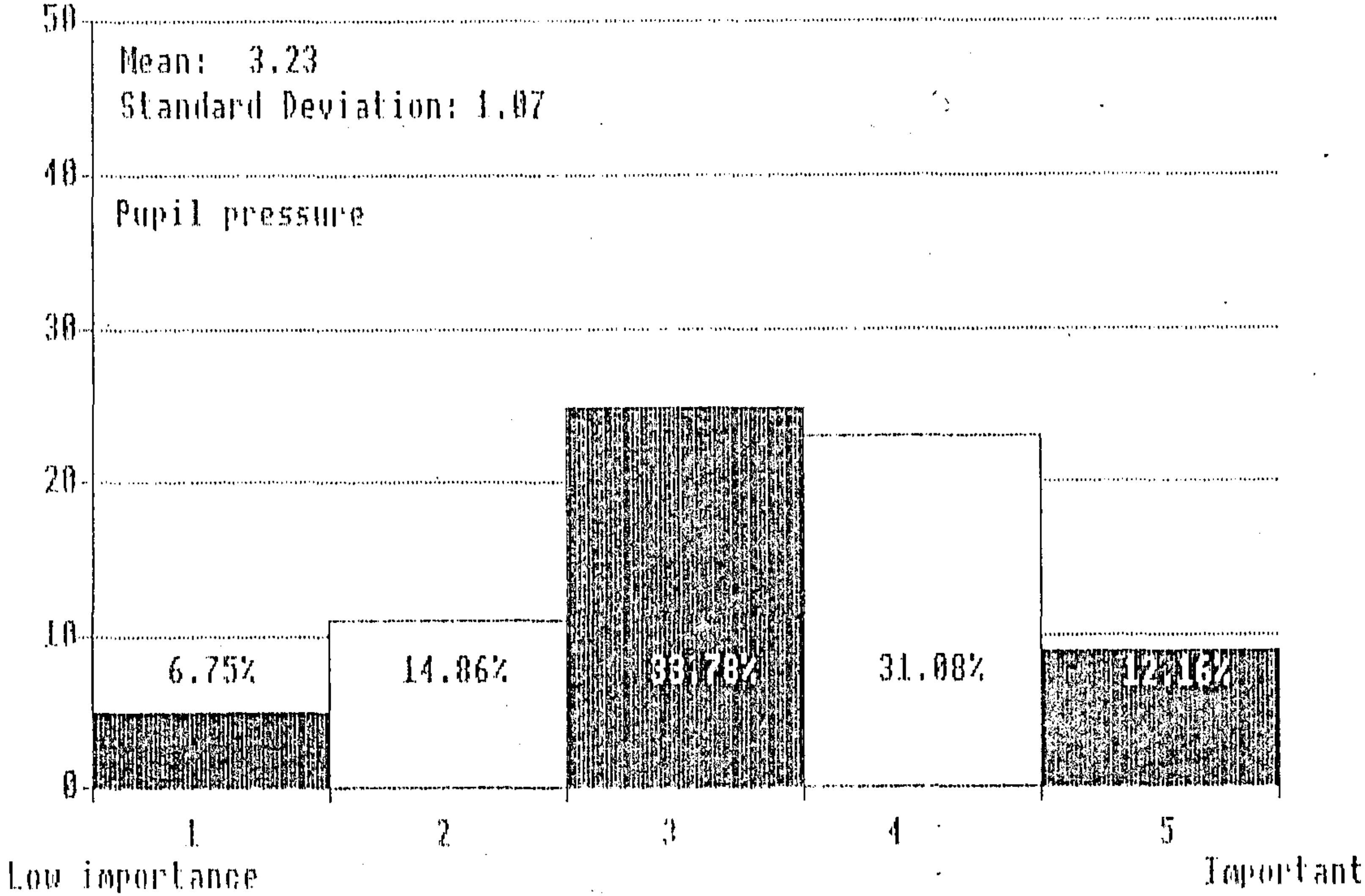
Mean: 3.82%
Standard Deviation: 1.22
Adequate time allocation
50
40
30
20
10
0
5.40%
10.81%
18.92%
25.67%
39.19%
1
2
3
4
5
Low importance
Important

Figure 6.41

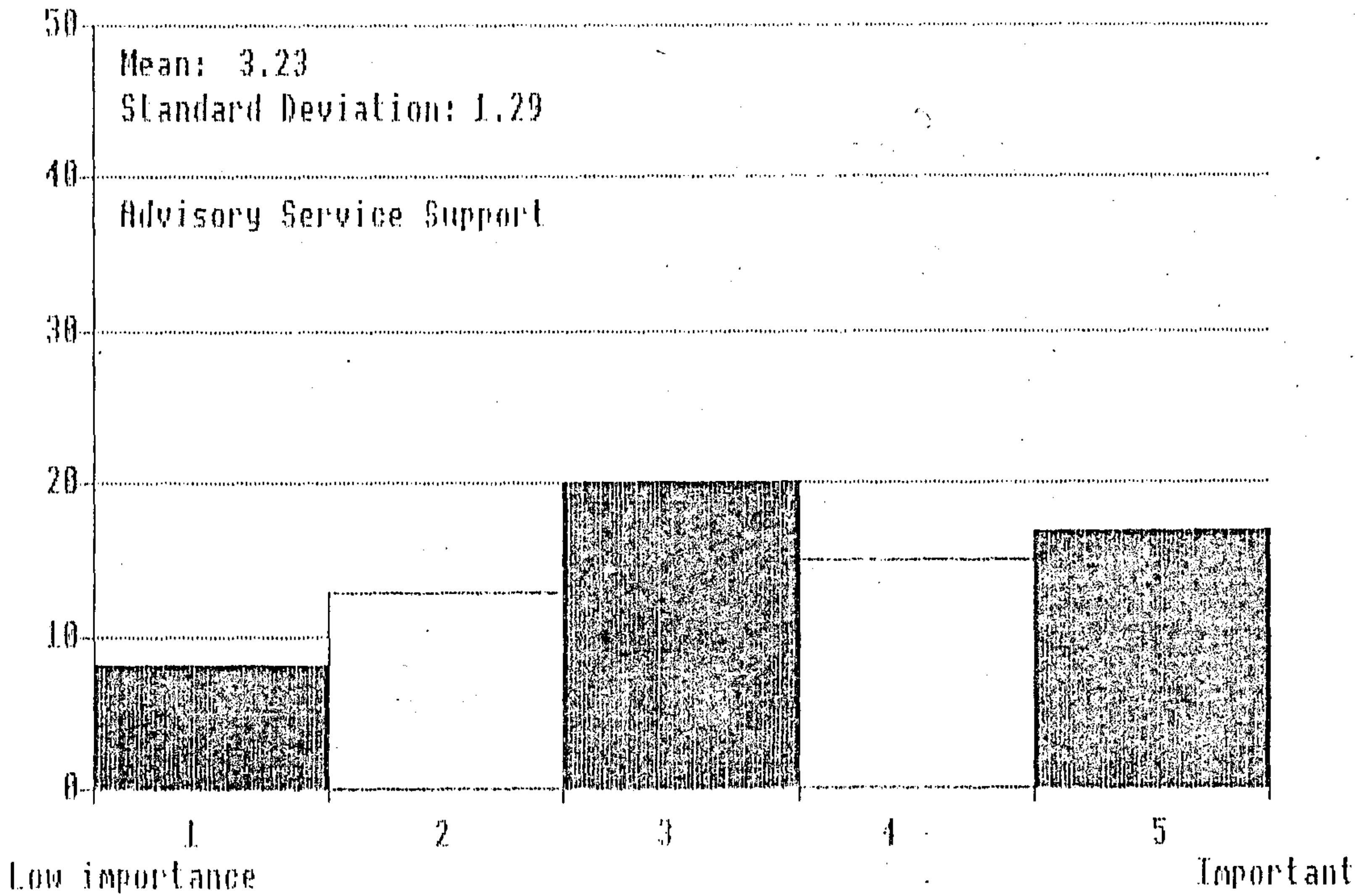


Mean: 3.40
Standard Deviation: 1.22
School management support
50
40
30
20
10
0
8.11%
16.21%
24.32%
29.73%
21.62%
1
2
3
4
5
Low importance
Important

Figure 6.42



Mean: 3.23
Standard Deviation: 1.07
Pupil pressure
50
40
30
20
10
0
6.75%
14.86%
31.08%
1
2
3
4
5
Low importance
Important



50
40
30
20
10
0
Mean: 3.23
Standard Deviation: 1.29
Advisory Service Support
1
2
3
4
5
Low importance
Important


Figure 6.43

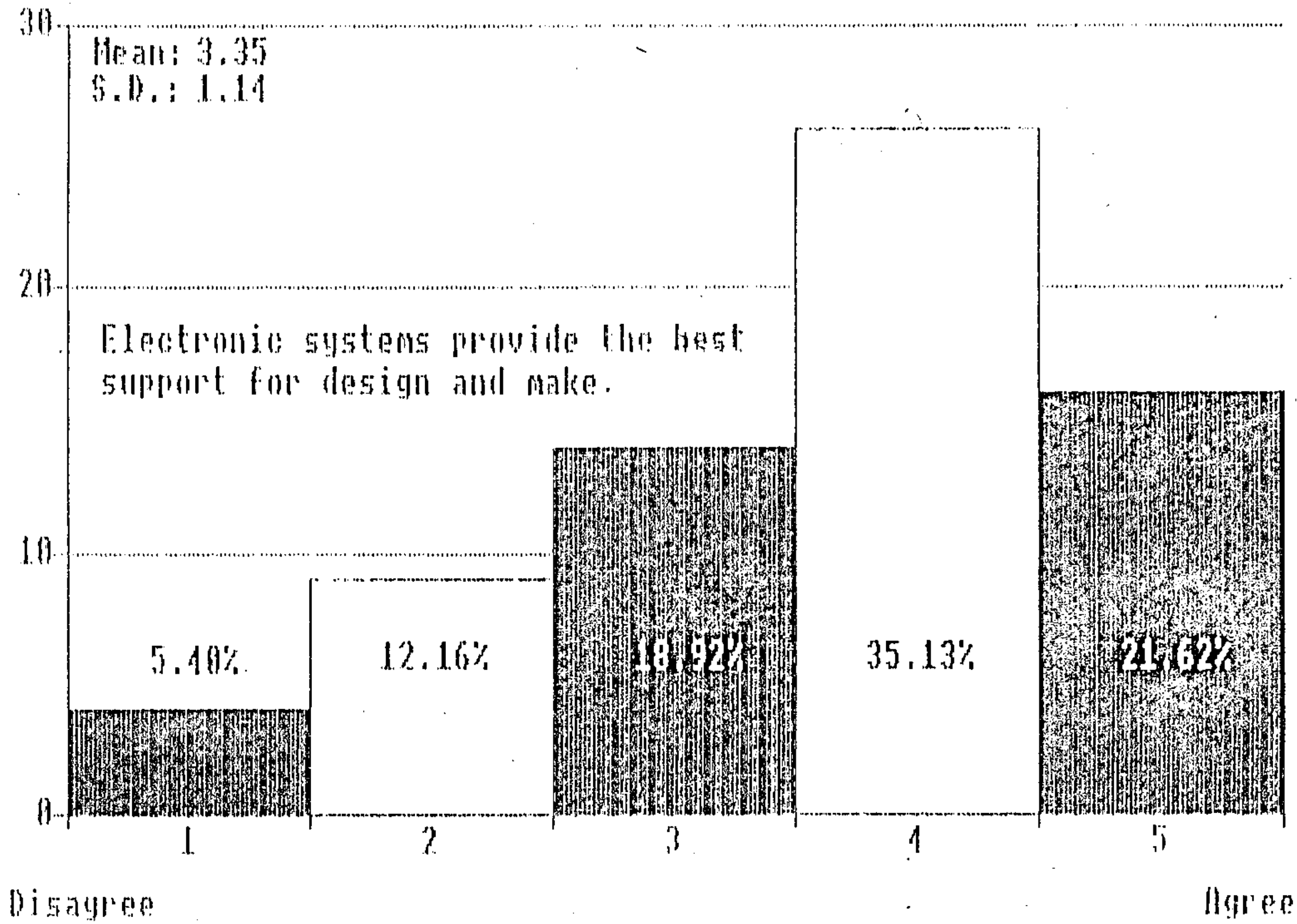
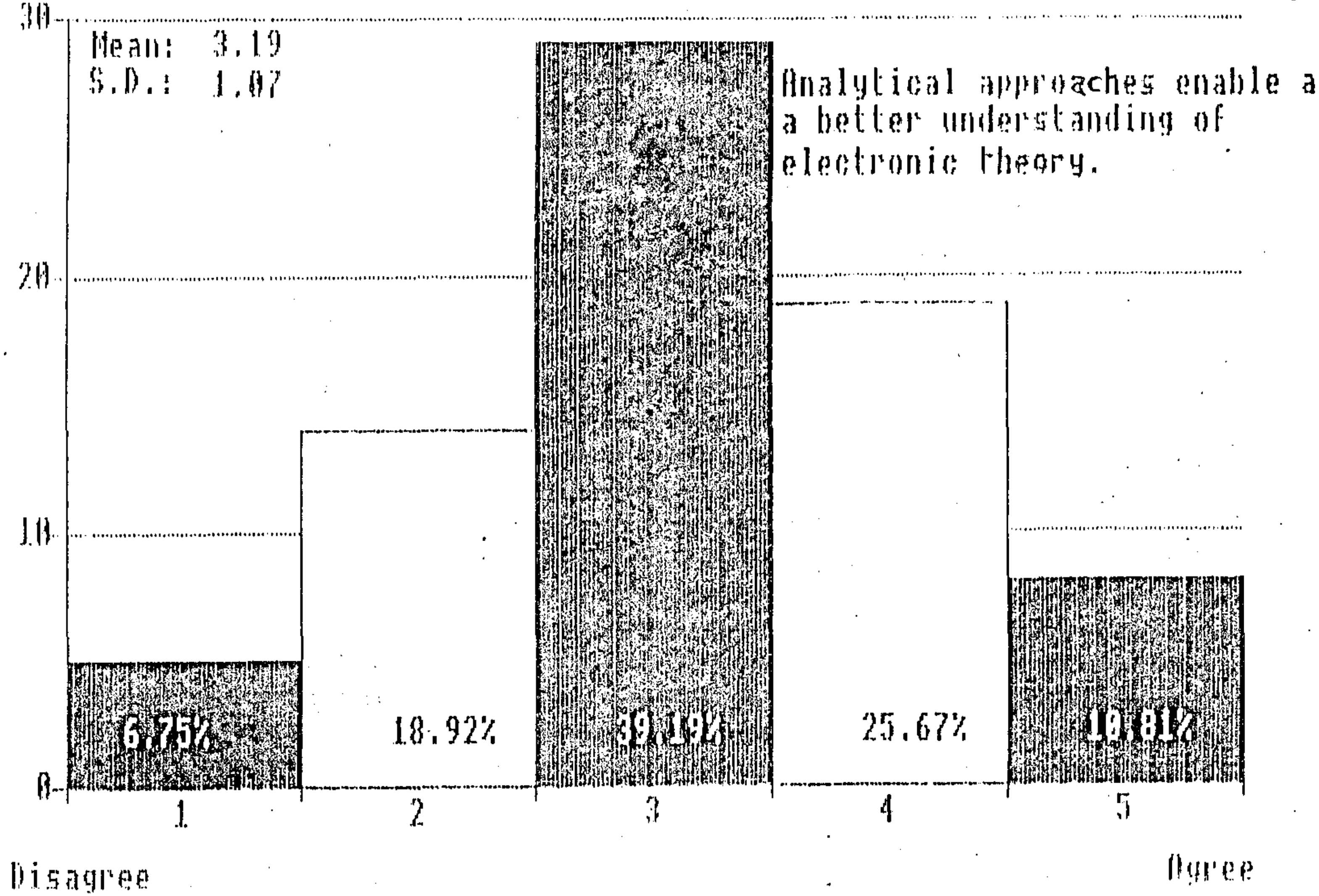
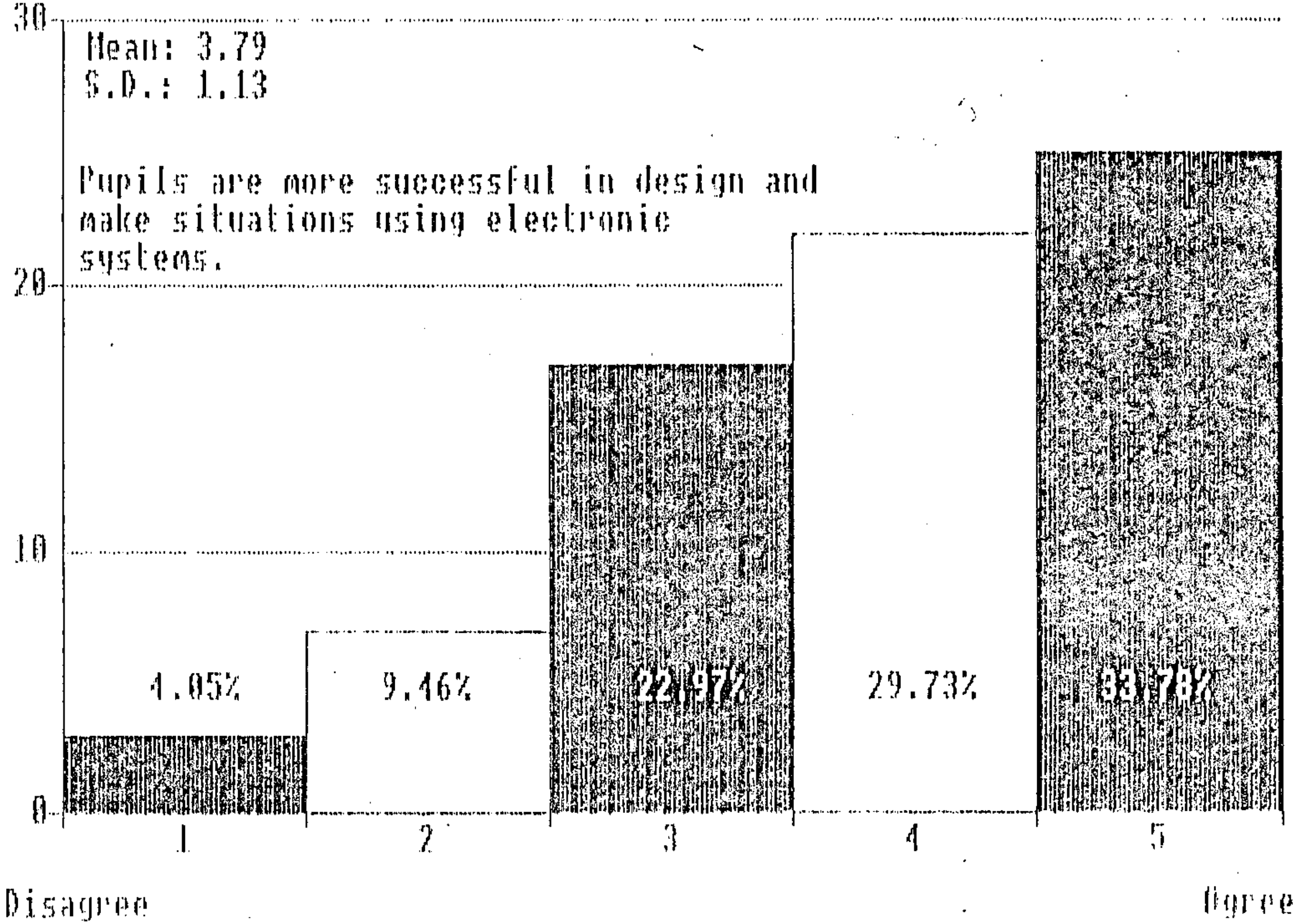

Mean: 3.35
S.D.: 1.14
Electronic systems provide the best support for design and make.
30
20
10
0
5.40%
12.16%
18.92%
35.13%
21.62%
1
2
3
4
5
Disagree
Agree

Figure 6.44

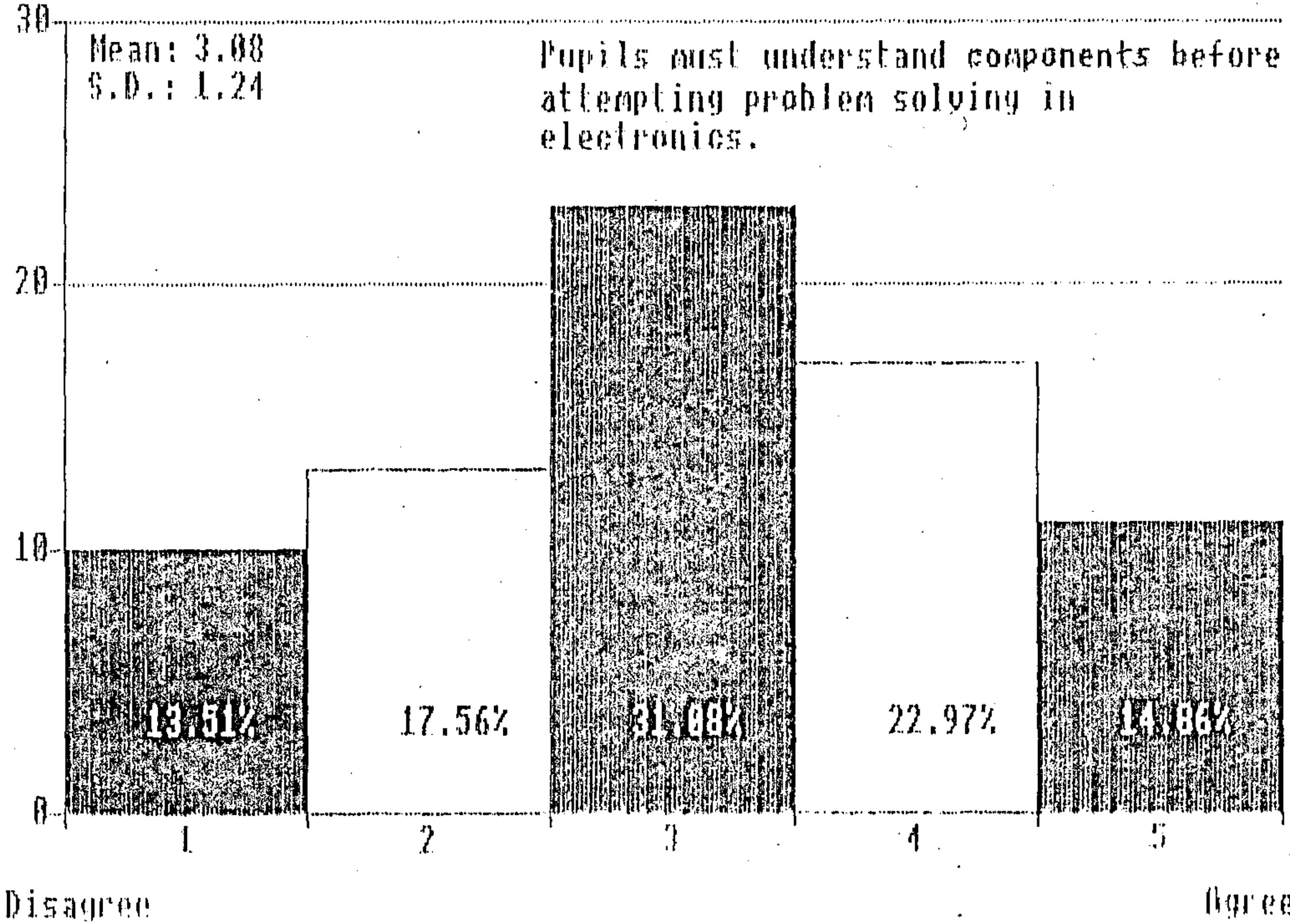
Figure 6.45


Mean: 3.19
S.D.: 1.07
Analytical approaches enable a
a better understanding of
electronic theory.
30
20
10
0
6.75%
18.92%
39.19%
25.67%
10.81%
1
2
3
4
5
Disagree
Agree



Mean: 3.79
S.D.: 1.13
Pupils are more successful in design and make situations using electronic systems.
30
20
10
0
4.05%
9.46%
22.97%
29.73%
33.78%
1
2
3
4
5
Disagree
Agree

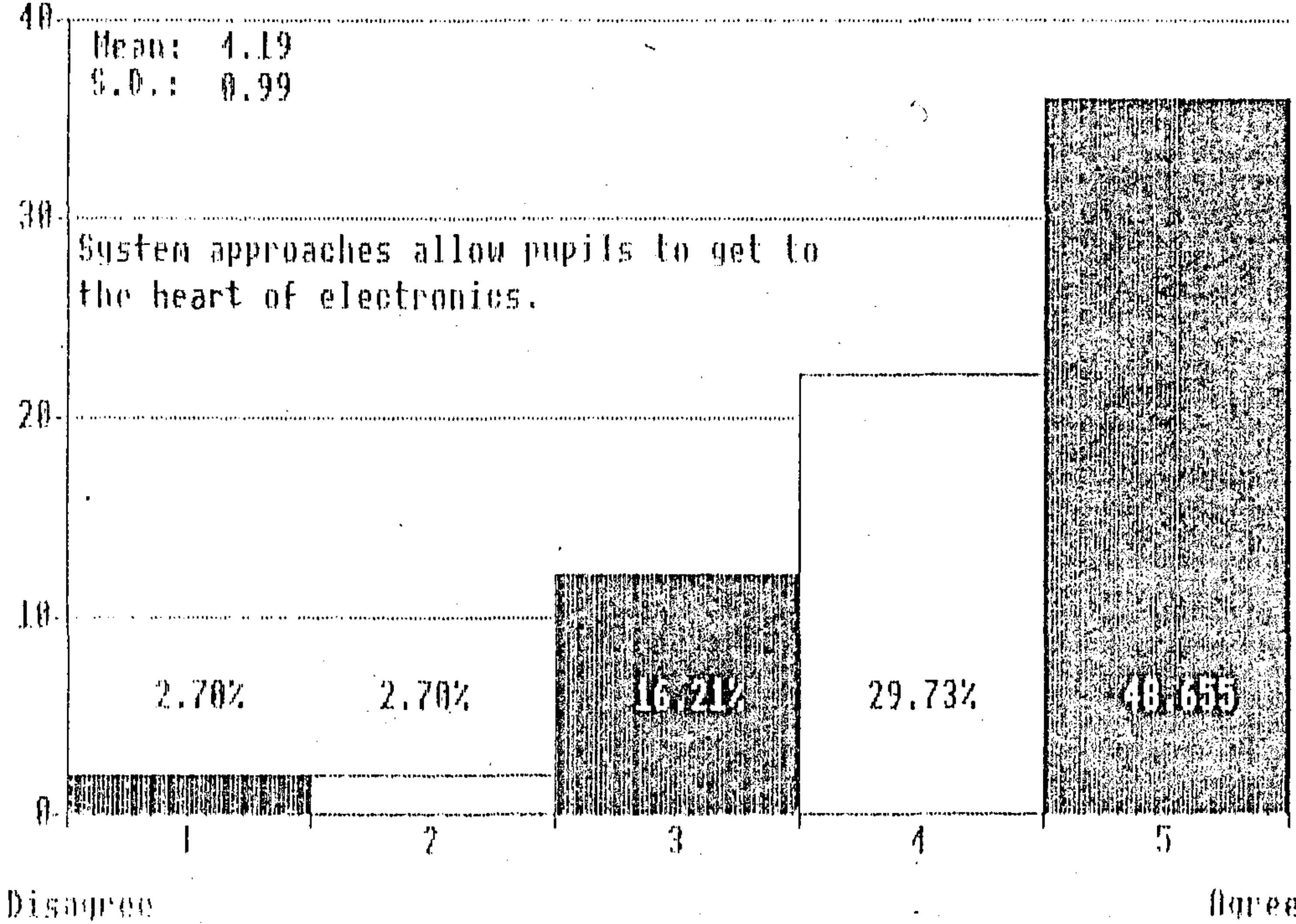

Figure 6.46



Mean: 3.08
S.D.: 1.24
Pupils must understand components before attempting problem solving in electronics.
30
20
10
0
13.51%
17.56%
31.08%
22.97%
14.86%
1
2
3
4
5
Disagree
Agree


Figure 6.47

Figure 6.48



Mean: 4.19
S.D.: 0.99
System approaches allow pupils to get to the heart of electronics.
40
30
20
10
0
2.70%
2.70%
16.21%
29.73%
48.65%
1
2
3
4
5
Disagree
Agree

Figure 6.49

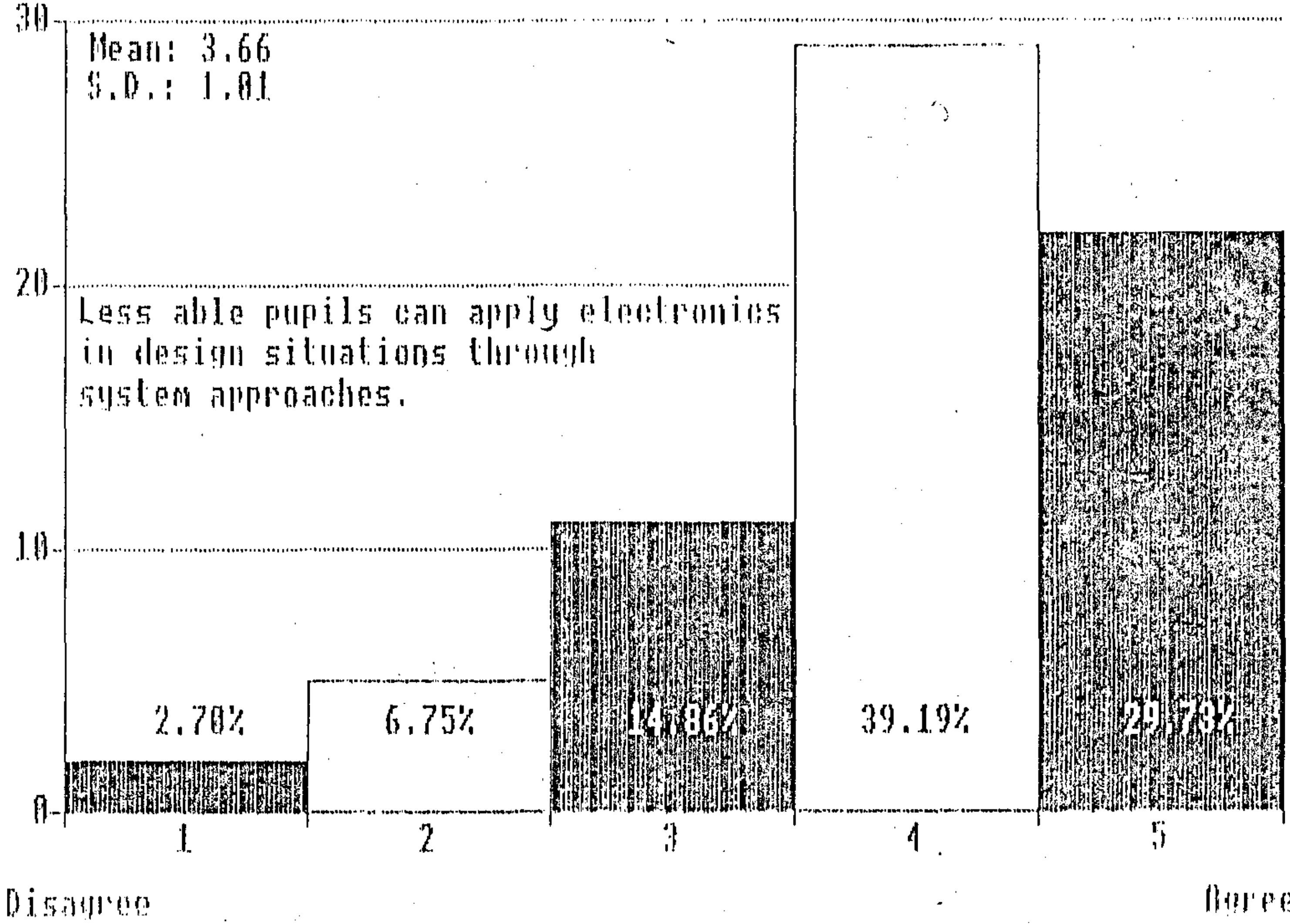
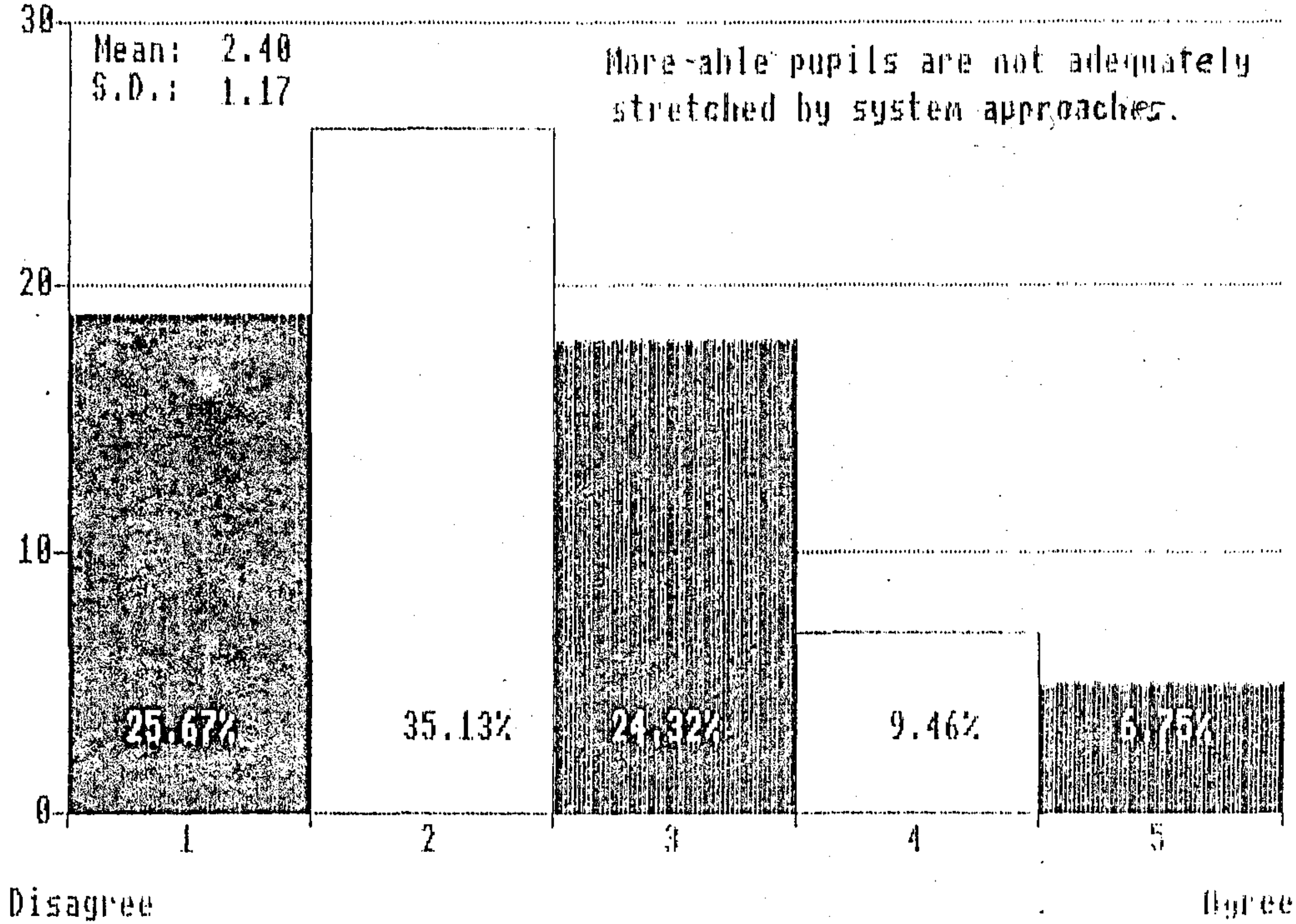

Mean: 3.66
S.D.: 1.01
Less able pupils can apply electronics in design situations through system approaches.
30
20
10
0
2.70%
6.75%
14.86%
39.19%
29.73%
1
2
3
4
5
Disagree
Agree

Figure 6.50



Mean: 2.40
S.D.: 1.17
More-able pupils are not adequately stretched by system approaches.
30
20
10
0
25.67%
35.13%
24.32%
9.46%
6.75%
1
2
3
4
5
Disagree
Agree

Table 6.10a Systems provide the best support for design and realization situations

Mean 3.35 S.D. 1.14

The results suggest that teachers perceive a Systems approach to provide the best support for electronic design activities. Interview questions confirmed that in a design and realization context the prerequisite of prior knowledge is not essential for students to undertake electronics in design activities. An attempt to substantiate this important statement is made in chapter eight.

Table 6.10b Students have a better understanding of electronic theory if they follow an analytical approach

Mean 3.19 S.D. 1.07

The results indicate that student's are provided with a better understanding of electronic theory through following a course of study based on analytical study of electronics and circuit theory. Interview responses differentiate between competence in solving electronic problems using Systems approaches and competence in electronic theory. A knowledge of circuit theory does not necessarily give an advantage in a problem solving context over those possessing lesser knowledge but who apply a Systems approach.

Table 6.10c Students will be more successful in design and realization situations if they apply a Systems approach to electronics

Mean 3.79 S.D. 1.13

Both the questionnaire data and the follow up interview responses supported the statement that students are more likely to be successful in design and realization situations through the application of Systems approaches rather than one based on an analytical approach.

Table 6.10d Students need to understand the properties of components and there use in circuits before

they can attempt electronic problem solving
Mean 3.08 S.D. 1.24

The results indicate a normal distribution with a bias towards agreement.

Table 6.10e Systems approaches enables students to get to the heart of electronics without wading through the difficult abstract first
Mean 4.19 S.D. 0.99

Questionnaire returns and interview responses strongly support the statement that Systems approaches allow students to get to the heart of electronics to solve problems and to explore new design opportunities.

Table 6.10f Less able students can apply electronics in through Systems approaches to electronics
Mean 3.66 S.D. 1.01

A criticism of approaches based on the analysis of components and electronic circuit theory is that it denies the less able student the opportunity to experience the challenge of electronics in design situations. An implication that may be drawn from the data is that Systems approaches permit electronics in design activities to be pursued by all ability groups.

Table 6.10g More able students are not adequately stretched by Systems approaches
Mean 2.40 S.D. 1.17

The statement that Systems approaches do not adequately stretch the more able student was not supported by the questionnaire results or the interview responses. Surprisingly interview responses suggest that prior knowledge may in some circumstances hinder the design development since solutions are restricted in perspective by a known answer.

## 6.11 Electronic teaching resources

The results highlight a marked inequality in teaching resources and provision. Many C.D.T. departments were struggling to respond to the new technological pressures that students and the new examination syllabuses were applying. In some instances C.D.T. departments had the material and equipment resources but lacked the confidence and expertise to make full use of the resources. In other schools well qualified teaching staff were deprived the opportunity to contribute their expertise because of inadequate funding. Although the somewhat dated Danum Trent kits appeared in nearly a quarter of all schools, teachers were sceptical of their value as a resource for problem solving. Interview responses clearly indicate that Danum Trent is becoming an obsolete resource for C.D.T.

Table 6.11 Electronic teaching resources

| Resource | Number | Percentage (74) | |
|---|---|---|---|
| Prototype boards | 24 | 32.43 | |
| Own built systems | 23 | 31.08 | |
| C.R.O. | 19 | 25.67 | (27) |
| M.F.A. | 18 | 24.32 | |
| Danum Trent | 18 | 24.32 | |
| M.E.P. Logic Tutor | 14 | 18.91 | |
| Locktronic | 13 | 17.56 | |
| System Alpha | 13 | 17.56 | |
| Fisher Technic | 6 | 8.10 | |
| Unilab Blue Chip | 5 | 6.76 | |
| Meccano | 5 | 6.76 | |
| Griffin | 3 | 4.05 | |
| Control Pathways | 2 | 2.70 | |
| Bytronic | 1 | 1.35 | |
| E and L Systems | 1 | 1.35 | |
| Harris Boards | 1 | 1.35 | |

NB: C.R.O. Cathode Ray Oscilloscope.

Table 6.11 provides an insight into the popularity of electronic teaching resources. The high percentage of own built systems is partially accounted for by reference to an inservice training course provided by the Derbyshire C.D.T. advisory service. Students on this course built their own simple electronic systems designed by the course tutor Malcolm plant of Trent Polytechnic. A small minority of schools had more than one electronic systems.

6.12 Examination courses

Table 6.12 examination courses (Technological areas)

| Subject | A | O | CSE | Mode3 | % |
|---|---|---|---|---|---|
| C.D.T. | 6 | 25 | 21 | 2 | 72.97 |
| Design and Technology | 14 | 18 | 8 | 1 | 55.40 |
| Control Technology | 0 | 15 | 5 | 5 | 33.78 |
| Modular Technology | 0 | 12 | 9 | 0 | 28.37 |
| Engineering Science | 0 | 7 | 6 | 0 | 17.56 |
| Electronics | 2 | 7 | 1 | 0 | 13.51 |
| Electronic Systems | 0 | 1 | 0 | 0 | 1.35 |

Similarly to the previous table, table 12 provides useful information into the popularity of examinations and by implication provide a tentative pointer to the preferred teaching approach. The final questions of the questionnaire requested information concerning the types and level of examination courses offered within C.D.T. departments. These questions attempted to highlight the extent to which teachers prefer design and realization syllabuses to those of a more theoretical and analytical base. The data above further supported by interview responses suggest that a majority of teachers prefer design based courses which allow technological elements to be featured within them. C.D.T. teachers were keen to apply electronics and to use Systems approaches within design and realization courses rather than to specifically follow electronic examination courses.

## 6.13 Chapter review

This chapter has presented the detailed results of information obtained from the issue of questionnaires which were further supported by interview responses. Further information is offered as an appendix. Where appropriate conclusions have been made within this chapter to support each data set. The interpretation and the implication of the data for C.D.T. electronics teaching is further developed in chapter nine. The questionnaire data provided information on aspects of the C.D.T. curriculum some of which are provided below:

[1] School establishment and the organization of C.D.T.
[2] C.D.T. teacher training and levels of expertise.
  i, initial and inservice training.
  ii, Levels of perceived expertise and confidence.
[3] Technological aspects of the C.D.T. curriculum.
  i, Perceived resource value of technological areas.
  ii, Methods adopted to introduce technology into design based courses.
[4] Electronics in C.D.T.
  i, The extent to which electronics feature in C.D.T.
  ii, The types of approaches and the teaching methods used to introduce electronics into C.D.T.
  iii, The major influences in establishing electronics into C.D.T.
  iv, The comparative value of different teaching approaches.
[5] Electronic teaching resources.
[6] Public examinations at 16+.

## Chapter Seven

# AN ANALYSIS OF THE PROCESS OF ELECTRONIC DESIGN USING THE SYSTEMS APPROACH

# Chapter Seven

# AN ANALYSIS OF THE PROCESS OF ELECTRONIC DESIGN USING THE SYSTEMS APPROACH

## 7.1 The development of a Systems Approach to Electronic Design

7.1.1 This chapter analyses the contribution that a systems approach offers to the introduction of electronics in a C.D.T. design and realization context. It analyses the iterative and cyclical nature of the system approach compared against the linearly sequential design technique characterized in many C.D.T. departments. An analysis of the theoretical concepts developed in earlier sections of this thesis is translated into the practical development of a working procedure, by means of the modelling language and control terminology developed in Chapters Three and Four.

This chapter distinguishes between the use of electronic systems to design circuits (its micro sense); and the wider application of a systems approach, to overcome complexity in electronic circuit design, by the application of a methodology that structures design situations and encourages innovative and wider perspectives (its macro sense). The wider contexts of systems supports the development of design, whilst through the use of ready made electronic sub-systems, students are simultaneously able to design and construct circuits of a complexity only limited by their imagination and the physical constraints of the systems kits. The preceding chapters have attempted to identify the contribution that a systems approach to electronic design activities may offer to students of all abilities and ages. This chapter focuses on a methodology comprising a number of separate but complementary stages which accent the classical top-down approach to design, involving a movement from generality and low resolution, to specificality and a high resolution of detail:

[1] Conceptualization of the system and the development of a preliminary model.

[2] Process modelling by means of symbolic techniques to

determine control requirements and the mode and quality of the links of connectivity between subsystems.

[3] Development of an electronic system by means of "ready made electronic building blocks"

[4] Experimental optimization of the designed system. The practical determination of a realistically viable system.

[5] Discussion of the essential electronic theory system (if appropriate).

[6] Translation of the optimized electronic system into a practical reality by means of appropriate printed circuit board construction techniques.

[7] Integration of the electronic elements into the wider system,involving the completion of the total design activity.

It will be argued that the above methodology, needs to be applied with flexibility to cater for the richness and the diversity of the C.D.T. problem solving situation and also to make the most of the opportunities offered by a study of electronics within a design context. Systems approaches, will be demonstrated to show that students of even the most limited electronics experience, are able to engage in quite complex design activities, thereby opening up to them an area of knowledge traditionally reserved for only the most able electronic engineers. Such a development must be considered progress, and has made possible completely new educational experiences, offered new rewards, new stimulations and a range of new challenges which may not be realized through a more conventional approach to the dissemination of electronic knowledge. The value of a systems approach should not be judged against the criterion of demonstrated understanding of scientific theory, but rather against the new experiences, opportunities and perspectives acquired by girls and boys of all abilities and ages. During a period when C.D.T. is moving from a knowledge orientation to a process base, systems offer a powerful and relatively new support for the progression of design and realization activities and which more closely supports the new context of the subject.

7.1.2 Technique or methodology?

Electronic design is more concerned with the "harder" end of the hard - soft problem continuum. B. Wilson (1984) contends that problems of the "hard" type tend to be more clearly defined than those from the "softer" end, the latter being derived from the human and social sciences. He suggests that "hard" problems are concerned with the "what" question, while "soft" problems are concerned with the "what and why" type of question. Problems stemming from the "multiple perceptions" that exist in soft situations, has led to methodologies that structure situations and move the emphasis away from techniques to solve problems. Wilson's suggestion that the "harder" type of problem is concerned with the "what" type of question, is often inappropriate for C.D.T. electronic design contexts, in which a major criterion of many courses is an appreciation and an understanding of the moral and social implications of design decisions. In such contexts, focus must be equally placed on the "what and why" type of question, indeed, a limited analysis of the more prosaic "what" type of analysis, restricts the development of a wider perspective of the role and range of the possible applications electronic design.

The process of system design, involves the preliminary conceptualization of a design situation, and is essentially concerned with the conversion of the "what and why" into questions of "how", and the practical realization of the initial model. This chapter makes substantial use of, and acknowledges the concepts established by B. Wilson (1984) in differentiating between the "how" and the "what" distinction. To persons engaged in design activity, decisions concerning "what is required" is not as problematical as those that may be associated with determining "how to achieve" a solution. Design experience in C.D.T. is a stimulating mixture of the "hard-soft" problem type involving questions of "how" and "what". Additionally in C.D.T. we should be encouraging a deeper critical, analysis concerning the "why" type of question. Management science approaches to problem solving, using systems analysis techniques, have tended to focus on mathematically orientated, modelling languages to solve recurring problems. Such techniques, although offering a powerful tool for managerial and other social problems, are too restricting and too inflexible to cope with "...the richness and variety of real world problem situations" B.Wilson (1984) that may be found in C.D.T. schemes.

Mathematical techniques, in some circumstances, may hinder the range and scope of design ideas by an emphasis on the analysis of situations through numeric techniques, rather than on the development of a range of different design solutions. The use of mathematically based techniques requires a high degree of precision and as a vehicle for real-world, problem solving in C.D.T. are either inappropriate or of little value. Additionally the cost of developing sufficient expertise to acquire competence places an unrealistic burden on the adoption of mathematical techniques. Over emphasis on the "technique" may also introduce the danger of contrived distortion of the problem to accommodate the technique. Methodologies require the application of techniques and it is incumbent upon the user of the relevant methodological tool to select the most appropriate of the techniques. "A more successful approach is to be "problem orientated" and to allow the situation to distort the way the analysis is being carried out. This orientation demands flexibility in the approach; hence the emphasis on methodology and not technique". B. Wilson (1984).

The implication of Wilson's comments, for C.D.T., are that there should be a change of direction away from techniques to solve problems and towards a new emphasis on strategies and methodologies to structure situations. It will be argued, later in this chapter, that C.D.T. has relied too heavily on a linearly sequential technique to solve problems, rather than on methodologies to structure design opportunities.

## 7.2 Iteration

The process of electronic design using the system approach is cyclical, rather linearly sequential, that is now demonstrated in the "traditional" design methodology followed by many C.D.T. departments. Professor M.W. Neil (1970) describes the systems approach in terms of being:

"...iterative and evolutionary. There is a main sequence of operations through which one goes - activities defined by a systems approach. One outlines a functional model, recognizes primary functional activities, defines subsystems boundaries and so on. As one advances it becomes possible to improve the functional model and specify more clearly primary functional activities. Initial boundaries are modified or redrawn. The whole process can be envisaged as a spiral arrangement of main activities with highly iterative linkages between points on the coil."

Neil makes the important point that there must be a clearly stated preliminary specification of primary purposes and objectives. Whilst working towards the preliminary purpose the iterative nature of the process enables the constant refinement and clarification of ideas. During the preliminary establishment of the preliminary purpose, the degree of detail or resolution, in the analysis is low, it needs be no more than what is adequate to enable an early tentative statement of purpose to be drawn. Attempts to introduce too high a resolution into the early modelling results in an over complication and the possibility of losing sight of the fundamental purpose of the system.

## 7.3 Intuitive design

A major criticism of the linear design method is that it does not cater sufficiently well enough, to allow for the more intuitive design response. By providing a tightly bounded design route, the missing out or jumping of a design link, may jeopordize the achievement of a successful solution. In most deign activities a point will be reached, either early or late in the process were the existing rules are unable to cope or meet the immediate needs of the problem. Reactions to this may vary, but many include an arbitrary strategy of randomly searching for an answer, drawing upon ones prior experiences and linking them to the demands of the new situation. One of the merits of the system approach is that it provides a flexible framework for encompassing the use of established design methods and also of accommodating the "eureka" type of experience.

Systems approaches allow the design of systems which pass beyond the bounds of existing knowledge and expertise. The linear design strategy relies to a certain extent upon the use of the designers existing knowledge, thereby placing constraints on the range of possible outcomes. Systems approaches however, by their preliminary techniques, of conceptual modelling ask the questions "why and what" before the "how" type of question. Systems additionally encourage and support the development of totally new technologies. The American President Kennedy, in his determination to place man on the surface of the moon, was advised of the necessary systems to achieve this task even though at that time, the required technologies did not exist. The type of system that was necessary to fulfill the task could be identified by the asking of questions concerned with "what" was required and not with "how" they would be practically realized.

Similarly, students can by the exclusion of the "how" question, identify the necessary systems to solve problems, even though they have little or no conception of the means of achieving the practical construction or the theory relating to the mode of operation. Significantly for C.D.T. this approach supports a movement away from the analysis of problems, towards the development of types of thinking which encourage students to see systems in terms of the new "opportunities" offered. Implications within this type of organisation for the development of the entrepreneurial type activity (in its widest sense) are encouraging.

## 7.4 The limitation of simple practical systems modelling

Systems may be used at two distinct levels: one being in its macro sense and the other in its micro sense. The former uses a system approach as a complete electronic design methodology, whilst the latter involves the use of systems approaches as a design resource to teach electronics and to design circuits. The macro sense of the word offers a complete methodology, whilst the latter, the micro sense, is encompassed as a technique within a wider methodology. The current practice, in the sample schools of the questionnaire, suggests a bias towards the use of systems approaches in their micro sense ie. to experimentally construct and to optimize electronic circuits. This involves the experimental manipulation of ready made electronic building blocks (ie. "System Alpha" or other system kits to construct circuits.

The use of electronic building blocks, through a limited practical application of the systems approach, has undoubtedly made a considerable contribution, in supporting the more technological type of project work associated with the new emphasis of C.D.T., but unfortunately has not proceeded far enough to realize the full potential this major resource offers. The early development of electronic systems approaches, was largely controlled by the availability of the appropriate building blocks, and early kits were most used by Science departments. The differing educational objectives of a science based approach, has limited the application of a system approach, to the teaching of electronics and to the simple experimental context. This early science based approach, has done little to foster an understanding of the decision making principles involved in electronic design, or allowed a wider perspective to be developed of the role of electronics. This limited approach is often marked by an arbitrary decision making process and an inefficient use of resources. On the credit side this approach has allowed limited access to the new challenges of electronics in C.D.T. to a students formerly denied the opportunity. Although system approaches permit the development of successful solutions to electronic design problems, by designers lacking electronic expertise, it is not enough to restrict experiences to simple practical modelling using ready made electronic building blocks. Practically based electronic modelling is only one technique within the total system design methodology.

Interview responses suggests that the application of a systems, approach to theoretical and practical design problems, is a stimulating, interesting and useful educational experience, but that in a C.D.T. context it is important not to lose sight of the rewards, challenges and the satisfaction students obtain from producing practical solutions to problems. Systems may be seen as a bridge between the theoretical and practical elements of using electronics in design C.D.T contexts. Ideas may be conceptualised on paper and then practically modelled by the application of ready made systems. This section identifies the limitation of over emphasis on simple practical modelling and suggests the need for a more comprehensive and structured strategy for the use of systems in electronic design activities. It is suggested that the system approach provides a powerful resource for any design activity, its usefulness extending beyond electronic design applications.

## 7.5 The process of electronic design using a systems approach

7.5.1 Early attempts at applying the system approach, to meet the opportunities offered by design and problem solving activities, would normally have constraints which lead to successful solutions. With increased experience more advanced design experiences may be offered, determined by the personal development of the individual student. Similarly to other design activities, the use of systems approaches should offer an incline in difficulty, to ensure a progressive learning situation. Although systems approaches support heuristic or discovery methods, this chapter supports the need for a structured teaching strategy to maximize the new learning opportunities offered. Systems approaches need to be taught and learnt in the same manner that any other methodological tool must be acquired. One such possible approach is outlined below.

### 7.5.2 The educational aims of applying a systems approach to electronics in a C.D.T. design context

Designing and making requires students to identify and analyze situations. To define needs and to propose and develop solutions. From the proposal of a solution the logical development is towards the realization of a practical functional artifact which is evaluated against the original need. It is through these activities that students develop analytical and intuitive powers and foster the improvement of their manipulative skills. The educational aims of a systems based approach should embrace those established in the National Criteria for C.D.T. (listed below) and include further aims specific to the application of a systems approach to electronic design activity. These may be may be summarized under the following headings:

[1] To foster an awareness, understanding and an expertise in those areas of creative thinking which can be expressed and developed through investigation and research, planning, designing, making and evaluating, working with materials and tools.
[2] To encourage the acquisition of a body of knowledge applicable to solving practical and technological problems operating through the processes of analysis, synthesis and realization.
[3] To stimulate the development of a range of communication skills which are central to designing, making and evaluation.
[4] To stimulate the development of a range of making skills.
[5] To encourage students to relate their work, which should demand active and experential learning based upon the use of materials in practical areas, to their personal interests and abilities.
[6] To promote the development of curiosity, enquiry, initiative, ingenuity, resourcefulness and discrimination.

[7] To encourage technological awareness, foster attitudes of cooperation and social responsibility, and to develop abilities to enhance the quality of the environment.
[8] To stimulate the exercising of value judgments of an aesthetic, technical, economic and moral nature.
[9] To help develop electronic design and problem solving skills which support the fundamental principles of C.D.T.
[10] To introduce an alternative methodology for developing design ideas, by means of a cyclical and iterative process, based on a progressive, combined materials and multi-technology approach.
[11] To develop a range of practical electronic modelling skills.
[12] To emphasise and support the perspective of electronic design "opportunity" rather than the "problem" orientation.
[13] To provide situations in which students are able to experience the stimulation and challenges of satisfying the needs of mankind through the use of a range of electronic resources and the application of scientific principles.

7.6 Conceptual modelling: Making the situation explicit

7.6.1 The first stage, in putting together a preliminary conceptual model, is concerned with making explicit the design situation and establishing the types of acceptable behaviour that the system should perform; which involves the generation and the analysis of questions relevant to the design situation, leading to the development of statements referring to the system boundary and the local and wider environment. This information may be provided by the "problem owner" or may be established by the "problem solver". B. Wilson sees this as an intellectual distinction, the names referring to two roles which may be held simultaneously by a single person. The fact that a student may be the "owner" of a problem situation may well have considerable motivational benefits. If it is possible to provide opportunities in which the student may identify more closely with the design situation (personalize the design situation), and to assume the role of "problem owner" the motivational factors generated, may encourage a greater creative response. a more appropriate term from that of problem owner is one of opportunity owner.

When the teacher "authorizes" a particular design study and causes the activity to "happen" he or she occupies the role of "problem owner". The "problem solver" may be a single individual or a group of individuals whose prime activity is to make the content of the design study explicit, to justify and defend the selected solution from a range of alternatives and to modify it if necessary. Making the thinking explicit through early conceptualization is important in communicating the design development to the "problem owner" and allows the opportunity for modification based on reassessed stateements contained in the model. When the student occupies both roles simultaneously the conceptual model provides an important vehicle by which the content of the model and the design decisions contained within may communicated, debated and modified. B. Wilson (1984) defines a root definition of this type of activity as follows: "A problem-orientated, problem-solving system to transform a statement of concern about some situation into a recommendations to alleviate that concern, that are acceptable to the problem owner". Conceptual modelling is therefore a system to transform inputs relating to concern about a situation into an output (behaviour) which consist of recommendations to alleviate the situation or which identify new opportunities.

Peter Checkland (1981) describes this first stage as "... an expression phase, during which an attempt is made to build up the richest possible picture, not of the "problem" but of the situation in which there is perceived to be a problem. The most useful guideline here - in the interest of assembling a picture without as far as possible imposing a particular structure on it - has been found to be that analysis should be done by recording elements of slow-to-change structure within the situation and elements of continuously-changing-process, and forming a view of how structures and processes relate to each other within the situation being identified."

7.6.2 The "what" - "how" distinction.

Distinction between the "what" and "how" type of question confirms the points established in this thesis that identifying what is needed is not so problematical, as those questions relating to "how" this may be achieved. Conceptual modelling is concerned with identifying "what" with very little concern for the "how" question. Conceptual modelling techniques focus on three major factors and the relationships between them:

[1] The situation.
[2] The structures
[3] The behaviours.

Structural features (defined in Chapter Two) include aspects related to environmental factors, the definition of subsystems, hierarchy and the communication links contained within the modelled system. Process is related to the behaviour of the system and the consequent effects of such behaviours upon the system. Included within this process definition is the early identification of the types and the degree of resolution of the control medium.

A danger inherent in the establishment of clear, initial, conceptual models is that the analyst of the situation may become committed to to the initial selection in such a manner which creates difficulties for a change of direction at a later stage. The cyclical nature of the methodology compensates for this danger by forcing the student analyst to reappraise the modelled system if subsequent learning determines that the selection was inappropriate. The minimization of this type of danger may be achieved by the development of a range of models rather than a single one. Additionally, to draw the attention of the danger, to the student analyst, is to go some way towards alleviating the problem. The actual initiation of the systems approach varies according to the aims of the design activity or the nature of the design investigation, however, the establishment of a clear conceptual model is essential in providing a sound foundation for subsequent systems analysis.

7.6.3 Structural and behavioural features: establishing the system statement.

Chapter Two identified the importance of establishing early, tentative, conceptual models - involving the setting out of the aims, objectives and primary goals of the system under consideration. The setting out of the above leads to the development of a statement which clearly delimits the structural and behavioural elements of the system ie. the stating of the system environment and the delimination of the boundaries. The boundary may be only tentative at this stage - because of the constant cyclical path around the conceptual model which enables redefinition of the design situation and the modification and readjustment of previous decisions. This iteration process (M.W. Neil 1971), involves the repeated movement around a loop of procedures, with increasing optimization with each pass of the loop, until a satisfactory solution is found.

7.6.4 Conceptualization of the subsystems.

Having determined the primary system goal, being clear about the environmental influences acting upon the system and having established and set out a clear set of reference levels and the criteria by which to judge performance by, the next stage is the conceptualization of "what" subsystems are required to enable the required type of system behaviour. This involves simple statements concerning what is deemed necessary and involves the establishment of links of connectivity. Questions relating to the mode of link, the quality, the type and the resolution are explored later in the text. In designing totally new systems it may be necessary to go outside the initial constraints and to even redefine the whole problem. J. Beishon et al (1971) make the important point: "...some of the most successful and dramatic solutions to problems have emerged from the refusal to accept conventional restraints". Students are largely unaware of the complexity or the sophistication of the electronic restraints imposed by reductionist techniques to electronics. When faced with questions which focus their attention to "what" is required their responses are unfettered by the constraints of limited expertise nor encumbered with concern over how the design situation may be realized. The result of systems modelling, involving this type of analysis, often produces responses of refreshing clarity and eloquent simplicity.

The identification of a system need not necessarily be a complicated process. Student analyst need only identify "what" is required and have addressed themselves to "why", to establish the most primitive links of connectivity between them. The early conceptual modelling approach involves five interconnected stages:

[1] Development of a statement outlining the behaviour and goals of the subject of the analysis. This involves being clear about "what" is required against the social, moral and technological context of "why" it is necessary.

[2] Defining the key structural concepts:
- System behaviour
- System environment
- System boundary
- Reference levels
- Subsystem
- Links of connectivity

[3] Determining reference levels and the degree of resolution.

[4] Developing a system model.

[5] Review of stages 1 to 4 as a consequence of creating 4.

## 7.7 Process modelling

7.7.1 The development of a conceptual model produces a root definition of what the system is, providing a range of information about the minimum necessary activities to fulfill the system goal. The development of the conceptual model logically leads to questions relating to the identification of "what" is required in the subsystems of a system. The function of these subsystems may form a basis for proposing alternative system models; the cyclical loop leading to a redefinition of earlier models. The list of subsystem "whats" enables the identification of and the selection from a range of alternatives, of the different input, control, output and performance monitoring systems.

### 7.7.2 Algorithm development

Typically at this juncture the modelling takes a more practical form. From a theoretical statement of what is required, the generation of a process model may be achieved by the use of algorithms. The development of algorithms may be created by either practical experimentation or by symbolic means. Chapter Three explored the use of symbols which could be manually manipulated to examine the links between subsystem parts and also to model the control process. From the generation of a graphically modelled process, an algorithm may be created which symbolically represents the system process. Such flow charts allow the student analyst to examine the links of interconnection between subsystems and to more clearly determine subsystem requirements. Questionnaire responses, outlined in Chapter Six, indicate the popularity of electronic system building blocks, as a resource for developing control systems. However, the value of such resources, when use solely in a practical experimental context, is limited unless preceded by a clear definition of purpose, and the development of the most appropriate conceptual system.

Without a tentative model upon which to develop ideas, the use of electronic building blocks, tends to be of an arbitrary and an ad hoc nature. Practical experimentation is a useful technique, but to gain the most from the opportunities offered by a system approach, it may be best to precede through a structured modelling technique, which more clearly rationalizes the purpose and the primary goals of the system within the context of a clear conceptual model. Chapter Three identified the key concepts involved in process modelling, by the use of symbolic techniques. It is important to comment that the use of the term feedback is often misleading and inappropriate for systems analysis. Communication links between systems and subsystems is not always of retrograde nature, but that in reality a number of communication links can be established in a number of different directions.

### 7.7.3 Primary subsystems

Symbolic modelling expands the depth of analysis and moves from the general level of the conceptual model, to the consideration of the four primary subsystems of any electronic system.

[1] Primary functional systems, control and process subsystems.
[2] Causes to which the system responds, inputs.
[3] Effects the system generates, outputs.
[4] Steady state maintenance, communication and performance monitoring subsystems.

### 7.7.4 Process modelling tools

At a practical level the relationships between the key concepts of system design (input, control or process, output and communication of performance and environmental disturbance) may be usefully examined by means of the practical manipulation of symbolic modelling tools. Chapter Three suggested the role that plastic icons might play in the rapid representation of the decision structures involved in modelling. Such iconic strategies should include a range of modelling tools similar to those identified in Chapter

Three. Not only do such models help students make clear relationships, but also give an insight into how a system functions and communicates this understanding to others. Such a technique helps predict the consequences of design decisions and allows the exploration of a systems performance under a range of different operating conditions.

7.7.5 Problems of "how" and "what".

Decisions regarding "what" cannot be implemented without a consideration of "how" it may be achieved. This involves a selection from the most appropriate "how" subsystems. For example if one wished to produce an intruder alarm system, it is necessary to select from a range of suitable input transducers to sense the system disturbance. B. Wilson (1984) suggests that in many circumstances a "how" is also a "what". For example the "what" question which determines the selection of the "how" input transducer, is also a "what" to which there will be a number of "hows". Wilson uses the example of the "what" concerned with the problem (should this not be an opportunity?) of investing spare cash. To do this it is necessary to select one "how" from a range of alternatives (pay into bank, buy a picture, etc.) The complication is examined by reference to the investing of spare cash to buy a picture. The "how" becomes transformed into a number of possible "whats" to which a number of "hows" are attached, ie. visit auctions, attend galleries, etc. Similarly the phenomenon is evident in electronic modelling. The question of "what" transducer to select, to determine the "how" question, results in the "how" being transformed into a "what". The selection of movement detection, leading to questions of the particular type of movement sensor (capacitive proximity, magnetic, tilt switch, infra-red, etc.). Wilson asserts that the key to understanding, and to the application of the distinction is through the concept of resolution level. Wilson's analysis leads to questions of hierarchy. Questions of "what" become converted to a "how" at a lower hierarchical level, generating in turn further questions of a "what" nature. By understanding this basic rule of hierarchy-resolution and the juxtaposition of the "how-what", student analysts can better order any system design.

Unlike the early conceptual model which consists of interconnected "whats" the process model comprises an interconnected series of "hows" which in turn generate further "whats" but at a higher resolution level of detail. The selection of the most appropriate "how" is determined by a number of strategies involving the operational comparison of suitable subsystems. The criteria applied to the analysis of the most appropriate subsystem, will vary from system to system, and the expertise of the student analyst. The use of symbolic modelling should generate questions and provide answers of a sufficiently high resolution for students to precede to practical experimentation using electronic system building blocks. Such a primary set of questions and their resultant answers may be grouped under the following headings:

[1] "What" are the environmental disturbances which perturb the system and "how" will they be monitored?
[2] In "what" way will the system respond to environmental disturbance and "how" will this be achieved?
[3] "What" are the consequent outputs generated by the system response and "how" will these be monitored?

7.8 The design of electronic circuits by means of ready made electronic building blocks.

7.8.1 The function of this stage of the system design methodology, is to provide for the experimental construction of an electronic system, which conforms to the specification developed first in the conceptual model and later in more detail, in the process model. The use of ready made systems requires a knowledge of the major properties of the subsystems and the methods of interconnection. Similarly to the use of any new hardware, common sense suggests that opportunities need to be made available, for the student to become familiar with the function and the means of interconnectivity of the electronic system kit. This would be achieved by a structured teaching programme in which the student develops an increased awareness of the potential applications and the capability of the electronic building blocks.

The purpose of ready made electronic system building blocks is quite straightforward, they allow microelectronic systems to be viewed as functional "black boxes" which can be applied in design activities to perform particular useful operations to solve problems and to allow investigations to proceed. To produce this assembly of "black boxes" requires a knowledge and an understanding of the function of the units and the procedures for inter connect or interfacing, but does not require a knowledge of the operation of the "black boxes". It does not require a mathematical or scientific background for students to be involved in real problem solving activities. Students are given greater autonomy and self direction in the use of resources and are able to proceed with less reliance upon the teacher as a knowledge resource. Able students are not constrained by the limitations of physical science experience and are free to develop their intellect by exploring possibilities which are only limited by the constraints of of hardware availability. These limits need not be restrictive; even highly sophisticated microelectronic devices are relatively inexpensive. The less able student is also able to gain from this approach and opportunities exist for them to develop confidence and to compete alongside their more able classmates.

7.8.2 Requisite variety

Chapter Two analysed R. Ashby's law of requisite variety, determining that complexity is related to description, predictability, control and an understanding of the demonstrated phenomena. If the phenomena is predictable and capable of control, the level of complexity is largely irrelevant. In these terms of cybernetics, the law of requisite variety determines the capacity of one system to exercise control over another. The law was seen to suggest, that to exercise control over a system it is necessary to have available as much variety by the person wishing to exercise control, as is present in the subject of control. If it is possible to describe, predict behaviour and exercise control, over an adequate requisite variety of electronic building blocks, the degree of complexity becomes irrelevant. "System Alpha" offers a sufficient variety of systems units to enable description, prediction and control to be exercised in the majority of situations that are encountered in C.D.T. design activity. When used in conjunction and combined with a range of other microelectronic systems the degree of control is multiplied. It would be expected that after the conceptualization of the system, and the analysis of the types of processes likely to be active within it, that the design would exist as a series of block diagrams, which outline the required subsystems. The design process now changes from the theoretical to the practical manipulation of "black boxes" to realize the designed system. The selection of the most appropriate of the building blocks to assemble the system, must be considered within the constraints of what is available and what is practically feasible.

7.8.3 "System Alpha"

There are a range of ready made commercial systems currently available. Of these, one of the most popular is the "System Alpha Systems Electronics Kit", produced by Unilab Limited, of Blackburn, England. Each kit comprises a comprehensive range of electronic building blocks. All electrical connections on the Alpha boards use a 4mm plug. The electronic building blocks comprise 60 x 80mm green plastic boards with the components securely mounted on the top and the P.C.B. work below. Each of the building blocks has the circuit drawn in a conceptually logical manner, by the use of visually clear transfers, which provide details of the descriptive functional name and the circuit details. A major advantage in the use of Alpha is the conceptual clarity of having a five volt rail at the top of the board, a zero at the bottom and a signal which is physically as well as electrically between the two rails. Additionally a solderless breadboard is available to allow the making up of systems not included in the standard set. The inclusion of the circuit details on the top of the system boards allows the transposition of the simpler boards direct to either the bread boarding stage or to further experimental optimization. The individual boards are connected together by strong plastic bars which have three 4mm sockets on them to secure the boards and connect the supply and a signal rail between the boards. Polarization slots are provided to ensure inadvertent inversion and subsequent damage. The board are robust in use and reliable in performance. Boards are well buffered were necessary and electrical, damage is rare even in the hands of the most accident prone student. Most of the range of commercially available boards are economically priced and within the budget of most C.D.T. departments.

7.8.4 System building blocks

Chapter Two identified the key system building blocks which are further expanded below, the list is not exhaustive, but is included to reflect those units essential for the types of investigation, students are likely to encounter in C.D.T. design activity:

| Input Transducers | Description |
|---|---|
| Infra-red sensor | Sense infra-red light |
| Light sensor units | Senses light |
| Magnetic switch | Senses magnetism |
| Metal sensor | Detects metals |
| Moisture sensor | Senses moisture |
| Movement sensor | Senses movement |
| Pressure sensor | Senses pressure |
| Pulse generator | Turns on and off continuously |
| Ph. sensor | Determines Ph. values |
| Proximity sensor | Senses non conductive materials |
| Radio receiver | Receives radio frequency signals |

## Chapter Seven

| | |
|---|---|
| Signal sensing | Detects rising or falling voltages |
| Sound sensor | Senses sound |
| Switch unit | Switches on and off |
| Temperature sensor | Senses temperature |

| Control/Process | Description |
|---|---|
| AND gate | Turns on when both inputs are on |
| Comparator | Turns on when the input reaches a set level |
| Computer | Controls events |
| Delay | Turns on after a short delay |
| Inverter | Turns on when the input is turned off |
| Latch | Turns on and stays on |
| Manual | Manually determined control |
| Memory | Single chip direct address memory controller |
| NAND gate | Turns off when both inputs are on |
| OR gate | Turns on when one or other inputs are on |

| Interface | Description |
|---|---|
| A-D converter | Converts analogue to digital signals |
| Computer I/O | Allows communication with remote computer |
| Darlington driver | Increases current to operate output units |
| Schmitt trigger | Conditions analogue signals to digital levels |
| Transducer driver | Increases current to operate output units |
| Transistor driver | Increases current to operate output blocks |

NB: The difference between transducer and transistor drivers used in "Alpha", is that the transducer (N-MOSFET) driver requires less current to operate it and provides a larger output current.

| Output actuators | Description |
|---|---|
| Bulb unit | Converts an electrical signal into light |
| Buzzer unit | Sounds a buzzer |
| Counter/divider | Counts up to ten |
| Infra-red | Emits infra-red light |
| Loud speaker | Converts electrical signals into sound |

| | |
|---|---|
| Motor unit | Turns on a motor |
| Relay unit | Turns on a switch |
| Solenoid | Pulls in a rod |

7.9 Experimental optimization

The production of a working collection of subsystems, by means of "Alpha" or other system boards, which fulfill the specification determined through conceptual and process modelling, may be translated into a viable circuit by the use of experimental optimization techniques. The simpler of the "Alpha" boards are suitable for almost direct transposition to the breadboarding stage, or more conveniently to electronic teaching equipment which allow the logical development of ideas established by means of the "black boxes". It is quite possible to either copy the displayed "Alpha" circuit direct from the displayed transfers, or to reverse the system boards and make a copy of the simpler P.C.B. work underneath the board. Particularly with the simpler of the boards this is relatively straightforward process and has been used successfully.

A more thorough method is achieved by the use of electronic teaching kits. Some of the most flexible, rugged and versatile boards currently available are produced by A.M. Lock and Company, Oldham, England. Their Locktronic circuit assembly system is suitable for a wide age and ability range and are currently popular in many schools. The Locktronic system consists of electronic components mounted underneath tough moulded polystyrene carriers with the appropriate circuit symbol display on the upper surface of each carrier. Circuits are assembled by inserting the component carriers between metal baseboard pillars which act as connectors. The self cleaning springs on the carriers ensure a good electrical contact and as no wires or other forms of connection are used the final uncluttered layout clearly resembles a theoretical circuit diagram. It is this powerful facility which makes the transposition of the simpler "Alpha" circuits to Locktronic such a viable proposition.

Once the circuit has been copied across, students are abe to experiment at a component level with different values to optimize the operation of their system. The evaluation of the function of the system should be encouraged, to create a cyclical iterative loop, where the constant reappraisal of the circuit enables the optimum operating conditions to be achieved.

Locktronic circuit systems teach the characteristics and features of a range of components, or the circuit under investigation. The assembled Locktronic circuit closely resembles the theoretical diagram and allow the development of conceptually logical circuit function without the "spaghetti" associated with the wire connections of many kits. This is particularly helpful where there is a danger of confusion being created by the random interconnecting of wires. Two types of carrier are available, depending upon the component underneath. The small carrier is used with components requiring only two connections whilst the larger carrier is used for components requiring three or more connections. Side cut outs permit the insertion of small carriers alongside or permit other large carriers to be placed at right angles, resulting in compact circuit design. A particularly useful feature of the Locktronic systems is the current probe which allows the measurement of current at any point in the circuit without the necessity of breaking the circuit. It is at this juncture that any essential electronic theory may be taught most effectively. This thesis has identified problems of lack of confidence and expertise in the ability of C.D.T. teachers to incorporate electronics into their scheme. For such teachers it is unreasonable to expect them to undertake, an in depth analysis, with their students, of the underpinning electronic circuit theory or to discuss the function of components. Fortunately other electronic resource systems exist, which allow teachers and students to overcome this problem.

## 7.10 The translation of the experimentally optimized electronic circuit into a practical reality

Unilab, the maker of "System Alpha", have developed a useful range of "Micro~Technology Resources" which permit circuits to be realized direct from "Alpha" boards. "MTR" modular P.C.B. (printed circuit board) systems comprise a students book and a set of transfers which form an etch-resist or ultra violet, opaque mask when applied to copper clad circuit board. After prototyping a solution with "Alpha" (and/or MFA together with the MTR modules) students then identify the system blocks and the components needed for them to practically produce a real circuit. The MTR modular P.C.B. system provides complete details of the components needed to assemble a particular building block to correspond with the transfer. Transfers (jig saw fashion) may be joined together on the copper clad to produce the designed system. The fourteen types of transfer are used to produce a layout of an equivalent circuit to that developed using the "black boxes". The board is etched and then drilled, and may be constructed using standard techniques. The use of the MTR system ensures that the completed circuit reflects the students own design development, from preliminary conceptualization of the electronic circuit through to the realization. The range of modules available ensures that students are given a wide degree of design freedom.

The alternative to the use of MTR P.C.B. systems is the conventional transfer of circuit details onto copper clad or any other suitable material. This may involve the transfer of the circuit developed by means of breadboarding techniques or by the use of Locktronic electronic teaching systems.

## 7.11 Integration

The final stage in the use of a systems approach is the integration of the constructed electronic system into the total designed artifact. This entails the completion and trialing of the entire project with the accompanying design report and evaluation of the total system. Typically in C.D.T. this involves a design development report, the production of a tested and functional system (or reasons for its failure), a design evaluation and finally the consolidation of the essential theory into form which aids its subsequent retrieval.

## 7.12 Chapter Review

Chapter Seven has analysed the process of electronic design by means of a systems based approach. This was achieved by the application of a range of theoretical concepts, generated in earlier chapters, and additionally by reference to the perceived needs of teachers and students identified in Chapter Six. Systems approaches were argued to offer a contribution to C.D.T. at two levels; a micro level and a macro level. The use of systems at a micro level was marked by an emphasis on the limited application of "black box" approaches to teach electronics and to investigate circuit design, without proceeding to a final realization. The use of systems at a macro level, was argued to best support the demands of C.D.T design and realization courses, offering a methodological resource as a complete design tool, which enables the better structuring of real world situations, and which encourages a more innovative and wider student perspective and design response. Discussion was pursued on the iterative and cyclical nature of a systems based approach, compared with the linearly sequential design route. Distinctions were drawn between the "how" and the "what" aspects of systems based design.

The main contribution, that this chapter has generated, is the production, of a complete systems based design methodology, to support the development of electronics in a C.D.T. design and realization context. Analysis has focused on the classic "top-down" design approach, and generated seven key stages, which were seen to express a movement, from low resolution and generality, towards high resolution and specificality. The process of systems design, developed by this thesis, follows a cyclical, iterative loop based on the following stages:

[1] Conceptual modelling.
[2] Process modelling.
[3] System building by "black box" approaches.
[4] Experimental optimization.
[5] Dissemination of the essential theoretical principles (if appropriate).
[6] Practical realization of the optimized circuit by P.C.B. construction techniques.
[7] Integration of ongoing product design (which has proceeded in parallel with the electronic aspects) with the designed and tested electronic system. The testing of the system and comparison with the original specification.

Chapter Eight

# A WORKED EXAMPLE OF THE SYSTEMS APPROACH FOR ELECTRONIC DESIGN ACTIVITY IN C.D.T

# Chapter Eight

## A WORKED EXAMPLE OF THE SYSTEMS APPROACH FOR ELECTRONIC DESIGN ACTIVITY IN C.D.T

During the period from April 30th to July 2cnd 1987, the C.D.T. department at the St John Houghton School, Ilkeston, Derbyshire, with the support and encouragement of the Headmaster Mr Terry Murphy, worked on the implementation of a systems approach to a technologically based design activity, by means of commercially available electronics systems. The application of the developed systems based approach, was conducted by means of a small scale feasibility trial involving one group of Third Year students, aged between 13 and 14 years. The main aims of the trial were to assess the educational feasibility, of following the systems methodology, in electronic design, to test the concepts developed in previous chapters and to generate an informed insight, into the new opportunities offered to students engaged in C.D.T. design activity.

Much of the direction for the practical activity, was based on the guidelines stated in the "Curriculum Statement for the 11-16+ age group" produced by H.M.I. (Her Majesty's Inspectors of Schools) and the major contribution made by this text is acknowledged. The criteria and method by which the trial was evaluated is outlined later in the text.

8.1 Proposed C.D.T. activity

8.1.1 The C.D.T. design and realization activities given below, were selected in an attempt to allow students the following electronic design opportunities:

[1] To tackle a technologically based design activity, appropriate to solution by electronic methods using cyclical and iterative design loops.

[2] To analyze the nature of the design situation, in an attempt to identify new opportunities for the development of the individual and the social group. To encourage the identification of a need.

[3] To provide opportunities for students to apply their

previous experience to a novel design situation.

[4] To initiate, develop and communicate by the most appropriate means the result of the design analysis.

[5] To provide opportunities to identify the key structural and functional requirements of any system (its "whats").

[6] To identify the key control or process elements (its "hows").

[7] To apply a range of reasoned strategies to experimentally optimize the chosen solution.

[8] To produce a manufacture/technique schedule and to plan the time/cost equation (simplified critical path analysis).

[9] To apply a range of manipulatory and craft skills to realize the solution.

[10] To monitor progress and to integrate the different strands of the design project. To coordinate the different elements and to complete the project within the prescribed time control.

[11] To integrate the diverse elements of the design activity into a final solution.

[12] To evaluate the effectiveness of the solution against the original specification.

[13] To provide students with the opportunity to work in "design teams" and experience the rewards (and difficulties) of cooperative approaches.

8.1.2 The target group

The target group, chosen to trial the approach, were their Third Year students, aged from 13 to 14 years. The project was undertaken during the second half of the Summer Term. The fifteen students in the group were of mixed ability and gender.

8.1.3 Previous design experience

All students had followed a progressive (in the sense of a progression of C.D.T. educational experiences) scheme, designed to provide a basic understanding of the applications, of the linearly, sequential approach (discussed previously) to design work and problem solving. Additionally these students had a rudimentary understanding and experience of producing conceptual models, developed during the second year. Specific previous design experiences, provided students with the listed design techniques:

[1] Observational techniques. All students had followed a course from the First Year onwards, which to a limited extent, provided them with skills of observation, the ability to identify a need, leading to the production of a preliminary specification in the form of a design brief.

[2] Breadth of creativity. Students had been encouraged to produce a diversity of ideas, to explore colour, shape, form, texture and proportion.

[3] Depth of imagination. Students had undertaken activities designed to encourage the sensitive treatment of, and the depth and quality, of the treatment of the subject of analysis.

[4] Information collation and research. Considerable emphasis had been placed upon the importance of making reasoned judgments, from the basis of an informed and knowledgeable foundation, generated by their own investigation and research.

[5] The linear design method. Students, according to their level of ability, were sufficiently informed to undertake a simple factor analysis.

[6] Graphical communication techniques. All students had followed a course designed to provide them with a range of basic communication skills.

[7] Evaluation. Most students had experienced terminal evaluation, mostly of their own coursework projects and occasionally the work of others. Self evaluation had occurred on several previous occasions.

8.1.4 Previous practical craft experience

By the end of the Third Term, most students at St John Houghton School, have had the opportunity of working in a range of resistant materials. Craft skills play an important dual role, of a technical and an aesthetic function. The key objective is to allow students to produce products of a high standard so that their conceptual may ideas develop, and allow their aesthetic awareness can be more fully and accurately expressed. Craft skills play an important role, in that the final product reflects the quality of thought at the design stage as well as reflecting the quality of craftsmanship. Specific craft and manipulatory experience is listed below:

[1] Materials: simple preparation techniques. An understanding of the physical properties of the materials being used (metals, woods, thermoplastics)
[2] Wasting techniques: The essential, basic hand process. Machine wastage limited to drilling, Shaper saw, Lathework (surfacing and turning a short shoulder). Observation of band saw techniques.
[3] Shaping materials by rearrangement: Purposefully designed scheme called the PB Scheme, developed by a member of the department to permit students to rapidly explore spatial relationships and the effective of combining materials of a range of colours, textures and properties.
[4] Deformation techniques: Simple strip bending and single curve deformation of thermoplastics. The lamination and deformation of birch veneers. Hollowing and planishing non-ferrous metals.
[5] Joining materials by chemical and physical methods: Limited to solvents, pop riveting, silver soldering, halving techniques and pinning, screwing and dowel construction.

8.1.5 Previous technological experience

Students had no previous experience of electronics. In their Physics lessons they had covered some basic electrical concepts and were familiar with the series rule.

[1] Materials technology: Comparative study of the

properties of a range of materials.

[2] Forces and structures: Sufficient expertise to design simple structures, being both stable and strong.

[3] Machines: velocity ratio of pulleys.

8.1.6 Previous Information Technology experience.

All Third Year students had followed a highly structured, formal teaching programme designed to develop the following I.T. experience:

[1] Information storage, manipulation and retrieval: Materials database interrogation techniques.

[2] Image processing: Micad-2D drawing software, to produce simple 2D drawings. AMX Super Art freehand drawing software.

8.2 Systems electronics design activity

8.2.1 In addition to the aims outlined above, the project was developed to provide further design experience, to allow students the opportunity to apply the range of craft skills acquired previously and to provide an opportunity for group activity. To cater for the all ability nature of the teaching group the basic design activity had two extension (although no group proceeded far enough to attempt the additional work). The basic design activity and the two extensions are listed below:

Basic design activity: Design, build and test a system which will provide an alarm if the level of fluid in a container exceeds a certain predetermined level.

Extension one: Design, build and test an additional system to test the function of the alarm.

Extension two: Design, build and test an additional system to monitor the performance of the above systems.

8.2.2 Course organization

Ten session of one hour twenty minutes were allocated, plus ten hours homework (for the production of the design report). Additional, extra curricula, time was available in a lunch time C.D.T. club. The course was organized to provide the following teaching inputs:

[1] The design context: discussion of the design activity and the personalization of the approach by group members.
[2] Producing a system model: conceptual modelling.
[3] Defining the control process: process modelling.
[4] Developing a functional electronic system: "System Alpha".
[5] Experimental optimization: "Locktronic" electronic kits.
[6] Practical P.C.B. construction and soldering techniques.
[7] Parallel production of the designed product and design report booklet.
[8] Integration of the various parts of the product, to produce a complete system.
[9] Testing and evaluation.

The commercial electronics systems "System Alpha" and the electronics teaching kit "Locktronics", are described later in the text.

8.2.3 Group organization

The class was split into groups of three, selected by the teacher to offer a blend of ability. Similarly to other projects attempted by group work previously, each team was required to allocate specific responsibilities to team members. Groups were required to elect a spokesperson, a secretary and a project manager.

### 8.2.4 Teaching resources

Although no specialized P.C.B. production resources were available, the following electronic equipment was available for use in the trial:

Unilab - "System Alpha".
Unilab - M.F.A. (Microelectronic for All systems).
A.M. Lock - "Locktronic".
Own built systems modules.
Two breadboards.
Five soldering irons.
One digital and one analogue test meter.

Of the commercial kits, in practice only "System Alpha" and "Locktronic" equipment was used. The usual range of C.D.T. practical equipment was available to the group. Plastic bending equipment was limited to a single strip heater and the use of a small kiln for simple drape, pressure moulding.

## 8.3 Evaluation techniques

8.3.1 The evaluation of the developed systems approach for the electronic design activity, was undertaken to determine the extent to which the methodology was effective. To ensure that the conclusions drawn from the trial were soundly based, four methods were adopted to assess student performance in the trial: testing, measuring, evaluation and assessment techniques. The evaluation techniques provided information and aided the development of the systems methodology by:

[a] helping to determine the initial expertise of students at entry to the trial;
[b] helping to set, refine, and clarify realistic goals for each student;
[c] helping to determine the extent to which objectives had been reached;
[d] helping to determine, evaluate and refine educational learning techniques.

## Chapter Eight

The testing techniques which were employed, may be considered the narrowest of the four methods, involving the presentation of a standard set of questions to be answered by students. From the results, of a students answer to a range of questions, it was possible to obtain a numeric value, to measure particular characteristics outlined below. The use of simple testing, was limited to determining the extent, of a students knowledge of the language and of the terminology, which support a systems approach.

Measurement was used to connote a broader concept than simple testing and was employed to measure more objective characteristics other than by giving tests. By the use of observations and rating scales for a students performance, during the use of the developed methodology, information was obtained that allowed the more objective and concrete characteristics of the application of systems concepts, to be measured.

Evaluation may be regarded as the process of delineating and providing useful information for judging decision alternatives and extends beyond the simpler meanings of test and measurement. Evaluation "...is the determination of the congruence between performance and objectives" Mehrens and Lehmann (1984), and involves the professional judgement process that allows one to judge the desirability or value of something. Mehrens and Lehmann contend that one can either evaluate with quantitive or qualitive data. The term assessment in this text is used broadly, like evaluation, but refers more specifically to the diagnosis at an individual level to a students particular qualities.

The term assessment is used broadly, like evaluation, in a number of different ways. Mostly the term is used to refer to the diagnosis of an individual or a groups performance in the use of the systems approach. Assessment offers subtle but significant distinctions from evaluation. In this text the term assessment is used in referring to the characteristics or properties of people: their scholastic performance, knowledge of systems concepts, electronic principles, etc.

This is should not be confused with evaluating the potential or worth of a person.

Objectives, educational experiences and evaluation procedures are closely related, each in turn having a consequent effect on the other. They may be regarded as a closed loop: objectives-experiences-evaluation. The objectives identified in 8.1.1 and 8.2.1 helped determine the teaching procedures and the methods used to evaluate both educational experiences and objectives. At the same time, evaluation and educational experiences helped clarify the objectives, and the learning experiences helped in turn to determine the evaluation procedures to be employed. Moreover, the results of the evaluation provided feedback on the effectiveness of the teaching experience and ultimately on the attainability of the objectives for each student.

Mehrens and Lehmann see the key to effective evaluation in the verb used, "General objectives such as "to become cognizant of", "familiar with", "mature" or "self-confident" are not behavioural. They do not tell us what the learner will be doing when demonstrating his achievement of the objective." Bloom's taxonomic classification of cognizant objectives, with its heavy reliance on imperative sentences in stating educational objectives, was therefore, applied in the trial to evaluate the effectiveness of the systems approach in terms of identifiable student outcomes.

In evaluating student performance, it was also important to specify the conditions that were imposed upon the learner whilst demonstrating the ability to perform the identified objectives. Additionally the criterion, or standard, by which the behaviour was evaluated in terms of comparative quality or degrees of performance, was evaluated by the production of a series of statements which, reflected high and low performance, relating to the criterion under consideration.

8.3.2 Evaluation procedures

This section identifies and describes the four key forms of evaluation that were used during the trial; summative, formative, placement and diagnostic. It was not possible to attempt comparative evaluation of the systems approach against the more traditional approaches to electronics teaching (hypothetico-deduction)ie., commencing with a study of the underlying scientific theory, moving to a study of circuit analysis, progressing to construction techniques and finally to the application of the theory. In the limited time available for the trial, ten weeks, it would have been unlikely to have proceeded far enough for students to have developed any real understanding of the design potential of the electronic theory.

B.S. Bloom (1971) suggests that summative evaluation is restricted to the end of an instruction unit, chapter or course. Summative evaluation, he sees has having a primary goal; the grading or judging of students, judging the effectiveness of the teacher and comparing curricula. Formative evaluation intervenes during the formation of a student and not when the process is thought to be completed. It points to areas of difficulty so that immediately subsequent to the evaluation, remedial help and study can be made more pertinent and respond to the identified area of concern. The formative techniques employed in this trial were used to assess a relatively small number of the objectives so that the method under scrutiny could be modified to respond to identified student needs. Summative evaluation which took place at the end of the trial was used to judge the extent to which the objectives had been attained at the termination of the course.

Placement evaluation performed a simple role in placing a student within a teaching group according to their performance in previous CDT activities. Placement evaluation was performed at the outset of the course to ensure that the grouping of students reflected an all ability blend. This was achieved by reference to school records of attainment, by consultation with C.D.T. staff within the department and liaison with the school pastoral system.

Diagnostic evaluation, which encompasses the placement component, is distinct from both summative and formative evaluation and yet draws many similarities. Like all forms of evaluation, diagnosis involves a valuing, a determination, description and classification of the various aspects of student behaviour. However, the two purposes of diagnosis, either to determine the level of support needed, or to identify strength and weaknesses, distinguish it from other forms of evaluation.

Summative, diagnostic and evaluation for placement purposes, rely heavily upon judgments made after the learning or instruction has taken place. Formative evaluation involves the collection of the appropriate evidence during the construction and trying out of a new curriculum, in such a way that revisions can be based on the evidence.

Most fundamental to the use of formative evaluation is the selection of the learning unit. Within any course or education programme there are parts or divisions which can, for analytical purposes, be considered in isolation from the other parts. Bloom et al (1971) suggest that for practical purposes a unit would be "...something larger than a single learning session." Although Bloom suggests that the divisions may be arbitrary; ideally "...it should be determined by natural breaks in the subject manner or by the content that makes a meaningful whole.

### 8.3.3 Formative Evaluation: specification of the learning unit (content).

Bloom et al (1971) suggest that for the purposes of formative evaluation it is necessary to analyze the components of the learning unit. This may be begun by constructing a specification table, in which the detail of the content be included, as well as the students behaviour or objectives, to be achieved in relation to this content. Bloom et al, suggest that the curriculum maker determines the desired standards to be met in the attainment specifications. Bloom in his work at the University of Chicago (1971) began his investigation into the formative aspects of evaluation by determining the new content of subject matter that was to be introduced into the new unit. Similarly, this trial involved the identification of the new knowledge and procedures that were to be investigated in terms of the terminology, facts, relationships, and the procedures which were to be explained, defined, illustrated and applied in the new learning materials. Much of the new knowledge, procedures and terminology has been developed in Chapters One, Two and Three.

8.3.4 Formative Evaluation: specification of the learning unit (behavioural considerations).

Behavioural considerations determine the new student behaviours or learning outcomes, that are related to each new element of content. Three behavioural considerations are identified by Bloom when students are given new ideas, relationships of knowledge, statement of truth, or other information: what are the students expected to learn; to remember and what are they expected to do with the specific subject matter introduced in the learning unit. The formative evaluation undertaken in this trial, classified the new elements, procedures and content according to some of the categories identified in Bloom's Taxonomy of Educational Objectives (1971). The classifications outlined below, therefore attempts to define a hierarchy of levels of behaviour that relate to the difficulty and complexity levels of the learning process.

Knowledge of Terms: The terms are the specific vocabulary of the systems approach that the student is expected to learn and apply. Students were expected to define the terms in question, recognize illustrations of them, determine when the term was used correctly or incorrectly, or recognize synonyms. This category of understanding reflects the lowest or simplest level in Bloom's taxonomy.

Knowledge of facts: Bloom sees facts as the specific information that a student is expected to remember. These include names, events, techniques and descriptions; in general they are the particular details which are to be known because they are regarded as important in understanding the systems approach. Students were expected to recall and remember information as discrete and separable content elements when asked in a relatively direct manner.

Knowledge of rules and principles: This classification entails recall and understanding of major ideas, schemes and patterns by which the phenomena and ideas associated with systems are recognized. Rules and principles bring together a large number of facts and describe the interrelationships among many specifics. Understanding of rules and principles enabled students to organize the information in a manner relevant to the context of their own investigation. This category only deals with the recollection of rules and principles and not with their application.

Skill in using processes and procedures: This particular category is concerned with the ability of students to use the systems approach accurately. That is, can the students perform the steps in the procedure in the correct order and perform the operation in an appropriate manner and can get to the correct result with the minimum of unnecessary operations.

Ability to make translations: The translation of systems thinking is essentially concerned with the personalisation of systems concepts to match the new design situation, which the student is currently engaged in. This category involves the transformation of systems terms, facts, rules, principles, from one context or form to another. In translation students can put an idea into their own words; can take a phenomena or event presented in one form and represent it by an equivalent form or mode. The representation may move the students idea from the graphical to the verbal, from the abstract to the concrete, or, from the objective to the symbolic. Students in this mode should demonstrate an ability to use new illustrations of the term.

Ability to make applications: "Application is the use of rules and principles to solve problems presented in situations which are new or unfamiliar to the student" (Bloom et al). The primary behavioural criterion at the application level is the use of the rules and principles in one context (ie those generated in Chapters One, Two and Three) to solve a problem or identify a new opportunity in a new context. At the application level, students must recognize the essentials of the design situation, be able to identify the essentials of the situation and the new opportunities; to determine the rules, principles, generalizations and so forth which are relevant and then use these ideas to undertake an investigation which is different from those previously encountered.

8.3.5 Formative evaluation: table of specifications

The specification for the evaluation of the trial was organised in tabular form. On one axis is placed the major behavioural categories, whilst the other axis lists the appropriate subject matter and details. By the use of connecting lines, the interrelationships among the instructional elements are highlighted. The process of developing a table of specifications was used to reveal in compact form the elements in the trial, as well as the relationships between the elements. The table of specification outlining the new terms, facts, rules and principles, processes and procedures and the ability to make translations during the trial, is provided below.

Table of specifications for trial (after B.S. Bloom et al)

[A] Knowledge of terms : system terms
1, System 2, Subsystem 3, Environment 4, Boundary
5, Input 6, Control 7, Output 8, Reference Levels
8, Behaviour
Knowledge of terms: Modelling terms
9, Open-loop 10, Closed-loop 11, Feedforward
12, Feedback 13, Transducer 14, Steadystate
15, Decision 16, Comparator 17, Sensor 18, Optimize

[B] Knowledge of facts: Name and function of "Alpha" subsystems

19, Input transducers: moisture sensor, light sensor, temperature sensor.

20, Control subsystems: Darlington driver, transistor driver, transducer driver.

21, Output transducers: Bulb unit, buzzer unit, motor unit, solenoid, unit.

[C] Knowledge of rules and principles

22, "Alpha" rules 23, Potential divider 24, Series rule

[D] Skill in using processes and procedures system based design skills:

25, Conceptualization 26, Identifying new opportunities

27, Research 28, Establishing reference levels

29, Modelling 30, Optimization

[E] Ability to make translations

31, Translation of theoretical system model into a practical and functional product.

[F] Ability to make applications

32, The primary behavioural criterion at the application level is the use of the rules and principles in one context to solve a problem or identify a new opportunity in a new context.

The formative evaluation included all the important elements as detailed in the specification table. In contrast to summative evaluation (where normally it is only possible to sample the range of contents), all thirty two elements were represented by one or more test items. For rapid administration and ease of scoring, students knowledge of (A) terms were evaluated by multiple-choice questions. Multiple choice results were compared against the demonstrated student understanding, inherent in the manner in which both the practical and design work was attempted. Knowledge of (B) facts were ascertained by a practical examination, involving students in identifying specified "Alpha" units from a range of alternatives and the subsequent classification according to their function. Knowledge of (C) rules and principles were simply determined by the ability of students to assemble the electronic system units correctly in relationship to their function. Although most students could identify (in graphical terms) a simple series circuit and a voltage divider, only the most able could perform the necessary calculations to determine amperages, voltages and the value of resistors in Ohms. Formative evaluation components (D) were determined by a students demonstrated ability to conceptualize a system and to manipulate and then optimize the "Alpha" systems to realize a solution. The ability to make translations (E) was similarly evaluated by a students demonstrated ability to translate the designed "Alpha" system into a functional electronic circuit. The primary criterion of the transfer of the system approach to new and unique situations (F) was evaluated by a students ability to recognize the new opportunities offered by the systems approach.

Table 8.1 Table of specification for the trial

| A | B | C | D | E | F |
|---|---|---|---|---|---|
| 1 | 19 | 22 | 25 | 31 | 32 |
| 2 | 20 | 23 | 26 | | |
| 3 | 21 | 24 | 27 | | |
| 4 | | | 28 | | |
| 5 | | | 29 | | |
| 6 | | | 30 | | |
| 7 | | | 31 | | |
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| 18 | | | | | |

# Chapter Eight

## 8.4 Teaching Log

### 8.4.1 Teaching Log: Week one - April 30th 1987

Objectives:

(a) Introduce design activity.

(b) Identify possible "needs".

(c) Introduce system model building:

i, Develop a system statement.

ii, Decide on the "whats".

iii, Learn the key structural concepts;

system
boundary
environment
behaviour
reference level
subsystem
link

iv, Identifying the "whats".

(d) Production of practice systems.

(e) Homework: identify environment and establish reference levels.

(a) Introduction to the design activity:

The introduction was achieved by reference to a recent flood in a teachers bathroom. The bath was left to fill unattended, with both taps fully turned on, whilst the telephone was answered. The overflow being unable to cope with the volume of water, the bath overflowed, flooding the bathroom, damaging a ceiling and ruining several, carpets.

(b) Group discussion: The investigation of events, from the groups own experiences, resulted in the identification of several possible areas of study. Students additionally identified problems experienced with fluids falling below predetermined levels. The main areas of interest that the students identified are listed:

Hydraulic fluid level warning system: The hydraulic fluid in one parents car had fallen to a dangerously low level. The group wished to investigate opportunities of making driving safer.

Aquarium warning system: The seam of an aquarium had failed, with the rapid loss of water.

Sink and bath overflow warning systems: Several students had experienced the problem, of the over flowing of water from sinks and other containers.

"Roll-on roll-off ferry" warning system to detect open doors or flooding: One group discussed the sinking of "The Herald of Free Enterprise" and wished to design a system to test whether the doors were open or closed, and also wished to design fluid detectors.

One student had seen a television programme, in which a device to aid blind persons when filling containers was demonstrated. She wished to investigate similar aids for the blind.

(c) Introduction to conceptual modelling: Discussion was undertaken, to establish the meaning of the term "system" - diagrams and physical examples of systems were shown to the group and students in turn were asked to give an example. This activity led to the establishment of a simple definition. The phrase, conceptual modelling, was not used with the group. Their initial, tentative, conceptual models, were defined "System Maps". The key concepts and a simplified vocabulary was taught to the students, with the opportunity being made available for them make a contribution from their own experience. Discussion was undertaken to identify the key "whats".

(d) Class activity: Completion of a prepared worksheets, which required students to fill in the missing words and to draw missing parts of the system map. In their own groups, students were required to build their own system map (figure 8.1). Emphasis was placed on the identification of the inputs

igure 8.1

YSTEM MAP (Conceptual modelling)

efining the system, identifying the environment and deliminating the oundaries.

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**SYSTEM STATEMENT** Low-water level detector for an acuarium.

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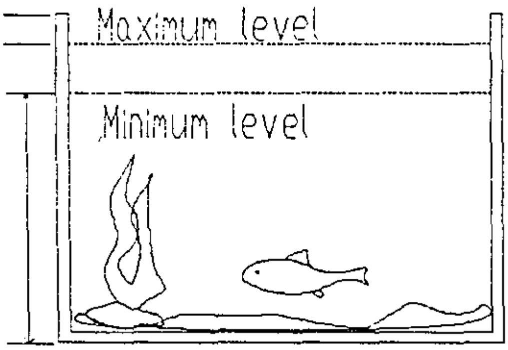
**ENVIRONMENT**




Cross section through aquarium.

**BOUNDARY**

Minimum water level: 200mm

Minimum water pressure:

Physical dimensions:
- size
- weight
- materials

**PUTS**

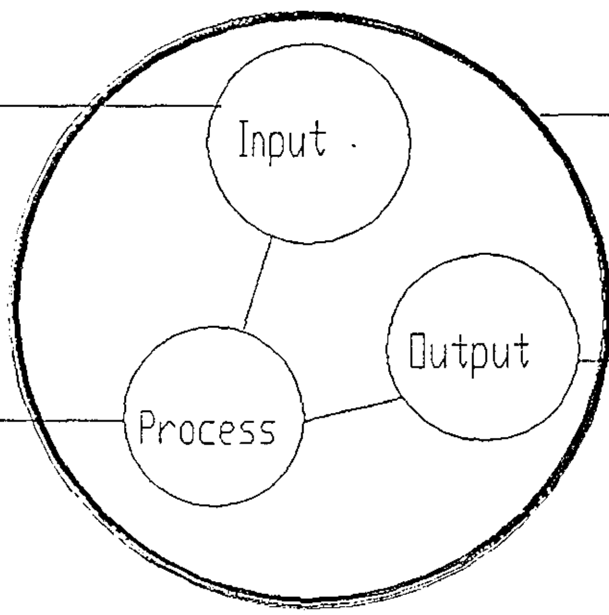
w-water vel.

**ocess**

?

**FERENCE LEVELS**

imum water vel.




Boundary

**OUTPUTS**

Sound an alarm.

and the outputs. Students were required to:

[1] Establish a clear system statement, describing their system ie. "Hydraulic fluid low-level warning system".
[2] Establish the "what" inputs ie. low water level.
[3] Establish the "what" outputs from a range of alternatives. ie. sound a warning.
[4] Establish the behaviour of the system was ie. provide information and to warn of danger.
[5] Identify the reference levels and to determine the system boundary.

(e) Homework: Students were required to conduct simple research into their system, under the headings of "Environment" and "Reference levels".

Lesson evaluation:

Students were reasonably successful in generating a simple conceptual model. All students were able to produce a statement which outlined the behaviour of a system, and could with some ease, identify the "what" questions.

Some difficulty was experienced in the use of the key structural concepts. Two concepts produced most difficulty; boundary and reference level. Students tended to view the boundary, in terms of the subject of control, rather than the system which was to achieve control. For example, the group investigating a warning system for the low level of a aquarium, determined the boundary to be the walls of the aquarium, whereas the system boundary should have been stated as the physical exterior of the system and the interface with the water. Although this is may appear a trivial distinction, in more advanced analysis the misuse of the concept could create difficulties. A teaching decision was taken to proceed with the design study and to remove any semantic confusion later in the study by reference to their practical project. Because boundary is closely allied to the notion of interface, the elimination of confusion over this term, may better be achieved, by discussion of the interface of the system with its surrounding environment.

8.4.2 Teaching Log: Week two - 7th May 1987

Objectives:

(a) Demonstrate the use of "System Alpha".
(b) Provide an opportunity to solve simple problems using electronic systems - determining the "hows".
(c) Discuss the terms of input, process and output. Introduce the term open-loop.
(d) The construction of simple block diagrams - process models.
(e) The development of simple algorithms.
(f) Review last weeks homework.
(g) Homework: attempt to build simple block diagram and algorithm of own designed system.

(a-c) Demonstrate the use of "System Alpha".

Worked examples within groups:

i, It is very annoying for clothes which have dried on the washing line to become wet again by an unexpected down fall of rain. You are required to design a system which will give an alarm should it rain unexpectedly.

(1) Build a system to fulfill the above specification.
(2) Fill in the block diagram model of your system.
(3) Fill in the control algorithm for your system.

Required boards identified by students: Moisture sensor, transducer driver, light unit, buzzer.

ii, An invalid living alone finds it difficult to move around the house. She gets tired during the day and often has a doze in the afternoon. On awaking, from her sleep, night has often fallen and the house is in darkness. She feels it would be helpful if there was a system of turning the lights on automatically when it gets dark.

(1) Build a system to fulfill the above specification.
(2) Adjust the sensitivity of the input board so that the output comes on when it is just getting dark.
(3) Alter the input board so that the output board is on when it is daylight, and off when it is dark.
(4) Fill in the block diagram model of your system.
(5) Fill in the control algorithm for your system.

Required boards: Light sensor, transducer driver, bulb.

iii, The hot summer weather, has made the C.D.T. room a very hot and uncomfortable place to work. The school is planning to buy a cooling fan and wish to design an electronic system to turn it on automatically when the temperature becomes too hot.

(1) Build a system to achieve the above specification.
(2) Fill in the block diagram model of your system.
(3) Fill in the control algorithm for your system.

Required boards: Temperature sensor, transducer driver, motor unit.

Essential points to bear in mind:
Connection of boards by Alpha links.
Power supply board to the left side of each system.
All output boards require a driver.
All connections by 4mm connectors.

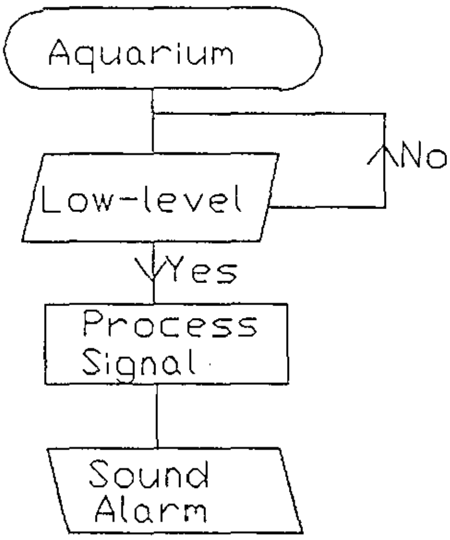
(d-e) Process modelling and control algorithms. Process models were produced retrospectively from the system modelled using "Alpha". Similarly the establishment of a simple control algorithm was achieved by referenced to their own modelled system. The important point was made that this activity would normally precede practical system modelling using "Alpha". Figure 8.2 demonstrates the use of this type of model.

igure 8.2

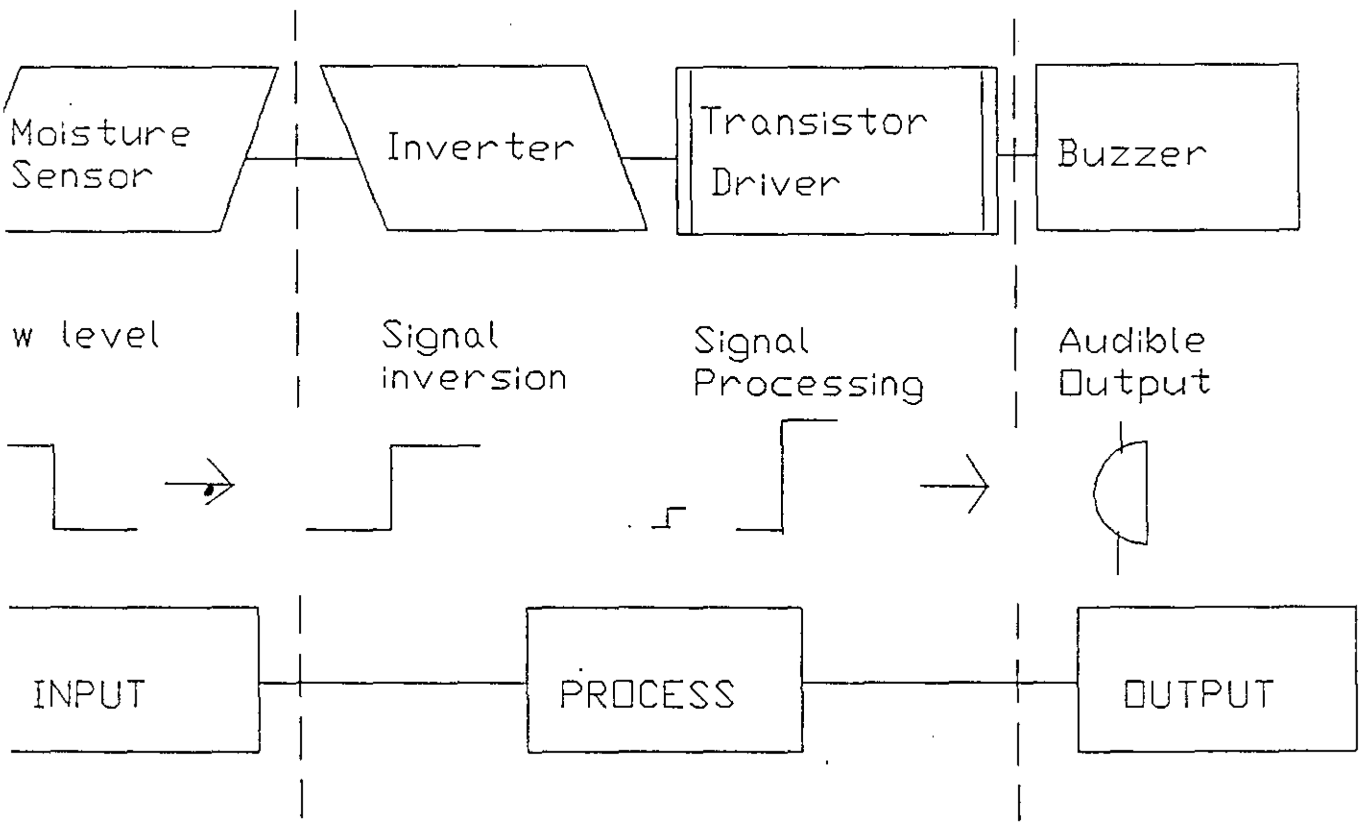
ROCESS MODELLING

ow-water detector for an
quarium.

Control algorithm




Block diagram



(f) Review previous weeks homework. One of the groups had attempted to build a water level warning system at home. From their Physics lessons, they knew that water was a poor conductor of electricity and had produced a simple circuit comprising a buzzer, a 9 volt battery and a length of wire which was broken in two places for immersion in water. The device was demonstrated to the rest of the class. The students could only get it to work if the leads were almost touching and then there was some doubt whether contact was in fact being made. This problem usefully introduced the concepts of control and the notion of signal processing and amplification.

The projects attempted by the five groups were as follows:

[1] Flood warning system for Townsend Thorsen "Roll-on Roll-off" ferries. Students had obtained the outline plans of the "Herald of Free Enterprise" and had constructed a three dimensional model of the hull in card. They had a clear notion of what the behaviour of the system was to be and planned to produce a "... system turned on by the weight of water flooding a car deck".

[2] Hydraulic fluid level monitoring system. The group wanted to design a system which would be attached to a master cylinder and warn of low level. The group were having problems. None of the parents would agree to the modification of their car! They decided to produce a simulation using a scrap cylinder.

[3] Aquarium low level warning system. This group required a system which would warn of low water level in a students aquarium.

[4] and [5] Bathroom flood prevention system. Two groups decided to design and make an unobtrusive system that would detect dangerously high water level in a bath.

(g) Homework: Students were required to use the techniques to establish a block diagram and a simple control algorithm of their own system map.

Product design: drawing previous C.D.T. experience commence investigation into the design of a product to fulfill the system statements generated in week one.Use the information obtained in week one ie. the environment that it will be used in and any special reference levels.

Lesson evaluation:

The rate at which students developed sufficient confidence, and the ability, to attempt problem solving, using Alpha, was underestimated. Students learnt the practical technique of manipulating the Alpha boards and enjoyed the new challenges of this type of activity in a faster time than was anticipated. Students were able to practically demonstrate their understanding of the concepts of input, control and output. Some further progress was achieved with respect to the decision concepts in the control algorithm.

8.4.3 Teaching Log: Week three - 14th May 1987

Objectives:
(a) Consolidation of Alpha techniques.
(b) Further teaching input on the use of process models - block diagrams and the development of simple algorithms.
(c) The categorization of the Alpha boards into; input, process/control and output subsystems.
(d) Introduce the concept of the communication of reference levels: feedback/feedforward "closed-loop" control.
(e) Experimentation with Alpha boards to produce a functional system to meet their own design specification.
(f) Produce graphics of the product design and list material requirements.
(g) Review last weeks homework.

(a,c,e) Consolidation of Alpha techniques and concepts. Students were engaged in individual group investigation and were able to practically model their required electronic system. The teacher role was primarily consultative and one of providing support and encouragement. All five groups had produced a functional electronic system using the Alpha boards by the end of the lesson. Additionally students had experimented with other arrangements.

[1] Flood warning system for Townsend Thorsen "Roll-on Roll-off" Ferries. This group changed their original specification to use a light triggered alarm, justified on the grounds of salt water corrosion. The solution was achieved using the following Alpha Boards:

Input boards: Light source (bulb unit), Light sensor.
Process board: Transducer driver.
Output boards: Buzzer and Bulb units

The product design comprised an acrylic tube, with light source and sensor, containing a plastic ball. Rising water level, it was predicted, would cause the ball to rise, interrupting the light beam and triggering the alarm. Further discussion revealed the possibility of the ferry keeling over to one side and draining the tube of water, hence turning the alarm off. The students were able to experimentally adapt their solution to incorporate a latch unit.

[2] Hydraulic fluid level monitoring system. Problems obtaining an old master cylinder hindered the progress of this group. They new in principle what was required but could not make progress without the cylinder to modify. A general lack of coordination observed within this group. Their list of "whats" predicted the use of a switch unit, a transducer driver and a flashing warning light.

[3] Aquarium low level warning system. This group arrived at a solution to the electronic part of their system within five minutes. The group were encouraged to investigate other

solutions, but were unable to discover a better system. The solution was achieved using the following Alpha boards:

Input board: Moisture sensor.
Process board: Inverter board, Transducer driver.
Output board: Buzzer.

The product design incorporated a folded acrylic bracket, which would fit over the glass . The protruding copper probes, normally immersed in water, would sound an alarm when exposed.

[4] and [5] Bathroom flood prevention system. Two groups decided to attempt to design and make an unobtrusive system that would detect dangerously high water level in a bath. The groups decided to join forces and share the work of research and design. A pleasing investigation was conducted, during which the following options were considered: pressure sensors (rising water level would increasingly apply more pressure), temperature sensors (discarded because of the large temperature range), light sensors (an interesting investigation of defraction was pursued), humidity sensors. The final solution was the simplest, comprising of a simple moisture sensor. The following Alpha boards were used:

Input boards: Moisture sensor.
Process boards: Transducer driver or transistor driver.
Output boards: Buzzer.

(b) Process models and control algorithms. All groups were required to summarize the operation of their designed electronic system by means of block diagrams and by the production of an algorithm. This task was completed competently and students were better able to see the relationship of such techniques when related to their practical work.

(d) Communication of reference levels: Feedback / feedforward "closed-loop" control. The group designing the bath water level system, instigated discussion on feedback.

Their concern being, that even if they could sound or flash an alarm, would it be noticed, and if not how could damage be prevented? Group discussion reveled the need for an automatic feedback system which would turn the tap off. After much investigation the groups decided on manual feedback. Because none of the groups were to use feed forward systems, this concept was deferred for another more suitable time.

(g) Homework review: The exercise of producing a block diagram of the system and the development of a simple control algorithm benefited the students in that they appeared to have abetter sense of purpose and direction in the manipulation of the Alpha systems.

(f) Production of product design and material lists.
The production of graphics was not attempted.

Lesson evaluation:

The groups had achieved mastery of the most elementary problem solving techniques, using Alpha systems. Students by this stage were familiar and capable of applying the concepts of input, process/control and output. Most students demonstrated an ability to produce block diagrams and control algorithms, of the most simple form. The need for feedback was recognized and the need for reference levels was becoming more apparent. Much of the mystique surrounding electronics was beginning to evaporate and students were becoming more confident and relaxed.

8.4.4 Teaching Log: Week four - 21st May 1987

(a) Product design investigation and graphics.
(b) Preparation of materials.
(c) Hand wasting techniques.
(d) Deformation of thermoplastics.

(a) Product design investigation and graphics

[1] Flood warning system for Townsend Thorsen "Roll-on Roll-

off" Ferries. A simple orthographic drawing of the flood level, tube with two square end plates, provided the diagram from which the students worked. The acrylic tube was sawn to length, and the ends faced on a centre lathe. The square end plates were cut to size and manually filed square, holes being drilled for attachment to the ferry deck.

[2] Hydraulic fluid level monitoring system. No progress was made in obtaining the scrap master cylinder. The group were beginning to lose patience with the student who had promised to obtain the spare part. Being concerned about the general lack of progress with the product design, a decision was made by the group (in consultation with the teacher) to attempt a different type of fluid sensing system.

The group decided on a system which was similar to the original specification and therefore the previous investigation was not wasted. The subject of their new analysis was an indicator to be attached to the old "Swan" kettle in the school workshop to warn of low water level. The group proceeded to study the system environment and planned to drill the top lip of the kettle and insert an insulated detection probe. The system was tested with the following Alpha boards:

Input board: Moisture sensor.
Process board: Transistor driver
Output board: Bulb unit.

[3] Aquarium low level warning system: A cardboard model was produced of the main body of the unit. This was folded and positioned over the aquarium. This experimentally developed model, produced the template for the eventual unit. The coloured acrylic sheet was cut to the required rectangular shape.

[4] and [5] Bathroom flood prevention system. A cardboard model was developed which conformed to the shape of the walls of the bath. A cardboard template of the bath profile was produced and the groups discussed the most suitable method of

producing a moveable unit to be positioned and fit snugly on the bath. A wooden former was laminated and then shaped, over which the acrylic would be drape moulded.

Lesson evaluation:

Some students experienced difficulty relating the green Alpha boards to their product designs. Student difficulties, were to be resolved by moving forward the experimental optimization and P.C.B. manufacture stages.

8.4.5 Teaching Log: Week five - 28th May 1987

(a) Experimental optimization.
(b) Practical product realization.

(a) Experimental optimization. The students had a clear understanding of the function of the output boards; the buzzer and the bulb units. Discussion was restricted to the function of the input and process boards (only those boards being used in the students projects). The function of the following input transducers was discussed at a level of "what" signals they produced, rather than "how" they achieved their performance: moisture sensor, light sensor (plus the inversion of the Alpha board light sensor to change the signal state). The signal from the sensors was fed into the transistor driver/indicator and secondly into the transducer driver. The relationship of light intensity to the signal level was understood. Students noted the improved performance and sensitivity of the transducer driver.

By means of the Locktronic kit, the process of transposing the Alpha boards was demonstrated. The boards that the groups had selected for their projects, allowed this exercise to be achieved with little difficulty. The light sensor was "read" from Alpha, and transposed to Locktronic. Students were encouraged to identify the supply rails, and the signal line, and to name and describe the function of the components. Opportunity was provided for groups to experiment at a component level with different settings for the variable resistors. The positioning of the light dependent resistor was switched with the variable resistor in the potential dived and the effects on the output noted. Students were curious to know the reason for this effect, an explanation was to be provided the following lesson.

Individual groups were given the task of transposing (figure 8.3) their system from "Alpha" to Locktronic. Using squared paper, the final activity modelling activity, was to graphically produce the circuit. The circuit diagram, copied from the Locktronic system, was scrutinized for errors and returned for corrections.

Lesson evaluation:

Difficulties became evident in transposition of the more complex of "Alpha" boards. Students attempted to transpose the inverter from "Alpha" to breadboard, but serious difficulties were encountered. Using the Locktronic the solution of inversion of the signal was straightforward (figure 8.3), however, to a teacher lacking the most basic electronic expertise this problem could have been a stumbling block. It would have been possible to transfer the circuits direct from Alpha to copper clad, either by use of MTR transfers, or by the copying, using an etch resist pen (or similar technique). This would not have supported, so effectively the dissemination of the essential theory, nor have allowed students to experimentally manipulate components to optimize their own systems.

An explanation of some aspects of the essential theory was determined by the students own needs and natural curiosity.

8.4.6 Teaching Log: Week six - 4th June 1987

Objectives:
(a) Production of a P.C.B.
(b) Practical product realization.
(c) Series circuits: resistors and the potential divider.

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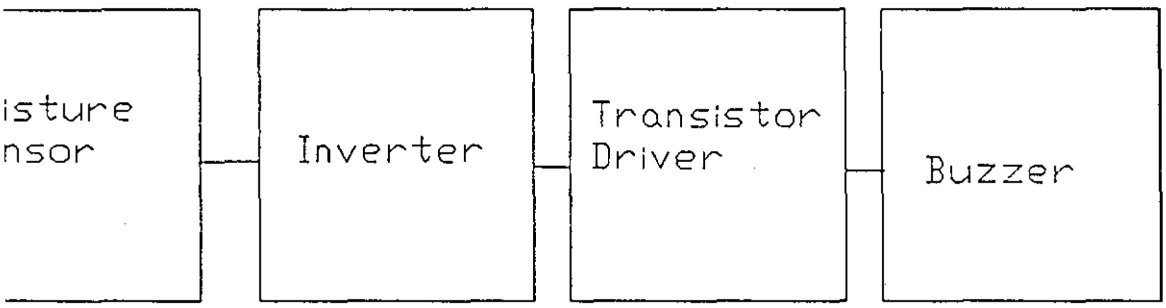
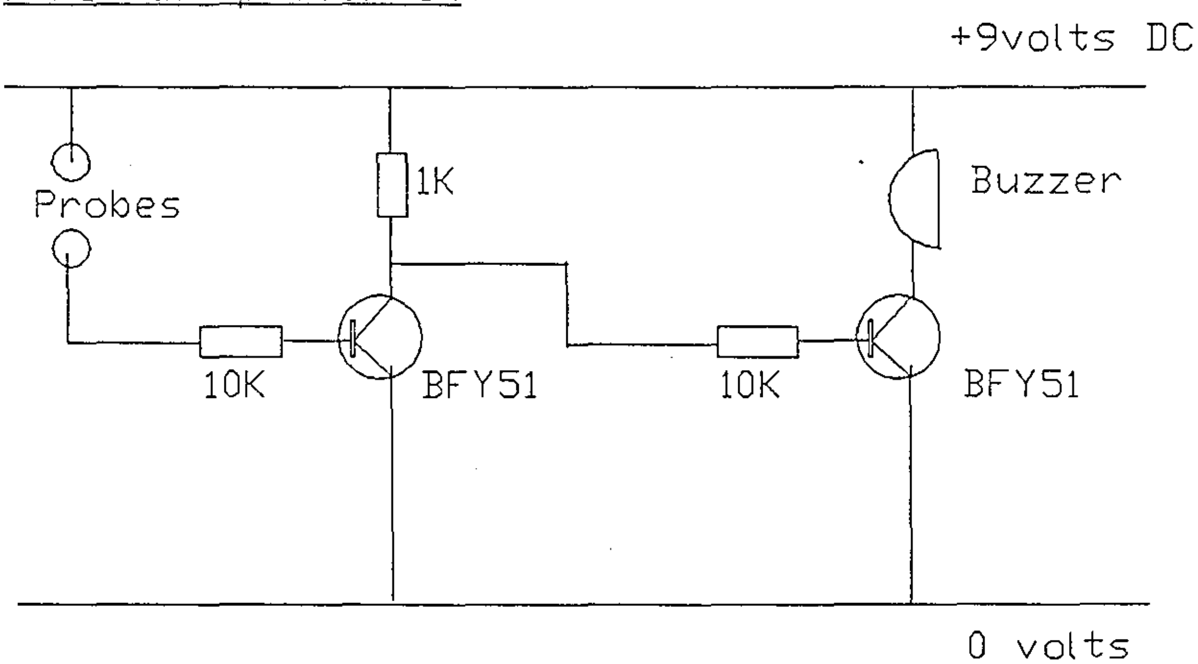



stem (Alpha) boards.

erimental optimization



## Chapter Eight

(a) Production of the printed circuit boards. Students were required to provide information concerning the location of the P.C.B. and the dimensions of the enclosure to hold the electronic elements. Single sided copper clad was provided to match the information provided. In all cases the groups had to scale their circuit diagram from the previous week to accommodate the smaller size of the copper clad. Because of the relatively simple nature of the designed systems this was achieved by the copying of the diagram to the surface of the copper using a fine tipped, water soluble (to allow for erasure of mistakes), over head projector pen. This in turn was "copied over" using an permanent, fine tipped overhead projector pen, Staedtler Lumocolor 318 providing an excellent etch resist mask.

The removal of the copper was achieved using standard techniques involving the use of ferric chloride, followed by the drilling of the boards to accommodate the legs of components.

(b) Practical product realization. The production of the P.C.B. proved to be a considerable motivator for the completion of the practical product.

(c) Series circuits: resistors and the potential divider. From their Physics lessons students were aware of the series rule; the sharing of the available voltage and the same current in all parts. They had a notion of the effects of a resistor on the current. Using Locktronic equipment a simple circuit was constructed involving 100 and 180 ohm series resistors,a 6 volt bulb and a 9 volt supply. Students were required to predict the effects of increasing and decreasing the value of a resistors. The circuit was changed to incorporated[orate a 250 ohm variable resistor. Students were able to predict the effect of increasing the resistance.

The practical investigation of the potential divider, was performed by the students using the following simple techniques:

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[1] The light sensor and temperature sensor boards from Alpha were examined by the students and then transposed to Locktronic.

[2] Similarities were identified. Students identified the components between the negative and positive rails, and recognized the output (the signal rail) taken from between the light dependent and variable resistors on one board, and the thermistor and the variable resistor on the other board.

[3] Students focus was placed upon the light sensor circuit, where it was determined that both resistors were variable, one being controlled by the intensity of the light, whilst the other was under the control of the designer of the system.

[4] The circuit was defined a voltage divider because of the manner in which the available voltage was shared between the resistors. Direct question and answer suggested that almost all students could conceptualize that the voltage was divided between the two components.

[5] The voltage at the power supply was measured at 5 volts. The voltage across each of the resistors was measured in turn. The sum of the voltage was found to be equal to the supply voltage.

[6] The resistance of the variable and light dependent resistors were adjusted and the relationships observed.

[7] The students arrived at the answer that the bigger the resistance the larger the voltage dropped across it; but that the voltage value depends upon the value of the other resistor. The voltage being divided in the ratio of the two resistors.

Lesson evaluation:

Students coped well with the production of the P.C.B. although many initial errors were made in the scaling and copying of their circuits to the copper clad prior to masking. Students would have preferred to have continued working on their P.C.B. rather than commence the investigation of series circuits. This activity ran into time troubles, and because of this, was not completed entirely satisfactory. A recap and data sheet was planned for the next lesson. Student understanding, measured by a question and answer session, of the potential divider was only partially complete.

8.4.7 Teaching Log: Week seven - 11th June 1987

Objectives:

(a) Manufacture of P.C.B.
(b) Deformation techniques (acrylic).
(c) Series circuits: the potential divider.
(d) Set homework: Commence production of the graphics and the writing up of the design report.

(a) Manufacture of P.C.B. Demonstration of soldering techniques.

(b) Deformation techniques. Using the students own prepared a former a demonstration of pressure forming of heated acrylic sheet was given.

(c) Series circuits: the potential divider. Recapitulation of last weeks work.

Lesson evaluation:

Practical circuit construction proceeded well, although some students struggled with P.C.B. soldering techniques. Practice exercise in soldering would have produced better results, rather than proceeding direct to the P.C.B. stage. Further progress achieved, in terms of student understanding of the potential divider.

8.4.8 Teaching Log: Week eight - 18th June 1987

Objectives
(a) Integration stage
(b) Homework: continuation of design report development

Students were required to pull together the different threads of their systems. No new techniques were required and individual group support was provided. A competitive atmosphere was developing. The students were self motivated and were keen to complete their system.

(b) Homework. Students were asked to consider methods of testing the effectiveness of their systems.

Lesson evaluation:

Students experienced some difficulty in establishing the precise manner in which the P.C.B.'s were to be secured within, the acrylic containments. Solutions ranged from the use of blue-tack to accurate drilling and screwing.

8.4.9 Teaching Log: Week nine - 25th June 1987

Objectives
(a) Integration stage.
(b) Completion of design report.
(c) Homework: Completion of design report.

No formal teacher input. Students worked to complete their systems for assessment, testing and evaluation.

8.4.10 Teaching Log: Week ten - 2cnd July 1987

Objectives
(a) Completion.
(b) Evaluation and testing.
(c) Homework: Insert results of the evaluation into the design report.

The final lesson of the trial allowed students the opportunity to simulate the operation of their systems. The lesson took the following format:

[1] Setting out of individual displays.

[2] Mini-exhibition, where groups could examine each others work.
[3] Simulations: Groups demonstrated the system working.
[4] Evaluation: Groups were encouraged to identify the good and bad features of each others systems and to identify areas of possible improvement, or performance enhancement.
[5] Assessment.

Lesson evaluation:

Students attempts at display and exhibiting their work was limited. A formal input, outlining the principles of display, would have allowed, the work to be exhibited to its advantage. A keenly competitive atmosphere was felt and students were anxious that their attempts be thoroughly examined. Details are provided below:

[1] Flood warning system for "Roll-on Roll-off" Ferries.

The finished flood detection system comprised, a clear diameter 20mm acrylic tube, with two square, end plates drilled to allow attachment to the deck of the ferry. The clear acrylic tube contained a plastic float (ball). At the top of the tube a hole was drilled to accommodate a light dependent resistor (ORP-12). Additional holes were positioned at the bottom of the tube to permit sea water to enter, and at the top to allow air to escape. Diametrically opposite to the sensor, was positioned a sealed light source comprising a 6 volt bulb. Rising water level interrupted the the beam of light falling on the light sensor, causing its resistance to increase and an audible alarm to be triggered. The total system was well constructed and worked reliably, after a modification (blackening) to the secondary tube, in which the light source was housed. The design report was well attempted and supported by an excellent cross sectional model of the hull of "The herald of free enterprise", which indicated car decks and water levels.

General assessment:

| | |
|---|---|
| System statement: identification of a need: | A |
| Conceptual model: | B |
| Process model: | B |
| Alpha modelling: | B+ |
| Optimization: | C+ |
| Construction techniques (all): | A- |
| Aesthetics: | B |
| Design report: | B+ |
| Communication: | B |
| Group activity: | A |
| Quality: | B |
| Performance: | B+ |
| Reliability: | B+ |
| Robustness: | C |
| Fitness for purpose: | B+ |
| Overall Grade: | B |

[2] Low water level indicator for a kettle.

Apart from the electronics, this system was not completed. The group had completed the P.C.B., tested the circuit and made some progress towards the completion of the probes and the holder. Particular problems were experienced in determining the optimum position of the probes and secondly the method of attachment to the body of the kettle.

General assessment:

| | | |
|---|---|---|
| System statement: identification of a need: | B+ | |
| Conceptual model: | B | |
| Process model: | B | |
| Alpha modelling: | B+ | |
| Optimization: | C+ | |
| Construction techniques (all): | C | |
| Aesthetics: | * | Unfinished |
| Design report: | C | |
| Communication: | C | |
| Group activity: | D | |
| Quality: | C | |
| Performance: | B | |
| Reliability: | C | |
| Robustness: | * | |
| Fitness for purpose: | * | |
| Overall Grade: | C- | |

[3] Aquarium low level warning system.

This system was produced to a high standard, was robust and worked reliably. It had a clean, professional appearance and fitted unobtrusively onto the sides of the aquarium. The design report was of an adequate standard, although better use could have been made of graphic techniques. The P.C.B. work was only of a satisfactory standard, with particular improvement needed with the soldering technique.

General assessment:

| | |
|---|---|
| System statement: identification of a need: | A |
| Conceptual model: | B+ |
| Process model: | B+ |
| Alpha modelling: | B+ |
| Optimization: | B |
| Construction techniques (all): | A- |
| Aesthetics: | A |
| Design report: | C |
| Communication: | C |
| Group activity: | A |
| Quality: | A |
| Performance: | B+ |
| Reliability: | B+ |
| Robustness: | B |
| Fitness for purpose: | B+ |
| Overall Grade: | B+ |

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[4] and [5] Bathroom flood prevention system.

A simple but effective solution which worked reliably. A major restriction on the use of the device was the limited volume of the output subsystem. To the students credit, they had resolved a number of theoretical methods of overcoming this difficulty. The most effective solution to this problem was deemed to be automatic shut-off of the taps. This could be achieved by measuring the inputs into the system, (a water flow meter in the water supply pipes) or by measuring the effects of the inputs reflected in rising water level. More work was needed on making the system smaller and also on the selection of a less obtrusive position when in use on the bath.

General assessment:

| | |
|---|---|
| System statement: identification of a need: | B+ |
| Conceptual model: | B+ |
| Process model: | A |
| Alpha modelling: | B+ |
| Optimization: | C+ |
| Construction techniques (all): | B |
| Aesthetics: | C |
| Design report: | B+ |
| Communication: | B |
| Group activity: | C |
| Equality: | B |
| Performance: | B |
| Reliability: | B |
| Robustness: | C |
| Fitness for purpose: | C |
| Overall Grade: | B- |

## 8.5 Chapter Review

This chapter has outlined the application of a systems approach to electronic design activity in a practical C.D.T. design and make context. The small scale trial was undertaken during the Summer term, 1987, involving a small group of fifteen all ability boys and girls, with no prior electronic experience. The limits of their knowledge was restricted to basic electrical principles the series rule, which was taught in a Physics lesson.

The trial enabled an all ability group to attempt an electronic problem solving activity, and to usefully incorporate the designed electronic system into a functional product. The basic design activity involved the design, construction and testing of a system to detect fluid levels. Additionally students were required to establish a need and to identify new opportunities that may be generated. The course was organised to offer the following teaching inputs:

[1] The design context: discussion of the design activity and the personalization of the approach by group members.
[2] Producing a system model: conceptual modelling.
[3] Defining the control process: process modelling.
[4] Developing a functional electronic system: "System Alpha".
[5] Experimental optimization: "Locktronic" electronic kits.
[6] Practical P.C.B. construction and soldering techniques.
[7] Parallel production of the designed product and design report booklet.
[8] Integration of the various parts of the product, to produce a complete system.
[9] Testing and evaluation.

The semantic difficulties of modelling in words, was lessened by the use of conceptual modelling techniques and the development of system maps. Students were generally successful in conceptualizing the type of system that would be required and readily understood the key structural concepts of the system vocabulary. The concepts which created most difficulty were those of boundary and reference level. The speed at which students were able to acquire confidence and competence was underestimated. Students were able to identify the "what" type of question and were able to move towards the determination of the "how" and the solution of the problem. The production of a retrospective process model and control algorithm, was a deliberate teaching decision, to more rapidly achieve an understanding of the techniques involved in this type of modelling. Students were able to understand the basic concepts and demonstrated their understanding by applying them to their own system design. Having developed the key system concepts, future application of process modelling could take place immediately after the conceptual modelling stage.

The problems of limited or no previous electronic knowledge was overcome, in this trial, by the use of ready made system building blocks. The use of ready made electronic building blocks ("System Alpha"), to design and investigate the systems properties, was achieved with little difficulty. This initial and relatively straightforward project, directed the students towards the simpler boards. The teaching approach was justified by the need to provide an incline in difficulty in the projects attempted. At this initial, simple level students were successful in applying the systems approach to solve electronic problems.

A major problem identified by the questionnaire research and confirmed by this trial, is the problem of transposing the designed "Alpha" system into a functional electronic circuit which may be incorporated into the entire design product. The simpler "Alpha" boards were transposed by the students with little difficulty to the Locktronic systems. The most complex board used in this project, an inverter board, was unsuccessfully transposed, instead a simpler solution to signal inversion, was achieved by use of transistor inversion. During this stage of experimental optimization students were able to experiment at a component level with different values of resistors. When confronted with problems of transposition it may be more convenient (and necessary) to adopt simpler solutions (ie. Transistor inversion of signal state). The development of M.T.R. has to a certain extent alleviated this problem, by the use of circuit transfers described in the text. This trial has confirmed the power of system modelling techniques for C.D.T. and has highlighted the need for a range of more basic system building blocks, in addition to those currently available. Although textual and other reference material may be made available, the level and depth of the dissemination of the supporting electronic theory will largely be determined by the expertise of the teacher. The trial suggest that students require an explanation of the function of the "Alpha" boards (not necessarily a detailed description of the physics which underpin their function) and textual support is required at this level.

# Chapter Nine

# CONCLUSIONS

## 9.1 Systems concepts

Systems have been demonstrated to be all pervasive and to exist at extremes of scale and complexity. Chapter Two, established a theoretical framework, comprising a literature review which led to the development of the key structural and process concepts. The literature based research, highlighted the hierarchical structure of systems, and the manner in which the term system denotes the interaction between the objective world and how it is perceived by the observer - its objective and subjective sense. The central holistic concept, synthesizes the notion of a set of interconnected elements, which establish a whole, which in turn generates new or emergent properties, that may no exist in the elements embodied within. A system may be described as a transformation processes, converting inputs into outputs. The main characteristics of a systems approach, involves a holistic view point, that centres on the function of systems and which is concerned with dynamic and interacting processes. Systems can help generate order and assist us in making sense of a complex world. Systems approaches encourage a world view which focuses on "what" is of interest, and the exclusion or partial exclusion of other information, thus allowing order and meaning to be established.

Systems analysis has developed an elaborate terminology, which provides a useful tool, in aiding the communication of ideas and permitting the discussion and collection of information about real world situations. Systems have structural and process features which were discussed in Chapter Two. Structural features include; notions of boundary, environment, subsystem, component, hierarchy and interaction or communication links. Structural features may exist in different dimensions; open-closed, hard-soft, evolved-designed, abstract-concrete, continuous-discrete and deterministic-probalistic. Process features include the concepts of entropy, disorder, decay, order, control, communication, equilibrium, stability, homeostatis, feedback/forward, synergy, adaptive, goal, purpose and loop. These system concepts provide a useful tool for dealing with complexity in C.D.T. and provide a basis of the preliminary conceptualization of any system, the generation of system maps and the establishment of the "what" type of question discussed in Chapter Seven.

9.2 Modelling concepts

Chapter Three discussed the role of modelling, with the intention of developing a theoretical framework, to help generate and legitimate, the creation of a modelling strategy for C.D.T. design and make activities. Modelling approaches were demonstrated to provide a powerful means of dealing with complexity in electronic design. Modelling was demonstrated to overcome much of the confusion and incompleteness found in verbal and written explanations and was shown to more effectively communicate design decisions. Modelling permits the clarification of complex situations, supporting the assessment of complex design questions and enabling the development of more successful solutions. Modelling approaches allow the quantification of risk profile to be assessed against the constraints of time, money, materials and limitations in expertise.

Of the four major modelling strategies discussed, conceptual and symbolic offer the most potential to describe, predict, communicate and explain the results of a students electronic design analysis. Conceptual modelling using the systems approach, is a utilitarian tool for helping make sense of complexity in electronic design activity and promoting the analysis of a variety of possible solutions from a range of alternatives. Modelling involves an incline in the level of abstraction. The use of conceptual modelling being the most abstract whilst iconic being the most concrete. The process of modelling involves the analysis of five major categories.

1, The observation of a real world situation and the establishment of the environmental context of the system. The observation of the environmental state and behaviour leading to the derivation of a set of assumptions. Establishing the systems context.

2, The statement of assumptions involves the defining of the systems function and parameters. Preliminary conceptual modelling. Establishing the reference levels.

3, Defining the system boundary and establishing the required behaviour. Ranking of the variables and establishing the control and process parameters. Generating the "what" type of question.

4, Formulation of a tentative process or control model. Simulation and symbolic modelling. Generating questions of how" the system is to be realized.

5, Testing the abstract model. Experimental optimization of the modelled system. Emphasis at this juncture, switches from the abstract to the concrete, with system modelling by means of ready made electronic building blocks and at a lower level by experimental optimization at a component level.

## 9.3 Control concepts

Chapter Four analysed system control concepts at a theoretical level, for subsequent application later in the text. The generation of an effective control vocabulary, is essential in developing and communicating the results of the earlier conceptualization of the structural features of the system. After a system has been conceptualized an effective process model must be developed so that the optimum control conditions may be realized. Control is the action a system initiates to reach and maintain control over its environment. Control is necessary because of the effects of environmental disturbances, which result in the deviation of the systems performance from the desired or predicted level of performance. System approaches emphasizes attention away from the practical discussion of circuit construction and focuses attention to questions of where control should be exercised, what level of sophistication is required, what the sampling incidences are and what subsystems are necessary. Early control analysis, is biased more to the "what and why" rather than the "how" question. A knowledge of the key control concepts enables the generation of the process model discussed in Chapter Seven.

An analysis of the different ways in which systems adjust to the effects of environmental disturbance, revealed the problems associated with open-loop control systems, which react in invariant ways to input level discrepancy. Analysis of closed-loop systems, highlights the two modes in which these control methods perform; either feedforward or feedback processes. Both forms of closed-loop operate at two further distinct levels; positive systems operate on the discrepancy to increase (or enhance) its effects, whilst negative systems operate on the level of the discrepancy to reduce its effects. Control is exercised in a linear manner or non-linear (bang-bang) operations with associated degrees of sampling frequency.

The operational aspects of exercising effective control were reviewed in the context of the classic systems loop; input-process-output and the communication loop of closed systems. Operational distinctions drew attention to the differences between; transducers and actuators, sensors, binary and linear interface transducers, and output actuators. The conversion of linear to digital highlighted the use of quantization techniques, whilst the assessment of performance drew attention to the difficulties that occur when multiple tests need to be made, where qualitive judgments need to be draw from the evidence and where sampling of the output/input needs to be made for reference purposes.

## 9.4 Questionnaire Design

Chapter Five outlined the principles of research design and the methods of analysis. Throughout the development of the questionnaire based research, the methods employed were designed to meet the criteria of validity, reliability, appropriateness, adequate control, sample adequacy, reliability, replicability and feasibility. Attention was drawn to the limitation of the sampling procedure and the problems of dealing with a sample which was not a true random sample. Research design focused on the following:

[1] Sampling techniques.
[2] Population selection.
[3] Data capture (collection).
[4] Questionnaire distribution techniques.
[5] Data collection and response rate.
[6] Piloting techniques.
[7] Reliability and validity: F-Ratio, Standard error of the sample mean.
[8] Computerised and manual processing techniques.
[9] Methods of data analysis: Central tendency, Dispersion and spread, Measurement of correlation.
[10] Variation in the dependent variable.
[11] Test for no association.
[12] Test for random effects.
[13] Attitude assessment using Likert type method of summated ratings.

The sample, drawn from the local education authorities of Derbyshire, Lincolnshire and Staffordshire (plus a smaller number nationally), numbered 74 from a distribution of 93. The small scale of the research, provided valuable insights into the current position of electronics C.D.T. and additionally, other aspects of design and technology teaching (which are offered as an appendix). The problems which were experienced in establishing a true random sample in Staffordshire, have limited the conclusions which may be drawn from the inferential and descriptive statistics, to only a limited and tentative value.

9.5 Interpretation of the questionnaire data.

9.5.1 Chapter Six presented the results of the information obtained from the issue of a questionnaire to 93 schools, outlined in Chapter Five. The results show that in 71 out of the 73 schools C.D.T. (95.95%) is taught in co-educational groups. The progress towards all ability teaching is also encouraging, 53 schools offer mixed ability teaching groups (71.62%).

9.5.2 C.D.T. technological teaching expertise.

The results demonstrate the limited provision of initial technology training for C.D.T. teachers (21.62%). This shortfall, in adequately technology trained C.D.T. staff, has not been off set, by the extensive attendance at in-service training courses (79.38%). 60.81% of all teachers questioned, responded that they lacked the confidence to cope with the range of technological demands found in C.D.T. design activity, disappointingly this results in 74.32% of all cases having constraints applied to technological design activity. The constraints of limited technological expertise, thus place considerable constraints, on the range of design and problem solving activities undertaken by students in C.D.T.

9.5.3 Perceived expertise of C.D.T. teachers and the resource value of the technological areas of the C.D.T. curriculum, with particular emphasis on electronics.

One of the research intentions of this thesis, was to rate perceived expertise and to establish those technological areas, considered to be of most value to C.D.T. By identifying levels of expertise and establishing those areas considered most useful, it is possible to gain insights and to recommend measures to more adequately support technological provision in C.D.T.

There was a strong tendency for high expertise to be paired with high resource value, if a teacher was competent in an aspect of technology, then he was likely to regard it as useful. Conversely if a teacher lacked the prerequisite expertise the technological area was likely to be of limited perceived resource value. The association of expertise and resource value was statistically confirmed by the product moment correlation coefficient, demonstrating a high positive linear relationship, where a high in one was mirrored by a high in the other. The system electronics result suggested only a fair degree (+0.61) correlation between the variables.

The correlation of high expertise and high resource value is not found in the results for systems electronics. Despite low perceived expertise, teachers identified this technological area of high resource value.

The generally high degree of correlation allows the prediction of scores on an unknown variable when the other variable is known. The independent variable, of teacher expertise provides an indication of the likely resource value of technological areas of the C.D.T. curriculum. It may be inferred from the results that increasing a teachers perceived expertise will correspondingly increase the perception of resource value. The degree of consensus indicated by the standard deviation shows the highest levels of agreement amongst teachers in the more traditional technologies associated with C.D.T., namely mechanisms, materials technology and forces and structures.

9.5.4 Electronics in C.D.T. schemes.

Of the four electronic areas on which teachers were questioned, teachers perceived their expertise to be highest in analogue electronics, whilst instrumentation (a strand of the modular technology) course ranked lowest. Concerning the question of perceived resource value of the electronic areas of the curriculum, the order from high to low was, Systems, digital, analogue and finally instrumentation. Significantly, an incline in the analytical nature of the electronic area is demonstrated. The greater the degree of specialised electronic expertise the lower the perceived value. Interview responses confirm that teachers identify systems electronics to have a high resource value for C.D.T. irrespective of teacher perceived, low expertise in electronics. Three additional questions were posed to determine the type of teaching approach; (a) to indicate whether the style of delivery is to introduce technological aspects in isolation of other areas (an analysis of separate technological areas); (b) design briefs which purposefully lead into a specific technological activity and; (c) whether open-ended briefs lead into a range of different technological investigations.

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The results suggest that design activities are more likely to be of an open-ended nature, leading into a study of particular technological areas, rather than an approach that teaches technological subjects in isolation of each other.

The results show that electronics featured in 81.08% of all the schools questioned, 40.54% regularly incorporating electronics into their schemes. Electronics tended to be taught as separate aspect of the C.D.T. curriculum. Follow up interview responses indicate the concern that teachers feel in supplying a prerequisite basic understanding of electronic theory prior to undertaking problem solving. Essentially, the concern is that the introduction of an increasing technological element into teaching schemes is resulting in courses which are losing sight of the underlying principles of the subject. The practical problems of coping with an infinite range of student response, in design activity generates uncertainty and unpredictable outcomes. By controlling the level of student understanding, it becomes possible to direct students design attention to the use of existing knowledge, rather than the uncertainty of open-ended schemes. This essentially pragmatic approach, ensures successful, controlled design activity, but does little to support the experiential and wider design context, increasingly a part of G.C.S.E and the national C.D.T. criteria.

Questions relating to the particular emphasis in electronic teaching, indicate that there is an almost equal split between those that always use a systems approach and those that always use an approach based on the study of components and electronic theory. Question 20 gauged teacher opinion concerning the most appropriate time to teach the underpinning electronic theory in systems approaches. Both teacher consensus and the highest mean score, points to the teaching of the theory during the investigation stage of design process. The results suggest that teachers are prepared, in systems approaches, to allow students to undertake electronic design, without a prerequisite knowledge of the underpinning theory.

# Chapter Nine

Electronics (similarly to other areas of the C.D.T. curriculum) cannot be taught without adequate support and material provision. The relative value and the influences, of the curriculum support agencies, and also the requirement of equipment, materials and funding, were assessed to indicate the key levels of support needed to establish electronics into C.D.T. schemes. With the exception of H.M.I. all influences were deemed important, with particular emphasis on adequate funding. To successfully introduce electronics into C.D.T. schemes a variety of support is required, financial, material, in-service training provision and at a more general level, support and encouragement.

A number of questions were presented to ascertain teacher opinion of the system approach in electronic design activity. The results suggest that teachers perceive systems to provide the best support for electronic design activity. Responses to interview questions, further support the statement that systems provides the best support for C.D.T. design and make situations. The statement, that students will have a better understanding of electronic theory if they follow an analytical study of the electronic circuit theory, was supported by respondents. This response is not surprising, since the educational objectives, and the expected outcomes of following a component/analysis of circuit theory based study programme, are likely to be divergent to those of a design and make course. Interview responses differentiate between competence in electronic theory and competence to apply electronic systems to solve problems. A knowledge of circuit theory does not necessarily give an advantage in a problem solving situation, where the range of possible responses is great. The cost of acquiring competence, sufficiently to cope with the range of possible electronic design responses make the adoption of a component centered approach unrealistic. Both the questionnaire and interview responses, agree that student's are more likely to be successful in design and make situations if they follow a systems based approach.

In that group of questions designed to assess teacher attitude to the system approach, greatest consensus and support was shown to the statement that "System approaches allow student's to get to the heart of electronics, without wading through the difficult abstracts first." Similarly strong support was given to the statement that the less able student can apply electronics in design situations through systems approaches. The statement that more able students are not adequately stretched by systems approaches was not supported.

The results highlighted an inequality in the provision of teaching resources amongst schools. Many departments were struggling to respond to the new technological emphasis being applied to C.D.T. In some instances departments had the material and equipment resources but lacked the teacher electronic expertise, to use effectively their resources. In other schools well qualified staff were deprived of contributing their expertise because of inadequate material provision. Most teachers regarded the Danum-Trent equipment redundant and becoming increasingly incompatible with the new fundamentals of C.D.T. The results highlighted a large number of own built systems (31.08%), which is partially accounted for by reference to the systems electronics course organised by Derbyshire C.D.T. advisory service, under the tutorship of Malcolm Plant. Additionally 24.32% possessed M.F.A. (Microelectronics for All kits), whilst 17.56% used "System Alpha" and a further 17.56% had Locktronic equipment.

9.5.6 Questionnaire: summary

The results of the questionnaire data may be summarized as follows:

[1] C.D.T. is almost exclusively taught in all ability groups of mixed gender.
[2] Many C.D.T. teachers lack both competence and confidence to cope with the technological emphasis of the new fundamentals of the subject.
[3] Initial training course have not adequately prepared

teachers for the technological demands of the subject.

[4] Extensive in-service training has failed to generate sufficient confidence to enable teachers to cope with the range of technologies necessary to support C.D.T. design and make course. The time/cost effectiveness of acquiring sufficient electronic expertise is prohibitive.

[5] Limitations in technological expertise results in restrictions in the range of problem solving activities students are able to attempt.

[6] There is a strong tendency for high perceived technological expertise to be paired with high perceived resource value of technological areas. The high degree of correlation allows the prediction of one variable from another.

[7] Electronics is identified by teachers as an area of key resource value for C.D.T. design and make activities.

[8] Increasingly technological and theoretical content, is resulting in schemes which are losing sight of the underlying principles of C.D.T.

[9] When confronted with problems of expertise, the control of student technological understanding directs design attention to the use of existing knowledge, rather than towards the uncertainty of open-ended schemes. This pragmatic approach supports controlled design activity, but offers little to support the experiential and wider C.D.T. design context.

[10] Most typically electronics is taught in isolation of other aspects of the C.D.T. curriculum, rather than as a integral part of a design activity.

[11] The results suggest that other design activities are more likely to be of an open-ended nature, leading into a study of particular technological areas, rather than an approach that teaches technological subjects in isolation of each other.

[12] Despite low perceived expertise teachers identify systems electronics to be of high resource value.

[13] The greater the analytical nature of the study area the lower that value is perceived as a resource

for design activity.

[14] The division between those who adopt a systems based approach and those who use an "analytical" approach is almost equally split.

[15] Systems were perceived of highest resource value for design activities, whilst highest expertise was perceived in analogue electronics.

[16] In systems approaches teachers prefer to teach the underpinning theory during the investigation stage of the design process.

[17] Ready made electronic systems provided the best support for design and make activities and allow students to produce more successful outcomes.

[18] Students are more likely to understand the electronic theory by following an "analytical" approach, but it is not necessary to understand the properties of components before electronic problem solving may be attempted.

[19] Less able students can attempt electronic design activity using ready made electronic systems.

[20] School electronic teaching resources exhibit marked inequalities.

[21] The key influences on the establishment of electronic design activity are those of adequate funding, teacher enthusiasm, the provision of materials and equipment and teacher expertise. Least important was H.M.I. support.

## 9.6 The process of electronic design using systems approaches.

Chapter Seven develops a new and complete systems based design methodology, which better supports the application of electronics in C.D.T. design contexts. Attention is directed away from the linearly sequential design approach and moves towards the iterative and cyclical systems approach. This methodology was developed and produced by the application of the theoretical concepts generated in earlier chapters. Distinctions where drawn between the "what" and the "how" aspects of system based design, and the benefits of establishing cognizance of the notions of hierarchy.

Analysis focused on the classic top-down design approach and generated seven key stages, which express a movement from low resolution and generality, towards high resolution of detail and specificality. The iterative cyclical loop comprises the following stages:

[1] Conceptual modelling.
[2] Process modelling.
[3] Electronic system building by "black box" approaches.
[4] Experimental optimization.
[5] Dissemination of the essential supporting theory.
[6] Practical realization of the optimized circuit.
[7] Product integration.

## 9.7 Small-scale trial of the systems approach for electronic design activity in C.D.T.

The testing of the methodology described above was conducted during the period from April 30th to July 2cnd 1987. The activity was designed to allow an all ability group, with no previous experience of electronics, the opportunity to tackle a technology based design activity, appropriate to solution by electronic methods. The basic design activity involved the design, construction and testing of a system to detect changing fluid levels. The course offered the following teaching inputs:

[1] The design context.
[2] Conceptual modelling and the production system maps.
[3] Process modelling and the analysis of the control process.
[4] Modelling using ready made electronic systems to produce a functional model.
[5] Experimental optimization of the functional system produced at above. Manipulation at a component level.
[6] Printed circuit construction techniques.
[7] On going product design and reporting.

[8] Integration of the various designed elements.
[9] Testing and evaluation.

This method lessened the semantic problems associated with the modelling in words. Students were successful in conceptualizing complex processes and were capable of producing clear system maps which outlined the key structural concepts of:

a, System definition
b, System environment.
c, Boundary and reference level determination.
d, Identifying concepts of "What" is required..

Identifying "what" was required, was not problematical, rather difficulties were experienced in establishing the "how", solution to the "what" question. The production of a retrospective process model and a simple control algorithm, enabled the opportunity to understand the relevance of this modelling system, by reference to the functional system produced using "Alpha". Students readily understood the concepts involved and demonstrated their understanding, by applying the model generated, to their designed systems. Having established the technique, any future use of process modelling would precede from the conceptualization of the system, to the process modelling stage discussed in Chapter Seven.

The problems of no previous electronic experience were successfully overcome by the use of ready made electronic building blocks. The speed at which students were able to acquire confidence was underestimated. The success of this stage was due largely to the fact that the students had established a clear model of "what" was required by means of conceptual modelling techniques. By offering a structured teaching programme, offering an incline in difficulty, students experiences could be guided to ensure that the educational objectives could be achieved.

The most difficult problem identified by the trial, was that of transposing the designed "Alpha" system, into a functional electronic printed circuit board, which could be integrated into the entire designed system. The technique adopted to solve this problem involved the use of Locktronic electronic equipment (a long established and popular electronic teaching system. The simpler "Alpha" boards, in this case, presented few difficulties but the more complex "Alpha" circuit boards proved difficult to transpose . The solution of transposition in this case, was achieved by experimentally optimizing a simpler circuit. This strategy, however, is unreasonable were serious problems of limited teacher expertise exist. The solution to this difficult problem has to a certain extent been alleviated by the development of M.T.R. teaching resources. The availability of circuit transfers, which may be linked together and "rubbed-down" onto copper clad, plus the complete list of required components offer the way forward for circuit design of the most complex designs. When necessary, the most appropriate stage for teaching the electronic theory (confirmed by the questionnaire research and dependent on teacher expertise), is during the investigation/experimental optimization stage of the design process. The trial highlighted the need for a range of simpler boards which may more readily be transposed to the printed circuit board. The trial confirmed the power of systems approaches for dealing with complexity in electronic design activities and provided opportunities for students to more fully embrace the fundamentals of C.D.T. outlined earlier in the text.

## 9.9 Summary

Substantial changes have occurred in the C.D.T. curriculum, moving the subject forward from a knowledge orientation to a process base, evolving through problem solving and design centred methods, which highlight the needs of man and the ways in which these may be satisfied. The new fundamentals of the subject, accent the control of the environment through design activities, students being encouraged to identify needs and to seek solutions to real world problems.

Legitimate demands are often generated, but sometimes we deny access to the means of realizing the solution because of limitations in teacher expertise.

Emphasis is placed upon the application of scientific and other principles, rather than the rote learning of a group of unconnected facts. To support and enhance the changes taking place in this area of the curriculum substantial changes in pedagogy, syllabus content and the suggested style of delivery must take place. Changes within the C.D.T. area of the education system moves electronics forward, from the didactic following of the reductionist scientific methods of detail, based upon study in single subject areas, to systems and other cross curricular approaches which accent the application and real world usefulness of the technological content of Science and some C.D.T. schemes. Students by following a systems approach are encouraged to view the whole of any technological artifact as a complete unit, in which input elicits the necessary response to alleviate environmental disturbance. An awareness that most technological systems cannot be described in terms of a single system, but must be understood in the context of the wider environment and a hierarchy of systems, may foster an understanding of how technological systems inter-relate with the wider society and the individual user. Implicit within this approach is the awareness of the social, consequences of design decisions. At a more prosaic level systems methodologies may equip young adults with the ability to make more rational judgments concerning aspects of purpose, quality and style in other aspects of the technological environment. It is also important not to lose sight of the dual role that craft skills plays in the technical and aesthetic function of C.D.T. The final product reflects the both the quality of craftsmanship as well as the quality of thought during the design stage and enables the discussion of the aesthetic aspects of design. Additionally,systems based approaches, may provide opportunities for students to experience the pleasure and satisfaction from producing practical solutions to real world problems.

Students legitimately turn to the teacher for support in realizing their design ideas, which in turn places a responsibility on the C.D.T. specialist to provide a comprehensive range of technologies. The current demand for technologically based project work and the identification of electronics as a key resource for C.D.T. design activity, has created a considerable demand amongst teachers to be provided with the necessary resources (human and material) to support student design activity. The time cost effectiveness of providing teachers with sufficient capability to cope with the necessary range of technologies is often prohibitive.

Personal contact, interview responses and questionnaire returns suggest that many teachers have responded to the challenge of increased complexity, by incorporating into teaching schemes, additional elements of scientific theory to support the new technological thrust. Examinations courses, such as Control Technology and Modular Technology G.C.E., required a study of scientific principles, and unfortunately generated pressures, which resulted in some teaching schemes losing sight of the underlying principles of C.D.T. The constraints imposed upon time and resources, resulted in a failure to proceed far enough for students to develop any real awareness of the potential of electronics for C.D.T. design activity. The current emphasis on the linearly sequential electronic design approach, with the prerequisite demand of technological expertise, places restrictions on the range and scope of design activity, because of limitations in teacher technological expertise. Extensive attendance at in-service training courses has done little to remedy the problems of limited expertise and low confidence.

System methodology helps provide a common language to support the communication of design ideas and allows the collection and discussion of data under appropriate headings. System approaches have been argued to offer a way forward for C.D.T. in allowing students to order and make sense of complexity in electronic design activity. By focusing on what is of interest and the exclusion of other information, order and meaning may well be, more readily established. The perception of any physical object as a single system, comprising of a set of elements connected by a distinguishing principle, may support modes of thinking, which allow students to get to the heart of any problem to the exclusion of irrelevances.

The abstracting of systems into real world experiences helps to unravel much of the complexity and uncertainty of the inter-relating elements of design. Studying phenomena from a systems viewpoint may help to develop a more reasoned and rational understanding of design situations, hierarchical context and the environment of which a system is an integral element. The fundamental systems approach of design conceptualization, process modelling, experimental optimization and product integration provides a powerful basic mechanism for dealing with complexity and control in all areas of our lives. Systems based approaches to design activity offer a transferable methodology of considerable potential and utilitarian value which extends into all aspects of life.

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# APPENDIX I

# QUESTIONNAIRE

CONFIDENTIAL

## Establishment

Please tick the appropriate box for your school:

1 School type:

- Primary ☐
- Middle ☐
- Comprehensive 11 to 16 ☐
- Comprehensive 11 to 18 ☐
- Sixth Form College ☐
- Independent ☐
- Grammar ☐
- Secondary Modern ☐
- Other, please specify: ☐

2 Number on Roll:

- 0 to 500 ☐
- 501 to 1000 ☐
- 1001 to 1500 ☐
- 1501 to 2000 ☐
- 2000 + ☐

3

- Coeducational ☐
- Boys School ☐
- Girls School ☐

4 Please tick the box(es) which describes the organisation of C.D.T. teaching groups at your school.

- Coeducational ☐
- Single sex ☐
- Mixed ability ☐
- Streamed ☐
- Other, specify: ☐

5 To what age ranges is C.D.T. taught?

Secondary

- Year One ☐
- Year Two ☐
- Year Three ☐
- Year Four ☐
- Year Five ☐
- Sixth Form ☐

Primary (please specify ages) ☐

## C.D.T. Staff Training and Expertise

6 Were you specifically trained to teach technology at either a College of Education, University or an establishment of Higher Education? Yes ☐ No ☐

7 Have you received In-Service training in any aspect of technology? Yes ☐ No ☐

8 Do you feel confident to cope with the full range of technological subjects encountered in C.D.T. teaching? Yes ☐ No ☐

9 Does any lack of technological expertise restrict the range of problem solving activities attempted by pupils. Yes ☐ No ☐

10 Please indicate the areas in which you have a particular expertise, by ticking the appropriate box. Five indicates a high level of expertise, one indicates limited expertise.

| | Expertise: High 5 | 4 | 3 | 2 | Low 1 |
|---|---|---|---|---|---|
| Analogue Electronics | | | | | |
| Digital Electronics | | | | | |
| Systems Electronics | | | | | |
| Instrumentation | | | | | |
| Forces and Structures | | | | | |
| Mechanics | | | | | |
| Materials Technology | | | | | |
| Pneumatics | | | | | |
| Computer control | | | | | |
| Others, please list: | | | | | |

## C.D.T. Curriculum

11 Which of the following areas of Technology do you consider to be the most useful resources for design activities? Five indicates very useful, one indicates limited usefulness.

| | Usefulness: High 5 | 4 | 3 | 2 | Low 1 |
|---|---|---|---|---|---|
| Analogue Electronics | | | | | |
| Digital Electronics | | | | | |
| Systems Electronics | | | | | |
| Instrumentation | | | | | |
| Forces and Structures | | | | | |
| Mechanics | | | | | |
| Materials Technology | | | | | |
| Pneumatics | | | | | |
| Computer control | | | | | |
| Others, please list: | | | | | |

| | Always | Sometimes | Never |
|---|---|---|---|
| 12 Are different aspects of Technology taught in isolation of each other? | | | |
| 13 Do design briefs deliberately lead into an application of a particular aspect of technology? | | | |
| 14 Are open-ended design briefs set which may lead pupils to a variety of different investigations? | | | |

## Electronics in C.D.T. Problem Solving

| | Always | Sometimes | Never |
|---|---|---|---|
| 15 Do Electronics feature in your C.D.T. curriculum | | | |
| 16 Are electronics taught separately from the other aspects of C.D.T.? | | | |
| 17 Is there a policy to promote a particular approach to electronics teaching? | | | |
| 18 Is emphasise placed on a knowledge of the properties of components? | | | |
| 19 Are Systems or black box approaches employed to solve the electronic problems pupils encounter in their design activities? | | | |

20 In Systems approaches, at what stage should the underpinning electronic theory be taught?

| | Always | Sometimes | Never |
|---|---|---|---|
| Before the setting of the problem? | | | |
| During the investigation? | | | |
| During the assembly stage? | | | |
| After the construction? | | | |
| Not at all? | | | |
| Other, specify? | | | |

21 What factors, do you consider, to be the major influences on the uptake of electronics in C.D.T. projects? Tick the appropriate box. Five indicates very important, one indicates least important:

| | Importance: Very Important 5 | 4 | 3 | 2 | Low Importance 1 |
|---|---|---|---|---|---|
| Teacher expertise | | | | | |
| Teacher enthuisiasm | | | | | |
| School management support | | | | | |
| Advisory Service support | | | | | |
| H.M.I. | | | | | |
| Pupil pressure | | | | | |
| Materials and equipment | | | | | |
| Adequate time allocation | | | | | |
| Adequate funding | | | | | |
| In-Service training | | | | | |
| Others, specify: | | | | | |

22 Please indicate whether you agree or disagree with the following statements. Five indicates strong agreement, one indicates strong disagreement.

| | Agreement: Strongly Agree 5 | 4 | 3 | 2 | Strongly Disagree 1 |
|---|---|---|---|---|---|
| i, Ready made electronic Systems provides the best support for design and make situations. | | | | | |
| ii, Pupils will have a better understanding of electronic theory if they follow an analytical approach. | | | | | |
| iii, Pupils will be more successful in designing and making situations if they apply a systems approach to electronics. | | | | | |
| iv, Pupils need to understand the properties of components and their use in circuits before they can attempt electronic problem solving. | | | | | |

| | Strongly Agree | | | Strongly Disagree | |
|---|---|---|---|---|---|
| | 5 | 4 | 3 | 2 | 1 |
| v, The use of Systems approaches enables a pupil to get to the heart of electronics without wading through the difficult abstracts first. | | | | | |
| vi, Less able pupils can apply electronics in design situations through electronic systems. | | | | | |
| vii, More able pupils are not adequately stretched by systems approaches. | | | | | |

23 Please indicate your electronic teaching resources for C.D.T. problem solving:

- Bytronic Boards
- Control Pathways
- Danum Trent
- E and L Systems Kit
- Griffin Kit
- Harris Modules
- Locktronic
- Logic Tutor
- MFA
- System Alpha
- Unilab Blue Chip
- Prototype Boards
- Cathode Ray Oscilloscope
- Own built System
- Others, please specify:

Computers:

- BBC
- Spectrum
- ZX81
- Pet
- Apple
- Other, please specify
- Control interface
- Buggy
- Robot Arm
- Others, please specify:

24 please tick the appropriate box to indicate the examinations subjects and the level at which they are taught.

| | GCE "A" | GCE "O" | CSE | MODE 3 |
|---|---|---|---|---|
| Control Technology | | | | |
| Craft, Design and Technology | | | | |
| Design and Technology | | | | |
| Electronics | | | | |
| Electronic Systems | | | | |
| Engineering Science | | | | |
| Modular Technology | | | | |
| Technology | | | | |
| Others, please specify: | | | | |

## ADDITIONAL COMMENTS

I would particularly welcome any additional comments that you would care to make concerning the role that Electronics plays in the C.D.T. curriculum.

THANK YOU FOR YOUR KIND ASSISTANCE

Please enclose the completed questionnaire in the provided S.A.E.

# APPENDIX II

## DETAILED SUMMARY OF THE QUESTIONNAIRE DATA

## Appendix B

### Summary of Questionnaire Data

The enclosed hardcopy, of a major portion of the computer spreadsheet which was used to process the data, from the questionnaire based research should be read in conjunction with the Questionnaire (Appendix A) and Chapters Four and Five of the main body of the text.

The row headings refer to question numbers, whilst the column headings provide the following information:

| | |
|---|---|
| Comp 11-18 | Comprehensive Schools 11 to 18 years. |
| High 13-18 | High Schools (Staffordshire) 11 to 18 years. |
| Middle 11-14 | Middle Schools 11 to 14 years. |
| Primary | Primary Schools. |
| GRA/IND | Grammar and Independent Schools. |
| Totals | Row totals. |
| % | Row total as a percentage of whole group. |
| Mean | Arithmetic mean. |
| Varianc | Variance. |
| Stand | Standard deviation. |
| PPMLCC | Pearson's product moment linear correlation coefficient. |
| F-Ratio | F-ratio test 5% level. |
| Standerror | Standard error 5% level. |
| No-asso | Test for no association. |
| PMLCCsq | PPMLCC squared (%) |

| omni calc | COMP 11-18 | HIGH 13-18 | COMP 11-16 | MIDDLE 11-14 | PRIMARY | GRA/IND | TOTALS JAN1987 | % | MEAN R+../87 | VARIANC | STAND DEVIAT | PPMLCC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q1 | | | | | | | | | | | | |
| NUMBER | 29.00 | 12.00 | 28.00 | 2.00 | 1.00 | 2.00 | 74.00 | | | | | |
| Q2 | | | | | | | | | | | | |
| ^500 | 0.00 | 2.00 | 9.00 | 2.00 | 1.00 | 2.00 | 16.00 | 21.62 | 925.67 | | | |
| ^1000 | 5.00 | 8.00 | 14.00 | 0.00 | 0.00 | 0.00 | 27.00 | 36.48 | | | | |
| ^1500 | 15.00 | 2.00 | 5.00 | 0.00 | 0.00 | 0.00 | 22.00 | 29.73 | | | 337.67 | |
| ^2000 | 7.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.00 | 9.46 | | | | |
| +2000 | 2.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 2.70 | | | | |
| Q4 | | | | | | | | | | | | |
| COED | 29.00 | 12.00 | 26.00 | 2.00 | 1.00 | 1.00 | 71.00 | 95.94 | | | | |
| SINGLE | 0.00 | 0.00 | 2.00 | 0.00 | 0.00 | 1.00 | 3.00 | 4.05 | | | | |
| MIXED A | 19.00 | 12.00 | 19.00 | 2.00 | 1.00 | 0.00 | 53.00 | 71.62 | | | | |
| STREAM | 10.00 | 0.00 | 9.00 | 0.00 | 0.00 | 2.00 | 21.00 | 28.38 | | | | |
| Q6 | | | | | | | | | | | | |
| YES TEC | 7.00 | 3.00 | 5.00 | 1.00 | 0.00 | 0.00 | 16.00 | 21.62 | | | | |
| NO | 22.00 | 9.00 | 23.00 | 1.00 | 1.00 | 2.00 | 58.00 | 78.38 | | | | |
| Q7 | | | | | | | | | | | | |
| YES INS | 24.00 | 11.00 | 19.00 | 2.00 | 0.00 | 2.00 | 58.00 | 78.38 | | | | |
| NO | 5.00 | 1.00 | 9.00 | 0.00 | 1.00 | 0.00 | 16.00 | 21.62 | | | | |
| Q8 | | | | | | | | | | | | |
| YES CON | 14.00 | 5.00 | 9.00 | 0.00 | 0.00 | 1.00 | 29.00 | 39.19 | | | | |
| NO | 15.00 | 7.00 | 19.00 | 2.00 | 1.00 | 1.00 | 45.00 | 60.81 | | | | |
| Q9 | | | | | | | | | | | | |
| YES RES | 21.00 | 9.00 | 21.00 | 2.00 | 1.00 | 1.00 | 55.00 | 74.32 | | | | |
| NO | 8.00 | 3.00 | 7.00 | 0.00 | 0.00 | 1.00 | 19.00 | 25.67 | | | | |

| omni calc | COMP 11-18 | HIGH 13-18 | COMP 11-16 | MIDDLE 11-14 | PRIMARY | GRA/IND | TOTALS JAN1987 | % | MEAN R+../B7 | VARIANC | STAND DEVIAT | PPMLCC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q10 | | | | | | | | | | | | |
| 1 ANAL | 7.00 | 1.00 | 5.00 | 0.00 | 1.00 | 0.00 | 14.00 | 18.92 | 2.70 | 1.50 | 1.22 | |
| 2 | 8.00 | 2.00 | 9.00 | 1.00 | 0.00 | 1.00 | 21.00 | 28.38 | | | | |
| 3 | 5.00 | 5.00 | 7.00 | 1.00 | 0.00 | 0.00 | 18.00 | 24.32 | | | | |
| 4 | 6.00 | 3.00 | 5.00 | 0.00 | 0.00 | 1.00 | 15.00 | 20.27 | | | | |
| 5 | 3.00 | 1.00 | 2.00 | 0.00 | 0.00 | 0.00 | 6.00 | 8.11 | | | | 0.85 |
| 1 DIGIT | 6.00 | 3.00 | 6.00 | 0.00 | 1.00 | 1.00 | 17.00 | 22.97 | 2.63 | 1.49 | 1.22 | |
| 2 | 3.00 | 2.00 | 10.00 | 1.00 | 0.00 | 0.00 | 16.00 | 21.62 | | | | |
| 3 | 10.00 | 4.00 | 8.00 | 1.00 | 0.00 | 1.00 | 24.00 | 32.43 | | | | |
| 4 | 6.00 | 2.00 | 3.00 | 0.00 | 0.00 | 0.00 | 11.00 | 14.86 | | | | |
| 5 | 4.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 6.00 | 8.11 | | | | 0.79 |
| 1 SYSTS | 8.00 | 4.00 | 6.00 | 0.00 | 0.00 | 0.00 | 16.00 | 21.62 | 2.56 | 1.43 | 1.20 | |
| 2 | 5.00 | 2.00 | 8.00 | 1.00 | 0.00 | 1.00 | 17.00 | 22.97 | | | | |
| 3 | 8.00 | 3.00 | 8.00 | 1.00 | 0.00 | 1.00 | 21.00 | 28.38 | | | | |
| 4 | 6.00 | 2.00 | 4.00 | 0.00 | 1.00 | 0.00 | 13.00 | 17.56 | | | | |
| 5 | 2.00 | 1.00 | 2.00 | 0.00 | 0.00 | 0.00 | 5.00 | 6.75 | | | | 0.61 |
| 1 INSTR | 11.00 | 6.00 | 9.00 | 1.00 | 1.00 | 1.00 | 29.00 | 39.19 | 2.06 | 1.21 | 1.10 | |
| 2 | 8.00 | 4.00 | 10.00 | 0.00 | 0.00 | 0.00 | 22.00 | 29.73 | | | | |
| 3 | 7.00 | 1.00 | 6.00 | 0.00 | 0.00 | 0.00 | 14.00 | 18.92 | | | | |
| 4 | 2.00 | 1.00 | 2.00 | 1.00 | 0.00 | 1.00 | 7.00 | 9.46 | | | | |
| 5 | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 2.00 | 2.70 | | | | 0.91 |
| 1 FORCE | 1.00 | 1.00 | 1.00 | 0.00 | 1.00 | 0.00 | 4.00 | 5.40 | 3.63 | 1.27 | 1.13 | |
| 2 | 2.00 | 2.00 | 4.00 | 0.00 | 0.00 | 0.00 | 8.00 | 10.81 | | | | |
| 3 | 7.00 | 3.00 | 7.00 | 0.00 | 0.00 | 0.00 | 17.00 | 22.97 | | | | |
| 4 | 11.00 | 4.00 | 9.00 | 1.00 | 0.00 | 2.00 | 27.00 | 36.48 | | | | |
| 5 | 8.00 | 2.00 | 7.00 | 1.00 | 0.00 | 0.00 | 18.00 | 24.32 | | | | 0.99 |
| 1 MECHS | 1.00 | 0.00 | 1.00 | 0.00 | 1.00 | 0.00 | 3.00 | 4.05 | 3.75 | 1.31 | 1.14 | |
| 2 | 3.00 | 1.00 | 4.00 | 0.00 | 0.00 | 0.00 | 8.00 | 10.81 | | | | |
| 3 | 7.00 | 2.00 | 7.00 | 0.00 | 0.00 | 1.00 | 17.00 | 22.97 | | | | |
| 4 | 7.00 | 6.00 | 8.00 | 0.00 | 0.00 | 1.00 | 22.00 | 29.73 | | | | |
| 5 | 11.00 | 3.00 | 8.00 | 2.00 | 0.00 | 0.00 | 24.00 | 32.43 | | | | 0.97 |
| 1 MATS | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 2.00 | 2.70 | 3.66 | 1.13 | 1.06 | |
| 2 | 4.00 | 0.00 | 4.00 | 0.00 | 1.00 | 0.00 | 9.00 | 12.16 | | | | |
| 3 | 7.00 | 3.00 | 9.00 | 0.00 | 0.00 | 0.00 | 19.00 | 25.67 | | | | |
| 4 | 9.00 | 7.00 | 7.00 | 1.00 | 0.00 | 2.00 | 26.00 | 35.13 | | | | |
| 5 | 8.00 | 2.00 | 7.00 | 1.00 | 0.00 | 0.00 | 18.00 | 24.32 | | | | 0.97 |
| 1 PNEUM | 13.00 | 5.00 | 13.00 | 0.00 | 1.00 | 1.00 | 33.00 | 44.59 | 2.05 | 1.47 | 1.21 | |
| 2 | 9.00 | 2.00 | 7.00 | 0.00 | 0.00 | 1.00 | 19.00 | 25.67 | | | | |
| 3 | 4.00 | 2.00 | 5.00 | 0.00 | 0.00 | 0.00 | 11.00 | 14.86 | | | | |
| 4 | 2.00 | 2.00 | 2.00 | 1.00 | 0.00 | 0.00 | 7.00 | 9.46 | | | | |
| 5 | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 4.00 | 5.40 | | | | 0.86 |
| 1 COMPU | 8.00 | 3.00 | 8.00 | 0.00 | 1.00 | 1.00 | 21.00 | 28.38 | 2.40 | 1.45 | 1.20 | |
| 2 | 9.00 | 4.00 | 7.00 | 1.00 | 0.00 | 0.00 | 21.00 | 28.38 | | | | |
| 3 | 5.00 | 2.00 | 8.00 | 1.00 | 0.00 | 1.00 | 17.00 | 22.97 | | | | |
| 4 | 4.00 | 3.00 | 4.00 | 0.00 | 0.00 | 0.00 | 11.00 | 14.86 | | | | |
| 5 | 3.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 4.00 | 5.40 | | | | 0.74 |

| | DERBYS | LINCS | STAFFS | ENGLAND | TOTALS | | MEAN | F-RATIO | VARIANC | STAND | STAND | NO-ASSO | PMLCC | PMLCC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| : | | | | | JAN1987 | % | R+../B7 | 5% | | DEVIAT | ERRORR | TEST | CORR.CO | SQUARED |
| ; | 22.00 | 17.00 | 22.00 | 13.00 | | | | FT=9.60 | | | 5%LEVEL | | | |
| | | | | | | | | | | | | | | % |
| . | 3.00 | 4.00 | 4.00 | 3.00 | 14.00 | 18.92 | 2.70 | 1.19 | 1.50 | 1.22 | 0.28 | 7.26 | | |
| | 5.00 | 4.00 | 7.00 | 5.00 | 21.00 | 28.38 | | | | | | | | |
| | 7.00 | 5.00 | 5.00 | 1.00 | 18.00 | 24.32 | | | | | | | | |
| | 5.00 | 3.00 | 4.00 | 3.00 | 15.00 | 20.27 | | | | | | | | |
| | 2.00 | 1.00 | 2.00 | 1.00 | 6.00 | 8.11 | | | | | | | 0.85 | 72.25 |
| T | 5.00 | 5.00 | 2.00 | 5.00 | 17.00 | 22.97 | 2.63 | 1.24 | 1.49 | 1.22 | 0.28 | 6.75 | | |
| | 6.00 | 4.00 | 6.00 | 0.00 | 16.00 | 21.62 | | | | | | | | |
| | 8.00 | 6.00 | 8.00 | 2.00 | 22.00 | 29.73 | | | | | | | | |
| | 2.00 | 1.00 | 3.00 | 5.00 | 11.00 | 14.86 | | | | | | | | |
| | 1.00 | 1.00 | 3.00 | 1.00 | 6.00 | 8.11 | | | | | | | 0.79 | 62.41 |
| S | 4.00 | 5.00 | 6.00 | 3.00 | 16.00 | 21.62 | 2.56 | 1.04 | 1.43 | 1.21 | 0.28 | 5.21 | | |
| | 6.00 | 1.00 | 6.00 | 4.00 | 17.00 | 22.97 | | | | | | | | |
| | 6.00 | 9.00 | 2.00 | 4.00 | 16.00 | 21.62 | | | | | | | | |
| | 4.00 | 1.00 | 6.00 | 2.00 | 13.00 | 17.56 | | | | | | | | |
| | 2.00 | 1.00 | 2.00 | 0.00 | 5.00 | 6.75 | | | | | | | 0.61 | 37.21 |
| R | 7.00 | 7.00 | 8.00 | 7.00 | 29.00 | 39.19 | 2.06 | 1.19 | 1.21 | 1.10 | 0.25 | 7.77 | | |
| | 8.00 | 3.00 | 8.00 | 3.00 | 22.00 | 29.73 | | | | | | | | |
| | 4.00 | 5.00 | 3.00 | 2.00 | 14.00 | 18.92 | | | | | | | | |
| | 2.00 | 2.00 | 2.00 | 1.00 | 7.00 | 9.46 | | | | | | | | |
| | 1.00 | 0.00 | 1.00 | 0.00 | 2.00 | 2.70 | | | | | | | 0.91 | 82.81 |
| E | 1.00 | 1.00 | 1.00 | 1.00 | 4.00 | 5.40 | 3.63 | 1.22 | 1.27 | 1.13 | 0.26 | 8.45 | | |
| | 5.00 | 0.00 | 2.00 | 1.00 | 8.00 | 10.81 | | | | | | | | |
| | 2.00 | 4.00 | 6.00 | 5.00 | 17.00 | 22.97 | | | | | | | | |
| | 6.00 | 8.00 | 9.00 | 4.00 | 27.00 | 36.48 | | | | | | | | |
| | 8.00 | 4.00 | 4.00 | 2.00 | 18.00 | 24.32 | | | | | | | 0.99 | 98.01 |
| S | 1.00 | 1.00 | 1.00 | 0.00 | 3.00 | 4.05 | 3.75 | 1.28 | 1.31 | 1.14 | 0.26 | 8.28 | | |
| | 3.00 | 2.00 | 3.00 | 0.00 | 8.00 | 10.81 | | | | | | | | |
| | 5.00 | 5.00 | 5.00 | 2.00 | 17.00 | 22.97 | | | | | | | | |
| | 7.00 | 5.00 | 6.00 | 4.00 | 22.00 | 29.73 | | | | | | | | |
| | 6.00 | 4.00 | 7.00 | 7.00 | 24.00 | 32.43 | | | | | | | 0.97 | 94.09 |
| | 1.00 | 0.00 | 1.00 | 0.00 | 2.00 | 2.70 | 3.66 | 1.09 | 1.13 | 1.06 | 0.24 | 8.28 | | |
| | 3.00 | 2.00 | 2.00 | 2.00 | 9.00 | 12.16 | | | | | | | | |
| | 6.00 | 6.00 | 5.00 | 2.00 | 19.00 | 25.67 | | | | | | | | |
| | 8.00 | 5.00 | 8.00 | 5.00 | 27.00 | 36.48 | | | | | | | | |
| | 4.00 | 4.00 | 6.00 | 4.00 | 18.00 | 24.32 | | | | | | | 0.97 | 94.09 |
| 1 | 6.00 | 5.00 | 3.00 | 7.00 | 33.00 | 44.59 | 2.05 | 1.16 | 1.21 | 1.21 | 0.28 | 7.34 | | |
| | 6.00 | 5.00 | 6.00 | 4.00 | 19.00 | 25.67 | | | | | | | | |
| | 4.00 | 4.00 | 8.00 | 1.00 | 11.00 | 14.86 | | | | | | | | |
| | 5.00 | 2.00 | 4.00 | 0.00 | 7.00 | 9.46 | | | | | | | | |
| | 1.00 | 1.00 | 1.00 | 1.00 | 4.00 | 5.40 | | | | | | | 0.86 | 73.96 |
| J | 6.00 | 7.00 | 4.00 | 4.00 | 21.00 | 28.38 | 2.40 | 1.12 | 1.45 | 1.20 | 0.27 | 6.32 | | |
| | 4.00 | 4.00 | 8.00 | 5.00 | 21.00 | 28.38 | | | | | | | | |
| | 6.00 | 5.00 | 5.00 | 1.00 | 17.00 | 22.97 | | | | | | | | |
| | 4.00 | 1.00 | 4.00 | 2.00 | 11.00 | 14.86 | | | | | | | | |
| | 2.00 | 0.00 | 1.00 | 1.00 | 4.00 | 5.40 | | | | | | | 0.74 | 54.76 |

| omni calc | COMP 11-18 | HIGH 13-18 | COMP 11-16 | MIDDLE 11-14 | PRIMARY | GRA/IND | TOTALS JAN1987 | % | MEAN R+../B7 | VARIANC | STAND DEVIAT | PPMLCC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q11 | | | | | | | | | | | | |
| 1 ANAL | 4.00 | 2.00 | 1.00 | 0.00 | 0.00 | 0.00 | 7.00 | 9.46 | 3.42 | 1.26 | 1.12 | |
| 2 | 2.00 | 2.00 | 2.00 | 0.00 | 0.00 | 0.00 | 6.00 | 8.11 | | | | |
| 3 | 10.00 | 4.00 | 4.00 | 1.00 | 0.00 | 1.00 | 20.00 | 27.02 | | | | |
| 4 | 9.00 | 3.00 | 16.00 | 1.00 | 1.00 | 1.00 | 31.00 | 41.89 | | | | |
| 5 | 4.00 | 1.00 | 5.00 | 0.00 | 0.00 | 0.00 | 10.00 | 13.51 | | | | |
| 1 DIGIT | 2.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 3.00 | 4.05 | 3.59 | 1.20 | 1.09 | |
| 2 | 3.00 | 1.00 | 4.00 | 0.00 | 0.00 | 0.00 | 8.00 | 10.81 | | | | |
| 3 | 8.00 | 2.00 | 10.00 | 1.00 | 1.00 | 1.00 | 23.00 | 31.08 | | | | |
| 4 | 8.00 | 4.00 | 8.00 | 1.00 | 0.00 | 1.00 | 22.00 | 29.73 | | | | |
| 5 | 8.00 | 5.00 | 5.00 | 0.00 | 0.00 | 0.00 | 18.00 | 24.32 | | | | |
| 1 SYSTS | 3.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 4.00 | 5.40 | 3.77 | 1.38 | 1.17 | |
| 2 | 2.00 | 1.00 | 3.00 | 0.00 | 0.00 | 0.00 | 6.00 | 8.11 | | | | |
| 3 | 6.00 | 3.00 | 8.00 | 1.00 | 0.00 | 1.00 | 19.00 | 25.67 | | | | |
| 4 | 8.00 | 3.00 | 7.00 | 0.00 | 0.00 | 1.00 | 19.00 | 25.67 | | | | |
| 5 | 10.00 | 5.00 | 9.00 | 1.00 | 1.00 | 0.00 | 26.00 | 35.13 | | | | |
| 1 INSTR | 10.00 | 2.00 | 9.00 | 0.00 | 1.00 | 0.00 | 22.00 | 35.48 | 2.38 | 1.44 | 1.20 | |
| 2 | 6.00 | 3.00 | 8.00 | 1.00 | 0.00 | 1.00 | 19.00 | 25.67 | | | | |
| 3 | 7.00 | 5.00 | 8.00 | 0.00 | 0.00 | 1.00 | 21.00 | 28.38 | | | | |
| 4 | 4.00 | 1.00 | 2.00 | 0.00 | 0.00 | 0.00 | 7.00 | 9.46 | | | | |
| 5 | 2.00 | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 5.00 | 6.75 | | | | |
| 1 FORCE | 2.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 3.00 | 4.05 | 3.79 | 1.04 | 1.02 | |
| 2 | 2.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 3.00 | 4.05 | | | | |
| 3 | 7.00 | 5.00 | 7.00 | 0.00 | 1.00 | 0.00 | 20.00 | 27.02 | | | | |
| 4 | 11.00 | 4.00 | 10.00 | 1.00 | 0.00 | 2.00 | 28.00 | 37.83 | | | | |
| 5 | 7.00 | 3.00 | 9.00 | 1.00 | 0.00 | 0.00 | 20.00 | 27.02 | | | | |
| 1 MECHS | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 2.00 | 2.70 | 3.78 | 1.02 | 1.01 | |
| 2 | 3.00 | 0.00 | 2.00 | 0.00 | 0.00 | 0.00 | 5.00 | 6.75 | | | | |
| 3 | 8.00 | 2.00 | 9.00 | 0.00 | 1.00 | 0.00 | 20.00 | 27.02 | | | | |
| 4 | 9.00 | 6.00 | 9.00 | 1.00 | 0.00 | 2.00 | 27.00 | 36.48 | | | | |
| 5 | 8.00 | 4.00 | 7.00 | 1.00 | 0.00 | 0.00 | 20.00 | 27.02 | | | | |
| 1 MATS | 0.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 2.00 | 2.70 | 3.92 | 1.03 | 1.01 | |
| 2 | 3.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 4.00 | 5.40 | | | | |
| 3 | 5.00 | 4.00 | 7.00 | 0.00 | 1.00 | 0.00 | 17.00 | 22.97 | | | | |
| 4 | 11.00 | 4.00 | 10.00 | 0.00 | 0.00 | 1.00 | 26.00 | 35.13 | | | | |
| 5 | 10.00 | 3.00 | 9.00 | 2.00 | 0.00 | 1.00 | 25.00 | 33.78 | | | | |
| 1 PNEUM | 3.00 | 2.00 | 9.00 | 0.00 | 1.00 | 0.00 | 15.00 | 20.27 | 2.51 | 1.40 | 1.18 | |
| 2 | 11.00 | 4.00 | 8.00 | 1.00 | 0.00 | 2.00 | 26.00 | 35.13 | | | | |
| 3 | 9.00 | 3.00 | 8.00 | 0.00 | 0.00 | 0.00 | 20.00 | 27.02 | | | | |
| 4 | 2.00 | 2.00 | 2.00 | 0.00 | 0.00 | 0.00 | 6.00 | 8.11 | | | | |
| 5 | 4.00 | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 7.00 | 9.46 | | | | |
| 1 COMP | 2.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 4.00 | 5.40 | 3.47 | 1.29 | 1.13 | |
| 2 | 4.00 | 2.00 | 4.00 | 0.00 | 0.00 | 0.00 | 10.00 | 13.51 | | | | |
| 3 | 10.00 | 2.00 | 10.00 | 0.00 | 0.00 | 1.00 | 23.00 | 31.08 | | | | |
| 4 | 8.00 | 2.00 | 9.00 | 1.00 | 0.00 | 1.00 | 21.00 | 28.38 | | | | |
| 5 | 5.00 | 5.00 | 4.00 | 1.00 | 1.00 | 0.00 | 16.00 | 21.62 | | | | |

| omni calc | DERBYS | LINCS | STAFFS | ENGLAND | TOTALS JAN1987 | % | MEAN R+../B7 | F-RATIO 5% | VARIANC | STAND DEVIAT | STAND ERRORR | NO-ASSO TEST | PMLCC CORR.CO | PMLCC SQUARE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q11 | | | | | | | | | | | | | | |
| 1 ANAL | 1.00 | 2.00 | 2.00 | 2.00 | 7.00 | 9.46 | 3.42 | | 1.26 | 1.12 | 0.26 | | | |
| 2 | 1.00 | 2.00 | 1.00 | 2.00 | 6.00 | 8.11 | | | | | | | | |
| 3 | 4.00 | 5.00 | 8.00 | 3.00 | 20.00 | 27.02 | | | | | | | | |
| 4 | 13.00 | 6.00 | 8.00 | 4.00 | 23.00 | 31.08 | | | | | | | | |
| 5 | 3.00 | 2.00 | 3.00 | 2.00 | 10.00 | 13.51 | | | | | | | | |
| 1 DIGIT | 0.00 | 1.00 | 0.00 | 2.00 | 3.00 | 4.05 | 3.59 | | 1.20 | 1.20 | 0.27 | | | |
| 2 | 3.00 | 2.00 | 1.00 | 2.00 | 8.00 | 10.81 | | | | | | | | |
| 3 | 7.00 | 6.00 | 6.00 | 4.00 | 23.00 | 31.08 | | | | | | | | |
| 4 | 6.00 | 6.00 | 7.00 | 3.00 | 22.00 | 29.73 | | | | | | | | |
| 5 | 6.00 | 2.00 | 8.00 | 2.00 | 18.00 | 24.32 | | | | | | | | |
| 1 SYSTS | 1.00 | 1.00 | 0.00 | 2.00 | 4.00 | 5.40 | 3.77 | | 1.38 | 1.17 | 0.27 | | | |
| 2 | 2.00 | 2.00 | 1.00 | 1.00 | 6.00 | 8.11 | | | | | | | | |
| 3 | 8.00 | 5.00 | 5.00 | 3.00 | 19.00 | 25.67 | | | | | | | | |
| 4 | 4.00 | 2.00 | 7.00 | 4.00 | 19.00 | 25.67 | | | | | | | | |
| 5 | 7.00 | 7.00 | 9.00 | 3.00 | 26.00 | 35.13 | | | | | | | | |
| 1 INSTR | 6.00 | 8.00 | 4.00 | 4.00 | 22.00 | 35.48 | 2.38 | | 1.44 | 1.44 | 0.33 | | | |
| 2 | 7.00 | 2.00 | 7.00 | 3.00 | 19.00 | 25.67 | | | | | | | | |
| 3 | 6.00 | 4.00 | 7.00 | 4.00 | 21.00 | 28.38 | | | | | | | | |
| 4 | 1.00 | 2.00 | 3.00 | 1.00 | 7.00 | 9.46 | | | | | | | | |
| 5 | 2.00 | 1.00 | 1.00 | 1.00 | 5.00 | 6.75 | | | | | | | | |
| 1 FORCE | 1.00 | 1.00 | 1.00 | 0.00 | 3.00 | 4.05 | 3.79 | | 1.04 | 1.04 | 0.24 | | | |
| 2 | 1.00 | 1.00 | 1.00 | 0.00 | 3.00 | 4.05 | | | | | | | | |
| 3 | 6.00 | 4.00 | 3.00 | 7.00 | 20.00 | 27.02 | | | | | | | | |
| 4 | 7.00 | 7.00 | 9.00 | 5.00 | 28.00 | 37.83 | | | | | | | | |
| 5 | 7.00 | 4.00 | 8.00 | 1.00 | 20.00 | 27.02 | | | | | | | | |
| 1 MECHS | 1.00 | 0.00 | 1.00 | 0.00 | 2.00 | 2.70 | 3.78 | | 1.02 | 1.01 | 0.23 | | | |
| 2 | 1.00 | 2.00 | 1.00 | 1.00 | 5.00 | 6.75 | | | | | | | | |
| 3 | 6.00 | 6.00 | 7.00 | 1.00 | 20.00 | 27.02 | | | | | | | | |
| 4 | 6.00 | 5.00 | 7.00 | 9.00 | 27.00 | 36.48 | | | | | | | | |
| 5 | 8.00 | 4.00 | 6.00 | 2.00 | 20.00 | 27.02 | | | | | | | | |
| 1 MATS | 1.00 | 0.00 | 0.00 | 1.00 | 2.00 | 2.70 | 3.92 | | 1.03 | 1.01 | 0.23 | | | |
| 2 | 1.00 | 1.00 | 1.00 | 1.00 | 4.00 | 5.40 | | | | | | | | |
| 3 | 3.00 | 5.00 | 8.00 | 1.00 | 17.00 | 22.97 | | | | | | | | |
| 4 | 8.00 | 6.00 | 6.00 | 6.00 | 26.00 | 35.13 | | | | | | | | |
| 5 | 9.00 | 5.00 | 7.00 | 4.00 | 25.00 | 33.78 | | | | | | | | |
| 1 PNEUM | 4.00 | 3.00 | 6.00 | 2.00 | 15.00 | 20.27 | 2.51 | | 1.40 | 1.18 | 0.27 | | | |
| 2 | 5.00 | 7.00 | 5.00 | 9.00 | 22.00 | 29.73 | | | | | | | | |
| 3 | 7.00 | 4.00 | 9.00 | 0.00 | 18.00 | 24.32 | | | | | | | | |
| 4 | 3.00 | 1.00 | 1.00 | 1.00 | 6.00 | 8.11 | | | | | | | | |
| 5 | 3.00 | 2.00 | 1.00 | 1.00 | 7.00 | 9.46 | | | | | | | | |
| 1 COMP | 2.00 | 1.00 | 1.00 | 0.00 | 4.00 | 5.40 | 3.47 | | 1.29 | 1.13 | 0.26 | | | |
| 2 | 3.00 | 3.00 | 2.00 | 2.00 | 10.00 | 13.51 | | | | | | | | |
| 3 | 7.00 | 2.00 | 8.00 | 6.00 | 23.00 | 31.08 | | | | | | | | |
| 4 | 8.00 | 3.00 | 6.00 | 4.00 | 21.00 | 28.38 | | | | | | | | |
| 5 | 2.00 | 8.00 | 5.00 | 1.00 | 16.00 | 21.62 | | | | | | | | |

| omni calc | DERBYS | LINCS | STAFFS | ENGLAND | TOTALS JAN1987 | % | MEAN R+../B7 | F-RATIO 5% | VARIANC | STAND DEVIAT | STAND ERRORR | NO-ASSO TEST | PMLCC CORR.CO | PML SQL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q12 | | | | | | | | | | | | | | |
| AL ISOL | 6.00 | 2.00 | 5.00 | 0.00 | 13.00 | 17.56 | 1.85 | | 0.48 | 0.69 | | | | |
| SOME | 15.00 | 9.00 | 11.00 | 1.00 | 37.00 | 50.00 | | | | | | | | |
| NEVER | 8.00 | 1.00 | 12.00 | 1.00 | 24.00 | 32.43 | | | | | | | | |
| Q13 | | | | | | | | | | | | | | |
| AL LEAD | 6.00 | 3.00 | 8.00 | 1.00 | 20.00 | 27.02 | 2.20 | | 0.30 | 0.55 | | | | |
| SOME | 21.00 | 9.00 | 17.00 | 1.00 | 49.00 | 66.21 | | | | | | | | |
| NEVER | 2.00 | 0.00 | 3.00 | 0.00 | 5.00 | 6.75 | | | | | | | | |
| Q14 | | | | | | | | | | | | | | |
| AL OPEN | 10.00 | 1.00 | 8.00 | 0.00 | 19.00 | 25.67 | 2.20 | | 0.27 | 0.52 | | | | |
| SOME | 19.00 | 10.00 | 18.00 | 1.00 | 51.00 | 68.92 | | | | | | | | |
| NEVER | 0.00 | 1.00 | 2.00 | 1.00 | 4.00 | 5.40 | | | | | | | | |
| Q15 | | | | | | | | | | | | | | |
| AL ELEC | 16.00 | 5.00 | 8.00 | 0.00 | 30.00 | 40.54 | 2.21 | | 0.55 | 0.74 | | | | |
| SOME | 10.00 | 5.00 | 13.00 | 1.00 | 30.00 | 40.54 | | | | | | | | |
| NEVER | 3.00 | 2.00 | 7.00 | 1.00 | 14.00 | 18.92 | | | | | | | | |
| Q16 | | | | | | | | | | | | | | |
| AL SEP | 8.00 | 3.00 | 10.00 | 0.00 | 22.00 | 29.73 | 2.11 | | 0.48 | 0.69 | | | | |
| SOME | 15.00 | 6.00 | 15.00 | 1.00 | 38.00 | 51.35 | | | | | | | | |
| NEVER | 6.00 | 3.00 | 3.00 | 1.00 | 14.00 | 18.92 | | | | | | | | |
| Q17 | | | | | | | | | | | | | | |
| AL POLI | 14.00 | 5.00 | 9.00 | 1.00 | 30.00 | 40.54 | 2.19 | | 0.59 | 0.77 | | | | |
| SOME | 8.00 | 4.00 | 13.00 | 1.00 | 28.00 | 37.83 | | | | | | | | |
| NEVER | 7.00 | 3.00 | 6.00 | 0.00 | 16.00 | 21.62 | | | | | | | | |
| Q18 | | | | | | | | | | | | | | |
| AL ANAL | 8.00 | 3.00 | 15.00 | 1.00 | 28.00 | 37.83 | 2.12 | | 0.63 | 0.79 | | | | |
| SOME | 14.00 | 5.00 | 8.00 | 0.00 | 27.00 | 36.48 | | | | | | | | |
| NEVER | 7.00 | 4.00 | 5.00 | 1.00 | 19.00 | 25.67 | | | | | | | | |
| Q19 | | | | | | | | | | | | | | |
| AL SYST | 8.00 | 5.00 | 11.00 | 2.00 | 28.00 | 37.83 | 2.11 | | 0.64 | 0.80 | | | | |
| SOME | 12.00 | 6.00 | 8.00 | 0.00 | 26.00 | 35.13 | | | | | | | | |
| NEVER | 9.00 | 1.00 | 9.00 | 0.00 | 20.00 | 27.02 | | | | | | | | |
| Q20 | | | | | | | | | | | | | | |
| AL BEFO | 2.00 | 1.00 | 2.00 | 0.00 | 5.00 | 7.93 | 1.47 | | 0.35 | 0.59 | | | | |
| SOME | 9.00 | 3.00 | 7.00 | 0.00 | 20.00 | 31.74 | | | | | | | | |
| NEVER | 12.00 | 9.00 | 13.00 | 2.00 | 38.00 | 60.31 | | | | | | | | |
| AL INVE | 9.00 | 1.00 | 11.00 | 0.00 | 22.00 | 33.84 | 2.26 | | 0.31 | 0.55 | | | | |
| SOME | 15.00 | 9.00 | 10.00 | 2.00 | 38.00 | 58.46 | | | | | | | | |
| NEVER | 2.00 | 0.00 | 3.00 | 0.00 | 5.00 | 7.69 | | | | | | | | |
| AL ASS | 10.00 | 3.00 | 11.00 | 0.00 | 25.00 | 39.68 | 2.20 | | 0.47 | 0.68 | | | | |
| SOME | 8.00 | 5.00 | 9.00 | 2.00 | 26.00 | 41.27 | | | | | | | | |
| NEVER | 7.00 | 2.00 | 3.00 | 0.00 | 12.00 | 19.04 | | | | | | | | |
| AL AFT | 9.00 | 2.00 | 9.00 | 1.00 | 21.00 | 35.59 | 2.23 | | 0.34 | 0.58 | | | | |
| SOME | 12.00 | 6.00 | 10.00 | 1.00 | 31.00 | 52.54 | | | | | | | | |
| NEVER | 3.00 | 1.00 | 2.00 | 0.00 | 7.00 | 11.86 | | | | | | | | |
| AL NOT | 4.00 | 1.00 | 1.00 | 2.00 | 8.00 | 14.54 | 1.65 | | 0.39 | 0.62 | | | | |
| SOME | 7.00 | 3.00 | 8.00 | 0.00 | 20.00 | 36.36 | | | | | | | | |
| NEVER | 13.00 | 4.00 | 9.00 | 0.00 | 27.00 | 49.09 | | | | | | | | |

| [illegible] calc | COMP 11-18 | HIGH 13-18 | COMP 11-16 | MIDDLE 11-14 | PRIMARY | GRA/IND | TOTALS JAN1987 | % | MEAN R+../B7 | VARIANC | STAND DEVIAT | PPMLCC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q12 | | | | | | | | | | | | |
| AL ISOL | 6.00 | 2.00 | 5.00 | 0.00 | 0.00 | 0.00 | 13.00 | 17.56 | 1.85 | 0.48 | 0.69 | |
| SOME | 15.00 | 9.00 | 11.00 | 1.00 | 0.00 | 1.00 | 37.00 | 50.00 | | | | |
| NEVER | 8.00 | 1.00 | 12.00 | 1.00 | 1.00 | 1.00 | 24.00 | 32.43 | | | | |
| Q13 | | | | | | | | | | | | |
| AL LEAD | 6.00 | 3.00 | 8.00 | 1.00 | 1.00 | 1.00 | 20.00 | 27.02 | 2.20 | 0.30 | 0.55 | |
| SOME | 21.00 | 9.00 | 17.00 | 1.00 | 0.00 | 1.00 | 49.00 | 66.21 | | | | |
| NEVER | 2.00 | 0.00 | 3.00 | 0.00 | 0.00 | 0.00 | 5.00 | 6.75 | | | | |
| Q14 | | | | | | | | | | | | |
| AL OPEN | 10.00 | 1.00 | 8.00 | 0.00 | 0.00 | 0.00 | 19.00 | 25.67 | 2.20 | 0.27 | 0.52 | |
| SOME | 19.00 | 10.00 | 18.00 | 1.00 | 1.00 | 2.00 | 51.00 | 68.92 | | | | |
| NEVER | 0.00 | 1.00 | 2.00 | 1.00 | 0.00 | 0.00 | 4.00 | 5.40 | | | | |
| Q15 | | | | | | | | | | | | |
| AL ELEC | 16.00 | 5.00 | 8.00 | 0.00 | 0.00 | 1.00 | 30.00 | 40.54 | 2.21 | 0.55 | 0.74 | |
| SOME | 10.00 | 5.00 | 13.00 | 1.00 | 0.00 | 1.00 | 30.00 | 40.54 | | | | |
| NEVER | 3.00 | 2.00 | 7.00 | 1.00 | 1.00 | 0.00 | 14.00 | 18.92 | | | | |
| Q16 | | | | | | | | | | | | |
| AL SEP | 8.00 | 3.00 | 10.00 | 0.00 | 1.00 | 0.00 | 22.00 | 29.73 | 2.11 | 0.48 | 0.69 | |
| SOME | 15.00 | 6.00 | 15.00 | 1.00 | 0.00 | 1.00 | 38.00 | 51.35 | | | | |
| NEVER | 6.00 | 3.00 | 3.00 | 1.00 | 0.00 | 1.00 | 14.00 | 18.92 | | | | |
| Q17 | | | | | | | | | | | | |
| AL POLI | 14.00 | 5.00 | 9.00 | 1.00 | 0.00 | 1.00 | 30.00 | 40.54 | 2.19 | 0.59 | 0.77 | |
| SOME | 8.00 | 4.00 | 13.00 | 1.00 | 1.00 | 1.00 | 28.00 | 37.83 | | | | |
| NEVER | 7.00 | 3.00 | 6.00 | 0.00 | 0.00 | 0.00 | 16.00 | 21.62 | | | | |
| Q18 | | | | | | | | | | | | |
| AL ANAL | 8.00 | 3.00 | 15.00 | 1.00 | 0.00 | 1.00 | 28.00 | 37.83 | 2.12 | 0.63 | 0.79 | |
| SOME | 14.00 | 5.00 | 8.00 | 0.00 | 0.00 | 0.00 | 27.00 | 36.48 | | | | |
| NEVER | 7.00 | 4.00 | 5.00 | 1.00 | 1.00 | 1.00 | 19.00 | 25.67 | | | | |
| Q19 | | | | | | | | | | | | |
| AL SYST | 8.00 | 5.00 | 11.00 | 2.00 | 1.00 | 1.00 | 28.00 | 37.83 | 2.11 | 0.64 | 0.80 | |
| SOME | 12.00 | 6.00 | 8.00 | 0.00 | 0.00 | 0.00 | 26.00 | 35.13 | | | | |
| NEVER | 9.00 | 1.00 | 9.00 | 0.00 | 0.00 | 1.00 | 20.00 | 27.02 | | | | |
| Q20 | | | | | | | | | | | | |
| AL BEFO | 2.00 | 1.00 | 2.00 | 0.00 | 0.00 | 0.00 | 5.00 | 7.93 | 1.47 | 0.35 | 0.59 | |
| SOME | 9.00 | 3.00 | 7.00 | 0.00 | 0.00 | 1.00 | 20.00 | 31.74 | | | | |
| NEVER | 12.00 | 9.00 | 13.00 | 2.00 | 1.00 | 1.00 | 38.00 | 60.31 | | | | |
| AL INVE | 9.00 | 1.00 | 11.00 | 0.00 | 0.00 | 1.00 | 22.00 | 33.84 | 2.26 | 0.31 | 0.55 | |
| SOME | 15.00 | 9.00 | 10.00 | 2.00 | 1.00 | 1.00 | 38.00 | 58.46 | | | | |
| NEVER | 2.00 | 0.00 | 3.00 | 0.00 | 0.00 | 0.00 | 5.00 | 7.69 | | | | |
| AL ASS | 10.00 | 3.00 | 11.00 | 0.00 | 0.00 | 1.00 | 25.00 | 39.68 | 2.20 | 0.47 | 0.68 | |
| SOME | 8.00 | 5.00 | 9.00 | 2.00 | 1.00 | 1.00 | 26.00 | 41.27 | | | | |
| NEVER | 7.00 | 2.00 | 3.00 | 0.00 | 0.00 | 0.00 | 12.00 | 19.04 | | | | |
| AL AFT | 9.00 | 2.00 | 9.00 | 1.00 | 0.00 | 0.00 | 21.00 | 35.59 | 2.23 | 0.34 | 0.58 | |
| SOME | 12.00 | 6.00 | 10.00 | 1.00 | 1.00 | 1.00 | 31.00 | 52.54 | | | | |
| NEVER | 3.00 | 1.00 | 2.00 | 0.00 | 0.00 | 1.00 | 7.00 | 11.86 | | | | |
| AL NOT | 4.00 | 1.00 | 1.00 | 2.00 | 0.00 | 0.00 | 8.00 | 14.54 | 1.65 | 0.39 | 0.62 | |
| SOME | 7.00 | 3.00 | 8.00 | 0.00 | 1.00 | 1.00 | 20.00 | 36.36 | | | | |
| NEVER | 13.00 | 4.00 | 9.00 | 0.00 | 0.00 | 1.00 | 27.00 | 49.09 | | | | |

| omni calc | COMP 11-18 | HIGH 13-18 | COMP 11-16 | MIDDLE 11-14 | PRIMARY | GRA/IND | TOTALS JAN1987 | % | MEAN R+../B7 | VARIANC | STAND DEVIAT | JJP GOODY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q21 | | | | | | | | | | | | |
| 1 T/EX | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 2.00 | 2.70 | 4.08 | 1.09 | 1.04 | |
| 2 | 1.00 | 1.00 | 3.00 | 0.00 | 0.00 | 0.00 | 5.00 | 6.75 | | | | |
| 3 | 3.00 | 2.00 | 4.00 | 1.00 | 0.00 | 0.00 | 10.00 | 13.51 | | | | |
| 4 | 9.00 | 4.00 | 9.00 | 1.00 | 1.00 | 1.00 | 25.00 | 33.78 | | | | |
| 5 | 15.00 | 5.00 | 11.00 | 0.00 | 0.00 | 1.00 | 32.00 | 43.24 | | | | |
| 1 T/ENT | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.35 | 0.61 | 0.78 | |
| 2 | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 2.00 | 2.70 | | | | |
| 3 | 4.00 | 0.00 | 4.00 | 0.00 | 0.00 | 0.00 | 8.00 | 10.81 | | | | |
| 4 | 10.00 | 2.00 | 13.00 | 0.00 | 0.00 | 1.00 | 26.00 | 35.13 | | | | |
| 5 | 14.00 | 10.00 | 10.00 | 2.00 | 1.00 | 1.00 | 38.00 | 51.35 | | | | |
| 1 SCH/S | 1.00 | 1.00 | 4.00 | 0.00 | 0.00 | 0.00 | 6.00 | 8.11 | 3.40 | 1.50 | 1.22 | |
| 2 | 5.00 | 2.00 | 5.00 | 0.00 | 0.00 | 0.00 | 12.00 | 16.21 | | | | |
| 3 | 7.00 | 3.00 | 6.00 | 1.00 | 0.00 | 1.00 | 18.00 | 24.32 | | | | |
| 4 | 9.00 | 2.00 | 8.00 | 1.00 | 1.00 | 1.00 | 22.00 | 29.73 | | | | |
| 5 | 7.00 | 4.00 | 5.00 | 0.00 | 0.00 | 0.00 | 16.00 | 21.62 | | | | |
| 1 ADVIS | 3.00 | 0.00 | 5.00 | 0.00 | 0.00 | 0.00 | 8.00 | 10.81 | 3.23 | 1.68 | 1.29 | |
| 2 | 5.00 | 2.00 | 4.00 | 0.00 | 1.00 | 1.00 | 13.00 | 17.56 | | | | |
| 3 | 11.00 | 1.00 | 8.00 | 0.00 | 0.00 | 0.00 | 20.00 | 27.02 | | | | |
| 4 | 5.00 | 2.00 | 7.00 | 0.00 | 0.00 | 1.00 | 15.00 | 20.27 | | | | |
| 5 | 5.00 | 6.00 | 4.00 | 2.00 | 0.00 | 0.00 | 17.00 | 22.97 | | | | |
| 1 HMI | 12.00 | 7.00 | 12.00 | 1.00 | 1.00 | 1.00 | 34.00 | 45.94 | 2.05 | 1.47 | 1.21 | |
| 2 | 9.00 | 1.00 | 6.00 | 0.00 | 0.00 | 0.00 | 16.00 | 21.62 | | | | |
| 3 | 5.00 | 2.00 | 5.00 | 1.00 | 0.00 | 1.00 | 14.00 | 18.92 | | | | |
| 4 | 2.00 | 1.00 | 3.00 | 0.00 | 0.00 | 0.00 | 6.00 | 8.11 | | | | |
| 5 | 1.00 | 1.00 | 2.00 | 0.00 | 0.00 | 0.00 | 4.00 | 5.40 | | | | |
| 1 PU/PR | 2.00 | 1.00 | 2.00 | 0.00 | 0.00 | 0.00 | 5.00 | 6.75 | 3.23 | 1.16 | 1.07 | |
| 2 | 4.00 | 1.00 | 5.00 | 0.00 | 1.00 | 0.00 | 11.00 | 14.86 | | | | |
| 3 | 11.00 | 5.00 | 7.00 | 0.00 | 0.00 | 2.00 | 25.00 | 33.78 | | | | |
| 4 | 10.00 | 3.00 | 8.00 | 2.00 | 0.00 | 0.00 | 23.00 | 31.08 | | | | |
| 5 | 2.00 | 1.00 | 6.00 | 0.00 | 0.00 | 0.00 | 9.00 | 12.16 | | | | |
| 1 MATS | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.35 | 4.11 | 1.03 | 1.01 | |
| 2 | 1.00 | 1.00 | 3.00 | 0.00 | 0.00 | 0.00 | 5.00 | 6.75 | | | | |
| 3 | 5.00 | 1.00 | 5.00 | 0.00 | 1.00 | 1.00 | 13.00 | 17.56 | | | | |
| 4 | 8.00 | 5.00 | 6.00 | 1.00 | 0.00 | 1.00 | 21.00 | 28.38 | | | | |
| 5 | 15.00 | 5.00 | 13.00 | 1.00 | 0.00 | 0.00 | 34.00 | 45.94 | | | | |
| 1 TIME | 1.00 | 1.00 | 2.00 | 0.00 | 0.00 | 0.00 | 4.00 | 5.40 | 3.82 | 1.49 | 1.22 | |
| 2 | 3.00 | 1.00 | 4.00 | 0.00 | 0.00 | 0.00 | 8.00 | 10.81 | | | | |
| 3 | 6.00 | 3.00 | 5.00 | 0.00 | 0.00 | 0.00 | 14.00 | 18.92 | | | | |
| 4 | 8.00 | 2.00 | 6.00 | 1.00 | 0.00 | 2.00 | 19.00 | 25.67 | | | | |
| 5 | 11.00 | 5.00 | 11.00 | 1.00 | 1.00 | 0.00 | 29.00 | 39.19 | | | | |
| 1 FUND | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.35 | 4.48 | 0.61 | 0.78 | |
| 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | |
| 3 | 5.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 7.00 | 9.46 | | | | |
| 4 | 7.00 | 4.00 | 8.00 | 0.00 | 0.00 | 1.00 | 20.00 | 27.02 | | | | |
| 5 | 17.00 | 6.00 | 19.00 | 2.00 | 1.00 | 1.00 | 46.00 | 62.16 | | | | |
| 1 INSET | 2.00 | 0.00 | 2.00 | 0.00 | 0.00 | 0.00 | 4.00 | 5.40 | 3.88 | 1.39 | 1.18 | |
| 2 | 2.00 | 0.00 | 3.00 | 0.00 | 0.00 | 0.00 | 5.00 | 6.75 | | | | |
| 3 | 4.00 | 1.00 | 6.00 | 0.00 | 0.00 | 1.00 | 12.00 | 16.21 | | | | |
| 4 | 5.00 | 4.00 | 6.00 | 1.00 | 1.00 | 1.00 | 18.00 | 24.32 | | | | |
| 5 | 16.00 | 7.00 | 9.00 | 1.00 | 0.00 | 0.00 | 33.00 | 44.59 | | | | |

| omni calc | COMP 11-18 | HIGH 13-18 | COMP 11-16 | MIDDLE 11-14 | PRIMARY | GRA/IND | TOTALS JAN1987 | % | MEAN R+../B7 | VARIANC | STAND DEVIAT | JJP GOODY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q22 | | | | | | | | | | | | |
| 1 SYS | 2.00 | 0.00 | 2.00 | 0.00 | 0.00 | 0.00 | 4.00 | 5.40 | 3.35 | 1.29 | 1.14 | |
| 2 SUPP | 2.00 | 1.00 | 3.00 | 2.00 | 0.00 | 1.00 | 9.00 | 12.16 | | | | |
| 3 | 5.00 | 3.00 | 6.00 | 0.00 | 0.00 | 0.00 | 14.00 | 18.92 | | | | |
| 4 | 10.00 | 5.00 | 10.00 | 0.00 | 0.00 | 1.00 | 26.00 | 35.13 | | | | |
| 5 | 5.00 | 3.00 | 7.00 | 0.00 | 1.00 | 0.00 | 16.00 | 21.62 | | | | |
| Q22 | | | | | | | | | | | | |
| 1 ANAL | 1.00 | 1.00 | 3.00 | 0.00 | 0.00 | 0.00 | 5.00 | 6.75 | 3.19 | 1.14 | 1.07 | |
| 2 UNDER | 6.00 | 1.00 | 7.00 | 0.00 | 0.00 | 0.00 | 14.00 | 18.92 | | | | |
| 3 | 11.00 | 6.00 | 11.00 | 0.00 | 1.00 | 0.00 | 29.00 | 39.19 | | | | |
| 4 | 8.00 | 3.00 | 5.00 | 2.00 | 0.00 | 1.00 | 19.00 | 25.67 | | | | |
| 5 | 3.00 | 1.00 | 2.00 | 1.00 | 0.00 | 1.00 | 8.00 | 10.81 | | | | |
| Q22 | | | | | | | | | | | | |
| 1 SUCC | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 1.00 | 3.00 | 4.05 | 3.79 | 1.28 | 1.13 | |
| 2 WITH | 4.00 | 0.00 | 3.00 | 0.00 | 0.00 | 0.00 | 7.00 | 9.46 | | | | |
| 3 SYSTS | 6.00 | 4.00 | 7.00 | 0.00 | 0.00 | 0.00 | 17.00 | 22.97 | | | | |
| 4 | 8.00 | 3.00 | 7.00 | 2.00 | 1.00 | 1.00 | 22.00 | 29.73 | | | | |
| 5 | 10.00 | 5.00 | 10.00 | 0.00 | 0.00 | 0.00 | 25.00 | 33.78 | | | | |
| Q22 | | | | | | | | | | | | |
| 1 UNDER | 2.00 | 4.00 | 4.00 | 0.00 | 0.00 | 0.00 | 10.00 | 13.51 | 3.08 | 1.55 | 1.24 | |
| 2 PROP | 4.00 | 3.00 | 5.00 | 0.00 | 1.00 | 0.00 | 13.00 | 17.56 | | | | |
| 3 | 9.00 | 3.00 | 9.00 | 1.00 | 0.00 | 1.00 | 23.00 | 31.08 | | | | |
| 4 | 8.00 | 1.00 | 7.00 | 1.00 | 0.00 | 0.00 | 17.00 | 22.97 | | | | |
| 5 | 6.00 | 1.00 | 3.00 | 0.00 | 0.00 | 1.00 | 11.00 | 14.86 | | | | |
| Q22 | | | | | | | | | | | | |
| 1 HEART | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 2.00 | 2.70 | 4.19 | 0.97 | 0.99 | |
| 2 | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 2.00 | 2.70 | | | | |
| 3 | 5.00 | 2.00 | 5.00 | 0.00 | 0.00 | 0.00 | 12.00 | 16.21 | | | | |
| 4 | 10.00 | 1.00 | 8.00 | 2.00 | 0.00 | 1.00 | 22.00 | 29.73 | | | | |
| 5 | 12.00 | 9.00 | 14.00 | 0.00 | 1.00 | 0.00 | 36.00 | 48.65 | | | | |
| 1 LESS | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 2.00 | 2.70 | 3.66 | 1.03 | 1.01 | |
| 2 | 2.00 | 0.00 | 3.00 | 0.00 | 0.00 | 0.00 | 5.00 | 6.75 | | | | |
| 3 | 2.00 | 3.00 | 6.00 | 0.00 | 0.00 | 0.00 | 11.00 | 14.86 | | | | |
| 4 | 11.00 | 5.00 | 11.00 | 1.00 | 0.00 | 1.00 | 29.00 | 39.19 | | | | |
| 5 | 8.00 | 4.00 | 8.00 | 1.00 | 1.00 | 0.00 | 22.00 | 29.73 | | | | |
| 1 ABLE | 8.00 | 4.00 | 7.00 | 0.00 | 0.00 | 0.00 | 19.00 | 25.67 | 2.40 | 1.36 | 1.17 | |
| 2 | 9.00 | 4.00 | 10.00 | 1.00 | 1.00 | 1.00 | 26.00 | 35.13 | | | | |
| 3 | 8.00 | 2.00 | 8.00 | 0.00 | 0.00 | 0.00 | 18.00 | 24.32 | | | | |
| 4 | 3.00 | 2.00 | 2.00 | 0.00 | 0.00 | 0.00 | 7.00 | 9.46 | | | | |
| 5 | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 | 1.00 | 5.00 | 6.75 | | | | |

| omni calc | COMP 11-18 | HIGH 13-18 | COMP 11-16 | MIDDLE 11-14 | PRIMARY | GRA/IND | TOTALS JAN1987 | % | MEAN R+../B7 | VARIANC | STAND DEVIA | JJP GOODY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EXAMIN | "A" | "O" | "CSE" | MODE3 | | | | | | | | |
| CONTROL | 0.00 | 15.00 | 5.00 | 5.00 | | | 25.00 | 15.15 | | | | |
| CDT | 6.00 | 25.00 | 21.00 | 2.00 | | | 54.00 | 32.72 | | | | |
| DT | 14.00 | 18.00 | 8.00 | 1.00 | | | 41.00 | 24.85 | | | | |
| ELECT | 2.00 | 7.00 | 1.00 | 0.00 | | | 10.00 | 6.06 | | | | |
| E.SYST | 0.00 | 1.00 | 0.00 | 0.00 | | | 1.00 | 0.60 | | | | |
| ENG. SC | 0.00 | 7.00 | 6.00 | 0.00 | | | 13.00 | 7.88 | | | | |
| MODTECH | 0.00 | 12.00 | 9.00 | 0.00 | | | 21.00 | 12.72 | | | | |
| INCTECH | | | | | | | | | | | | |
| | 22.00 | 85.00 | 50.00 | 8.00 | | | 165.00 | | | | | |
| %'S | | | | | | | | | | | | |
| CONTROL | 0.00 | 17.64 | 10.00 | 62.50 | | | | | | | | |
| CDT | 27.27 | 29.41 | 42.00 | 25.00 | | | | | | | | |
| DT | 63.63 | 21.17 | 16.00 | 12.50 | | | | | | | | |
| ELECT | 9.09 | 8.23 | 2.00 | 0.00 | | | | | | | | |
| E.SYST | 0.00 | 1.17 | 0.00 | 0.00 | | | | | | | | |
| ENG. SC | 0.00 | 8.23 | 12.00 | 0.00 | | | | | | | | |
| MODTECH | 0.00 | 14.11 | 18.00 | 0.00 | | | | | | | | |
| INCTECH | | | | | | | | | | | | |
| BYTRONI | 1.00 | | | | | | | | | | | |
| C/PATHW | 2.00 | | | | | | | | | | | |
| D/TRENT | 18.00 | | | | | | | | | | | |
| E&LSYS | 1.00 | | | | | | | | | | | |
| F/TECHN | 6.00 | | | | | | | | | | | |
| GRIFFIN | 3.00 | | | | | | | | | | | |
| HARRIS | 1.00 | | | | | | | | | | | |
| LOCK/T | 13.00 | | | | | | | | | | | |
| MECCANO | 5.00 | | | | | | | | | | | |
| MEP LOG | 14.00 | | | | | | | | | | | |
| MFA | 18.00 | | | | | | | | | | | |
| S/ALPHA | 13.00 | | | | | | | | | | | |
| UNI/BLU | 5.00 | | | | | | | | | | | |
| PROTO/B | 24.00 | | | | | | | | | | | |
| C.R.O. | 27.00 | | | | | | | | | | | |
| OWN SYS | 23.00 | | | | | | | | | | | |
| BBC | 29.00 | | | | | | | 44.61 | | | | |
| ZXSPEC | 8.00 | | | | | | | 12.30 | | | | |
| ZX 81 | 16.00 | | | | | | | 24.61 | | | | |
| PET | 1.00 | | | | | | | 1.54 | | | | |
| APPLE | 2.00 | | | | | | | 3.07 | | | | |
| R.M. | 9.00 | | | | | | | 13.84 | | | | |
| CON/I.O | 25.00 | | | | | | | | | | | |
| BUGGY | 19.00 | | | | | | | | | | | |
| ROB/ARM | 7.00 | | | | | | | | | | | |
| PLOTTER | 3.00 | | | | | | | | | | | |
| CNC LAT | 4.00 | | | | | | | | | | | |
| CNC MIL | 1.00 | | | | | | | | | | | |
| AMX MOU | 6.00 | | | | | | | | | | | |
| | | COMPS. | 65.00 | 87.83 | | | | | | | | |
| | | NONE | 14.00 | 18.92 | | | | | | | | |