The development and testing of a multiple-choice programme to teach systematic fault finding in electronic equipment

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THE DEVELOPMENT AND TESTING OF A MULTIPLE-CHOICE PROGRAMME TO TEACH SYSTEMATIC FAULT FINDING IN ELECTRONIC EQUIPMENT

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WINGATE T.H. MASTER OF EDUCATION THESIS ABSTRACT

The development and testing of a multiple-choice programme to teach systematic fault finding in electronic equipment.

Fault finding, and the repair of faults, in electronic equipment used by the Royal Navy, are presenting problems which have become more and more difficult in recent years. This is due to two main factors; the first being that the increasing complexity of equipment is producing a requirement for higher levels of training, and the second factor being the difficulties surrounding the recruiting and retention of men with high levels of education and training.

Maintaining equipment in a ship at sea also presents special problems due to the measure of self-reliance which is necessitated by the ship being away from home ports for long periods.

In an attempt to overcome these problems, an investigation was commissioned to examine new methods of fault finding. The aim was to discover a new generalised method of fault finding which could be applied to all electrical and electronic equipments, and to devise a training course which would instruct men in this new method, if it improved performance.

Such a method was found, and on testing was discovered to work extremely well.

Having found the method, investigation then took place as to the best way of disseminating this information. In order that training in the new method could take place in the field, without the necessity of bringing men back to training establishments, a teaching programme of the multiple choice style was written covering the fault finding method.

This thesis covers the development and testing of the method of fault finding chosen, and the rigorous development and testing of the teaching programme.

Both the method of fault finding, and the teaching programme, have been accepted as standard for the electrical branch of the Royal Navy, the acceptance being based on the successful outcome of the investigation.

CONTENTS

INTRODUCTION

The following work covers the development of a multiple choice programme in scrambled text form, designed to teach a generalised method of Systematic Fault Finding in any electronic equipment. The development was carried out at H.M.S. COLLINGWOOD, the Royal Naval Weapons and Electrical School, whilst the author was on the instructional staff of the establishment.

This is a report on a specific aspect of the use of Programmed Instruction, and there is no generalised discussion in the text of Programmed Instruction theory and methods, or of the historical development of programmed instruction, because this would expand the work to unmanageable proportions. A general knowledge of the subject of Programmed Instruction must therefore be assumed.

Although the period of development of this programme was between November 1964 to August 1967, work was not carried out continuously during this time. However, these dates should be borne in mind when considering the following work in the context of other work carried out in this country and elsewhere. A general view of the immediate historical development of programmed instruction can easily be found.[22] A review of the other work being carried out at the time of the development covered by the following thesis may be found in the Proceedings of the 1966 Conference of the Association for Programmed Learning.[24]

The theory and methods of Programmed Instruction have already been well discussed in published works.[3,4,25,30,33]

The specific subject of the programme considered here was Systematic Fault Finding in Electronic Equipments. There has been a large amount of work on this subject,[1,5,7,16,19,32] but the work reported here represents a basically new approach. Previously the line of attack advocated was almost invariably to base the method of fault finding on a specific electronic or electric equipment. Detailed faults were given which were said to be common for that equipment, and the recommended fault finding and repair procedure was given for that fault. Moreover, it has also been usual to include a section dealing with the use of test equipment such as oscilloscopes, signal generators and meters.[42] As an example, this latter reference goes from test equipment to specialised maintenance procedures, and then to "... common faults and how to cure them..." Some fault finding courses have included such preliminary work as teaching the colour code of resistors.

This type of approach outlined above is very wasteful in time and effort for the purpose of Royal Navy electronic and electrical technicians. It is impossible to cover in detail the vast range of equipment now in service in the Royal Navy, and some generalised method is required. Moreover, test equipments and basic theory are already well covered in existing courses.

The method developed for the programme covered by this thesis differs from the above methods in both respects. Firstly, a level of knowledge of electronics was assumed comparable to the existing training requirements. This level required that trainees would have a working knowledge of circuit theory for the equipment under consideration sufficient to differentiate between normal and faulty measurements and test results. The trainees were also required to be able to operate the range of test equipment necessary for the fault finding procedure. Secondly, the method of fault finding taught in this programme was completely general and logical, and it could be applied to any electronic equipment.

The approach described in this thesis is also rather different from techniques using the Pressey Punchboard.[(22)] In the punchboard technique specific problems are posed and the punchboard is used to check answers in the fault finding sequence. This makes it more of an equipment simulator device, comparable to the Trainer Tester sheets[(54, pp28)] used for testing during the production of the method described in this thesis.

A further tool in fault finding techniques is that of the concept of signal or data flow in the circuit. This technique depends upon monitoring signals at various points in the circuit and comparing monitored signals to expected signals. It has appeared under various names, and in fact may be considered partly as related to the well-known half-split method.[21]

Use of this technique can occur in one of the stages in the fault finding method advocated in the programme covered by this thesis, but only if a schematic including the necessary signal flow data has been prepared for the equipment in question. This raises problems of the vast amount of documentation required to cover the range of equipment in service in the Royal Navy, and also in the scale of some of the schematics which would be required for the very complex equipment. If any such schematics are already available for naval equipment, then the use of these should fit into the signal tracing section of the fault finding method advocated here. If no schematics are available, the principles behind this tool of fault finding can still be used within the method advocated, and this use is in fact encouraged. Thus the tool of signal flow, which has sometimes been used as a method of fault finding complete in itself, in fact fits within the method discussed in this thesis as only one of the steps in the overall method.

It can be seen from this discussion that the programme following cannot stand as a fault finding method complete in itself. It must be preceded by general work on electronic theory and test equipment, and followed by work and experience on specific equipments. In the actual use of the programme this programmed course in fault finding was fitted into existing courses to fulfill this requirement, and to allow a logical and general method of fault finding to be used throughout the Royal Navy.

At all stages of development of the programme, extensive testing was carried out, and the total test population numbered over two hundred. At the conclusion of development and testing the work was accepted as standard practice for all electrical personnel in the Royal Navy.

In 1964, when the work was commenced, the history of Programmed Instruction in this country was very recent, and the Royal Navy, itself one of the leaders and initiators in the development of Programmed Instruction, had only been studying the subject seriously for two years. This work therefore represents an early attempt to use programmed instruction methods when compared to present day work and research. There remains a great deal of work to be done in both the programming field, and the subject of fault finding, and this can only be a beginning. The Toyal Navy is continuing extensive development of both of these subjects.

It was thought necessary to submit several items with this thesis to facilitate study of the work, and to avoid over-lengthy descriptions of technical details. A list of these items is included, but brief desrciptions are included in the text.

ITEMS SUBMITTED WITH THE THESIS

1. Systematic Fault-Finding.
   A Programmed Instruction Manual.
   Printed in H.M.S. COLLINGWOOD, July 1965.
   Reference number D.P. 65/6352.

2. Systematic Fault-Finding.
   Programmed Instruction Manual Supplement.
   Printed in H.M.S. COLLINGWOOD, July 1965.
   Reference number D.P. 65/6352b.

3. Engraved "Clue Board".

4. Printed "Clue Sheet".

5. Set of "Printechnic Trainer Tester Fault Finding sheets", comprising twenty faults based on a superheterodyne radio receiver, reference EL 53.

6. Punched "Clue Board".

7. Book of solutions to the fault finding sheets in reference 5 prepared for use with the programme under test.

CHAPTER 1.

PREPARATORY WORK

The ships now coming into service with the Royal Navy are being fitted with an ever increasing amount and complexity of electronic and electrical equipment. On commissioning the ship is often fitted with sufficient equipment in this category for the electrical branch on board to be the largest single specialisation, and this equipment is constantly being added to and modified during the life of the ship. No part of the ship is immune from these changes, from the installation of computor complexes for the weapon systems, to automatic toasters in the crew's messes.

In these circumstances, the servicing and maintenance of this electrical equipment is a task which is becoming more complex and diverse every year, besides having a steadily increasing growth rate.

The responsibility for this task of servicing and maintenance falls upon the electrical branch of the ship's complement, and the overall size of the electrical

The particular requirements of servicing and maintaining a ship whilst at sea also mean that there are special problems concerned with the training of the personnel who have been recruited. Although the ship can come into the dockyard for major overhauls and repairs, the vast majority of servicing must depend upon the unaided resources of the ship itself. The major resource of the ship is its crew, and therefore the crew must be trained to carry out any servicing and maintenance necessary without relying on dockyard assistance. As the accommodation on board a fighting ship is necessarily strictly limited, sufficient personnel cannot be carried to provide experts for each main item of equipment. Every man must be capable of performing several tasks, and every man in the electrical specialisation must be capable of servicing and maintaining several types of equipment. (35,4)

In fact a small degree of sub-specialisation in the electrical branch does take place, with the personnel divided into three main branches. These three branches are as follows :

(a) Ordnance

(b) Control

(c) Radio.

As a general guide, the duties of these sub-specialisations can be described as follows :

(a) Ordnance - Weapons systems

(b) Control - Heavy electrics

(c) Radio - All radio and radar equipment, together with associated equipment.

However, the variety of equipment in each sub-specialisation is still extremely diverse, and the strict allocation of responsibilities is virtually impossible, on, for instance, a full weapons system with elements of all the three above divisions.

Broadly speaking, each man in any of these sub-specialisations must be capable of performing any task within the sphere of that group, dependent, of course, on the level of his technical ability. He must therefore understand the operation of many different types of equipment and must be capable of performing the maintenance schedules and servicing on that equipment.

In the electrical branch of the Royal Navy, the training policy is therefore to give a broad theoretical basis of understanding upon which to build detailed knowledge of specific equipments. When the actual amount of equipment fitted in ships was less in quantity and complexity, it was then possible to follow up this general training with specific training on maintenance techniques and servicing on particular equipments. One of the main items in this training was the technique of fault finding on that particular equipment.

This was done by providing special courses which would be taken by a man going to a certain ship, and would consist of instruction on the specific equipment which he would be expected to maintain on that ship. The length of this course could vary a great deal corresponding to the amount and complexity of the equipment covered, and the fault finding technique taught during the course dealt only with that particular item of equipment, not containing any general fault finding instruction.

However, when the men were required to be capable of servicing any of a large range of equipments, it was no longer possible to include detailed fault finding techniques in these training periods to cover all the equipments the man was likely to meet.

specialisation, together with the proportion of the ship's complement with this specialisation, is constantly increasing. However, the special problems involved in maintaining a fighting ship in front line readiness whilst at sea are not solved by the simple expansion of the branch involved. As the equipment becomes more complex and more diverse, a higher level of technical training is required for the electrical branch.

If the need for higher levels of technical training could be offset by the recruitment of personnel of a higher standard of ability and training, then the problem would be very much simplified. However, the electrical branch has for some time required the highest standards of the entrants to the Royal Navy, and this problem cannot be rectified by the internal drafting of personnel. Also, in the growing technical society of the world at large, competition is already very keen for persons of high technical ability and training. The result of this situation is that the Navy is finding it very difficult to maintain the standards of entry, and almost impossible to raise them. Thus the situation cannot be remedied by demanding a higher entry level.

Moreover, with ships being designed for specialist roles, the equipment on board each ship was necessarily rather different. It is not possible to leave a man on one particular type of ship for an extended period, as in fairness to the man's domestic life, he must be allowed to serve in a variety of ships giving some time in home waters, and also giving some time ashore. If the man were then given specific training on each equipment which he was likely to encounter in his next ship, he would be spending a much greater proportion of his time on courses than in performing his alloted task in the Royal Navy.

This situation was worsened by the increasing complexity of equipment and the correspondingly increasing length of time required to give this detailed training. In an extreme case, one course in detailed techniques took approximately one year to complete. It was obviously impossible to give this sort of training every time a man joined a new ship, which would be an average of once every two years.

In view of these problems, it was thought that a possible solution lay in continuing the broad theoretical training in basic principles, which was already in existence in the training schools, and attempting to find a method of fault finding which could be taught in a specific fault finding course, and which would be a general method applicable in principle to any electrical or electronic equipment. The author was given the task of investigating this possibility.

The following task requirements were given :

1. To instigate an investigation into the possibility of discovering a general method of fault finding in electronic and electrical equipment, which would be generalised in content and which could be applied to any type of equipment.
2. To formalise such a method, if found, and discover the degree to which it would assist in fault finding techniques.
3. To discover if this method could be taught to the normal entry level of electrical trainee, and to what higher levels it would also be of use.
4. To initiate a pilot scheme if the above requirements were satisfied, and to carry out an investigation of the improvement,

if any, in fault finding performance shown by trainees taking the course.

The method had to be a systematic, logical, development, which would appeal to the trainees. Unless the method could be seen to produce results, it would be extremely difficult to justify any time and effort spent on this training, both from the trainee's point of view and from the training administration point of view. Moreover, unless this could be done in a reasonably short course no advantage would be gained, as manpower shortages precluded any drastic increase in training time.

Following from the task requirements, an investigation was started to determine whether such a general method of fault finding could be discovered. The first task was to consider any existing publications on fault finding in electronic equipments. Many such publications were investigated, but almost invariably these consisted of specific fault finding detail on stated equipments, with little or no information on generalised fault finding techniques.[1,5,6,19,32]

The general line of attack advocated by the authors of these works usually started from a list of common fault symptoms in that particular equipment. It then gave the actual fault condition for these particular symptoms, and the method of confirming this diagnosis. This was of no use in the investigation into possible general fault finding methods for use in the Royal Navy, firstly because none of these works was applicable to service equipment, and secondly to produce standard works using this method for service equipment was not praticable due to the vast range and complexity of service equipment, requiring very large lists of possible faults running into hundreds and often thousands of possible faults for each equipment.

However, some work produced by the United States Navy for use at the Polaris School seemed to offer a starting point. This establishment had produced a method of fault finding based on the use of six basic steps in a certain order. These steps were shown in a simple flow diagram, and the method of fault finding was based on following information flow through this diagram. The titles of the six basic steps, in their correct order, are shown below :

(a) Symptom Analysis

(b) Equipment Inspection

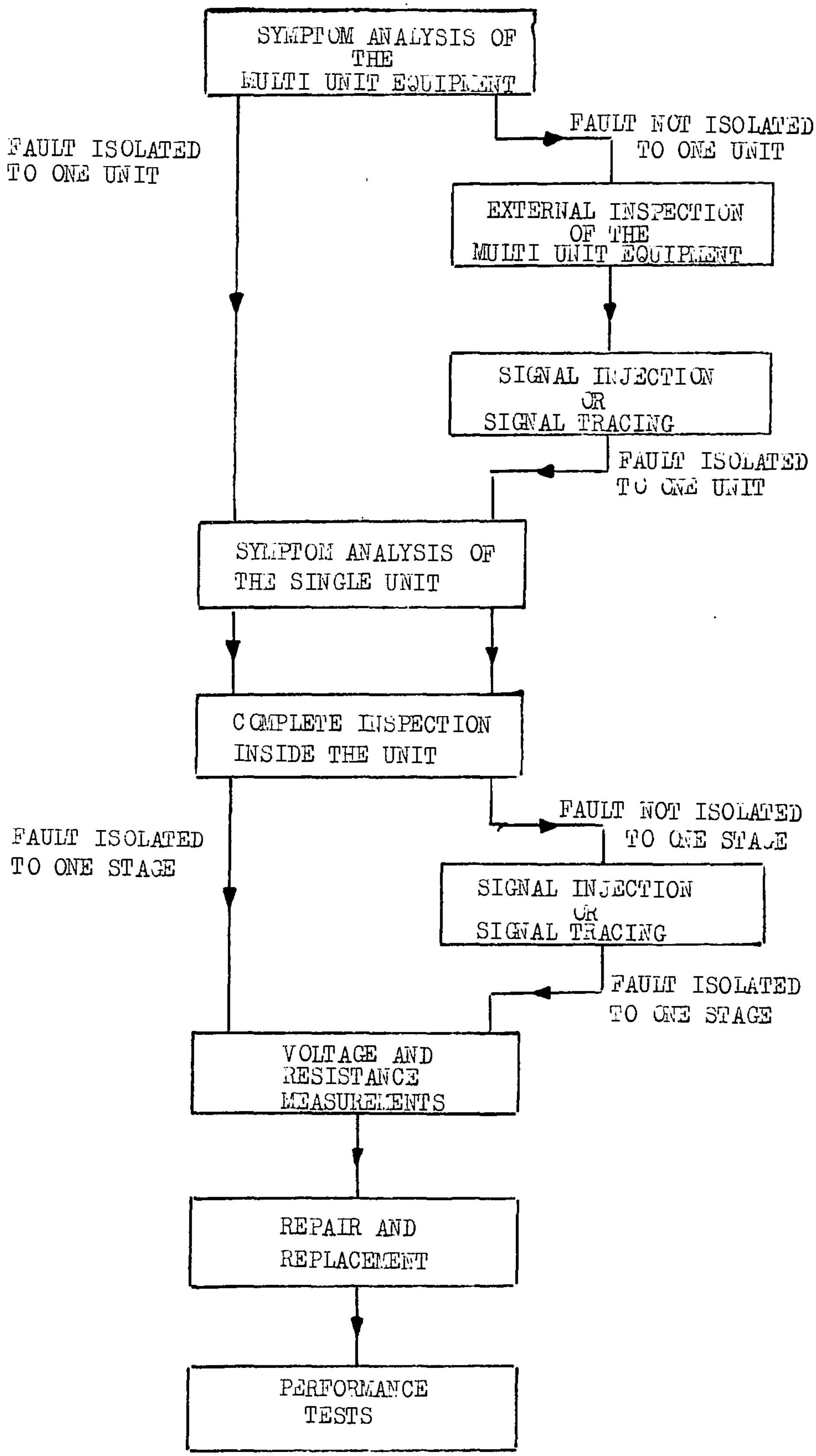
(c) Signal Injection and Signal Tracing

(d) Voltage and Resistance Measurements

(e) Substitution of Components and Repairs

(f) Performance Tests.

The flow diagram for the correct use of these steps is shown overleaf.


SYMPTOM ANALYSIS OF THE MULTI UNIT EQUIPMENT
FAULT ISOLATED TO ONE UNIT
FAULT NOT ISOLATED TO ONE UNIT
EXTERNAL INSPECTION OF THE MULTI UNIT EQUIPMENT
SIGNAL INJECTION OR SIGNAL TRACING
FAULT ISOLATED TO ONE UNIT
SYMPTOM ANALYSIS OF THE SINGLE UNIT
COMPLETE INSPECTION INSIDE THE UNIT
FAULT ISOLATED TO ONE STAGE
FAULT NOT ISOLATED TO ONE STAGE
SIGNAL INJECTION OR SIGNAL TRACING
FAULT ISOLATED TO ONE STAGE
VOLTAGE AND RESISTANCE MEASUREMENTS
REPAIR AND REPLACEMENT
PERFORMANCE TESTS

A brief description of each step is as follows :

1. <u>Symptom analysis of the multi-unit equipment.</u>

Firstly a multi-unit equipment is one made in several different sections, each section being a separate unit, the complete equipment consisting of the separate sections connected electrically. Each section or unit is a physical entity in itself. Symptom analysis is the consideration, or analysis, of the facts, or symptoms, which are known concerning the fault. Such symptoms could range from complete breakdown of the system, to interference showing in the loudspeakers or display screens.

Faults can also be divided into three types :

(a) Catastrophic - complete breakdown.

(b) Non-Catastrophic - system operates but not at peak efficiency.

(c) Intermittent - a fault which is not always present.

If at this stage the fault is not isolated to one particular unit of the equipment, then the right hand branch of the flow chart is followed. If the fault is isolated to one unit, then the left hand branch of the flow chart is followed.

2. <u>External inspection of the multi-unit equipment.</u>

An examination is made of the outside of the cabinet or container of the whole system to try to determine facts such as broken connections between units.

3. Signal tracing or signal injection.

Signal tracing is using an oscilloscope or other similar device to trace the passage of correct signals between the units of the multi-unit equipment.

Signal injection is injecting the correct signal to various points between the units to determine whether the correct final output is obtained.

In each case, the object is to discover the actual unit which contains the fault, without going inside the units at all.

In each case, a method known as the "half-split method" is used to cut down the number of actual steps taken. This consists of injecting or tracing the signal at the mid-point of the suspected faulty area, thus determining which half contains the fault. This is continued progressively until the faulty unit is traced.

4. Symptom analysis of the single unit.

This step is similar to symptom analysis of the complete system, except that in this case only the faulty unit is considered.

5. <u>Complete inspection inside the unit.</u>

The unit which has been determined to be the one containing the fault is now subjected to an internal visual inspection, the object being to determine any immediately apparent faults without the use of test equipment.

If the fault is now isolated to one stage, that is an area of the circuit having one particular function, then the left hand branch of the flow chart is followed.

If the fault is not isolated to one stage, then the right hand branch of the flow chart is followed.

6. <u>Signal injection or signal tracing in the faulty unit.</u>

This step is similar to the previous signal injection and signal tracing except that it takes place in the unit which has been determined to contain the fault. It has the object of discovering the stage of the circuit which is at fault.

The "half-split method" is again used, but in this case the test points are the circuit points between the stages contained in the unit.

7. <u>Voltage and resistance measurements.</u>

The previous steps should have isolated the faulty stage, and now fault finding is pursued by taking voltage and resistance measurements around the faulty stage. The object of this test is to discover the actual component or connection which is at fault.

8. Repair and/or replacement.

The fault, having now been isolated by the previous steps, is repaired.

9. Performance checks.

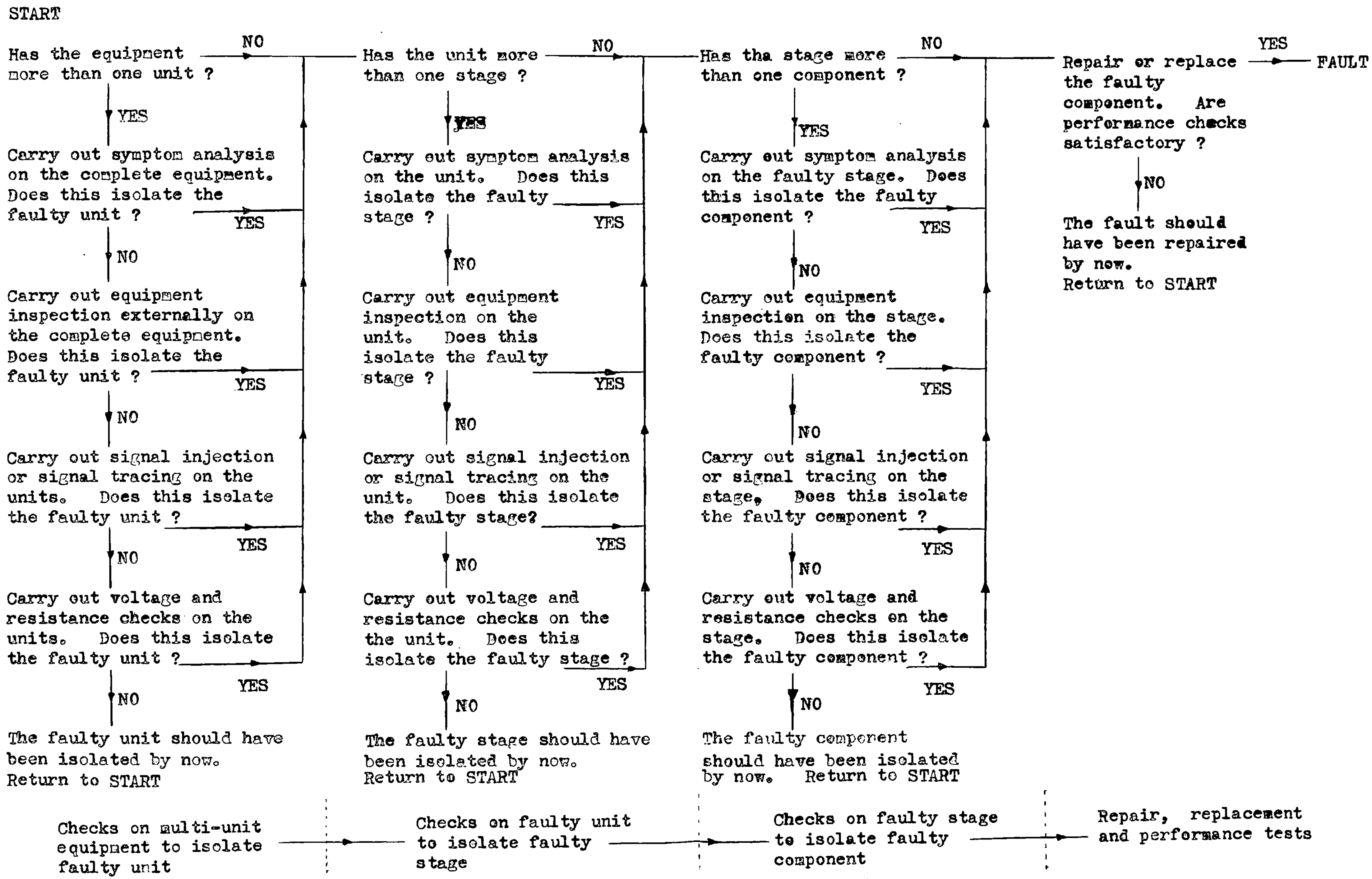
These are carried out on the system as a whole to check the validity of the repair.

This method as described above provided a starting point for fulfilment of the first requirement of the investigation, namely, a general method of fault finding in electronic and electrical equipment had been discovered which could be generalised in content and which could be applied to any type of equipment.

This basic method was investigated in an effort to determine the extent to which it would prove useful in the situation under consideration. A precis was produced of the method, and this was circulated amongst interested personnel for comment. In the light of these comments, a revised version of this method was adopted as the basis of the fault finding method which would be taught in H.M.S. COLLINGWOOD in an attempt to discover whether a basic method of fault finding could be usefully and easily taught.

The revised method of fault finding is summarised on the flow chart shown overleaf.

FAULT FINDING FLOW CHART



This type of flow chart has become known as a dichotomous choice algorithm, and the use of charts such as these was discussed extensively at the 1967 Conference of the Association for Programmed Learning.[23] The chart is self-explanatory, being entered at the START position, and then following the instructions implicitly. A loop facility is provided so that unsuccessful attempts re-enter the flow sheet.

The formulation of this method fulfilled part of the second task requirement. This was to formalise a method of fault finding, and to discover the degree to which it would assist in fault finding techniques.

To fulfill the second part of this requirement, the method was again extemsively circulated amongst expert personnel at all levels, in an attempt to discover whether it would assist in fault finding techniques. From the full comments received on this revised method, it was decided that it would assist significantly in fault finding techniques, if the subject could be adequately taught.

This then led on to the third task requirement, to discover whether this method could be taught to the normal entry level of electrical trainee, and to what higher levels it would be of use.

It was thought that this course would not easily lend itself to conventional methods of instruction for several reasons. These were as follows :

(a) As this was a new venture not catered for in the syllabus of any existing course, it would probably be necessary to include extra time in the present courses for this purpose. In the rigid system of military training it was not particularly convenient to write into specific courses some extra time in which this fault finding course could be developed.

(b) Any development of the course would have to be with a test population which would be a floating one, not necessarily all being available at the same time.

(c) It would not necessarily be convenient to provide a full time instructor for the course as this was at the outset only experimental development.

There were also difficulties associated with the running of the course as an established one if the trial proved to be successful. The course would be required to be given to large numbers of very diverse types of trainees, as it was enviseaged that if the course was successful it would eventually be given to all members of the electrical specialisation of the Royal Navy. Some of these personnel could be given this fault finding course as part of existing courses already programmed, but there would still be a large number of personnel who were not expected to be included in a formal course at a training school for a long interval, and even some personnel who would not be expected to be included in a formal course for the remainder of their service. (29, 31)

It was therefore decided that here was a situation in which the benefits of programmed instruction could prove to be particularly useful. (11, 25, 30) There was already in existence a nucleus of experienced workers in the field of programmed instruction among the staff of H.M.S. COLLINGWOOD, * amongst these being the author. Most of the reports dealing with this work are Royal Navy or joint service reports, and as such are not generally available. However, those which are more readily available are given at the end of this thesis.

* (23, 24, 26, 27, 28, 29, 31, 36, 37, 38, 39, 40)

Bearing in mind these considerations concerning the actual running of the course, and the success which had been noted in previous experiments by the Royal Navy in the use of programmed instruction,* permission was given to the author to proceed on the development of this method of fault finding with a view to producing it using programmed instruction techniques.

It is of interest at this stage to summarise the formalised ideas of Mr. D. Wallis, Senior Psychologist of the Naval Manpower Division of the Ministry of Defence (Navy), concerning characteristics of an "ideal" training course. These ideas were presented in a paper entitled " Production and Maintenance of Human Capacities in Manpower Systems " at a conference held in Brussels by the NATO Science Committee, entitled "Operational and Personnel Research in the Management of Manpower Systems ", in 1966.(15)

Mr Wallis was at this time engaged in training research for the Royal Navy, and one of his particular subjects was programmed instruction.

* (8, 9, 10, 26, 27, 36, 37, 39)

In this paper, the principal characteristics of an "ideal" training course would consist of at least the six following features :

(a) a clear and comprehensive statement of objectives, couched in behavioural terms. They are identifiable as the final output of the system.

(b) the skill or information to be acquired is broken down into steps or items, each of which is a necessary prelude to its successor, and is capable of being handled in one "cycle" of the instructional process. The steps are displayed and responded to in a continuous series. Each response is an intermediate output of the system, indicative of any progress in learning.

(c) a particular sequence of instruction which is appropriate to each student. It is derived in the first place from a prior analysis of all the successive skilled behaviours, or increments of knowledge, which the designer has decided may have to be taught during the progress towards achieving a final output. This generalised sequence of itemised data and instructions serves the purpose of injecting an initial, but not inflexible, programme into the system's information store. But the actual sequence experienced by any individual student can be modified as instruction proceeds, under the control permitted through feedback of his particular progress.

(d) a means of eliciting and recording responses from a student throughout each cycle of the entire sequence of instructional steps.

(e) a facility for continuous comparison of actual behavioural outputs with the responses which ought to occur at each stage. A mechanism will probably be needed to subverse this function if the instruction applies to complex skills such as manual tracking or target classification. Under other circumstances a human instructor, or even the student, may be capable of exercising the role. The results of comparison are at the earliest practical moment brought to the student's notice, perhaps after some filtering or modification by the controller.

(f) a built-in set of decision-rules, operating as a "controller" upon data from the response comparator. It is on the basis of these rules that the information store will be directed to display confirmatory or corrective feedback, and to introduce new or remedial steps towards the system's objectives. Decision-rules correspond to a "strategy" of instruction; and whatever set of them is actually adopted will be an expression of the designer's own experience or preferred theory of instruction.

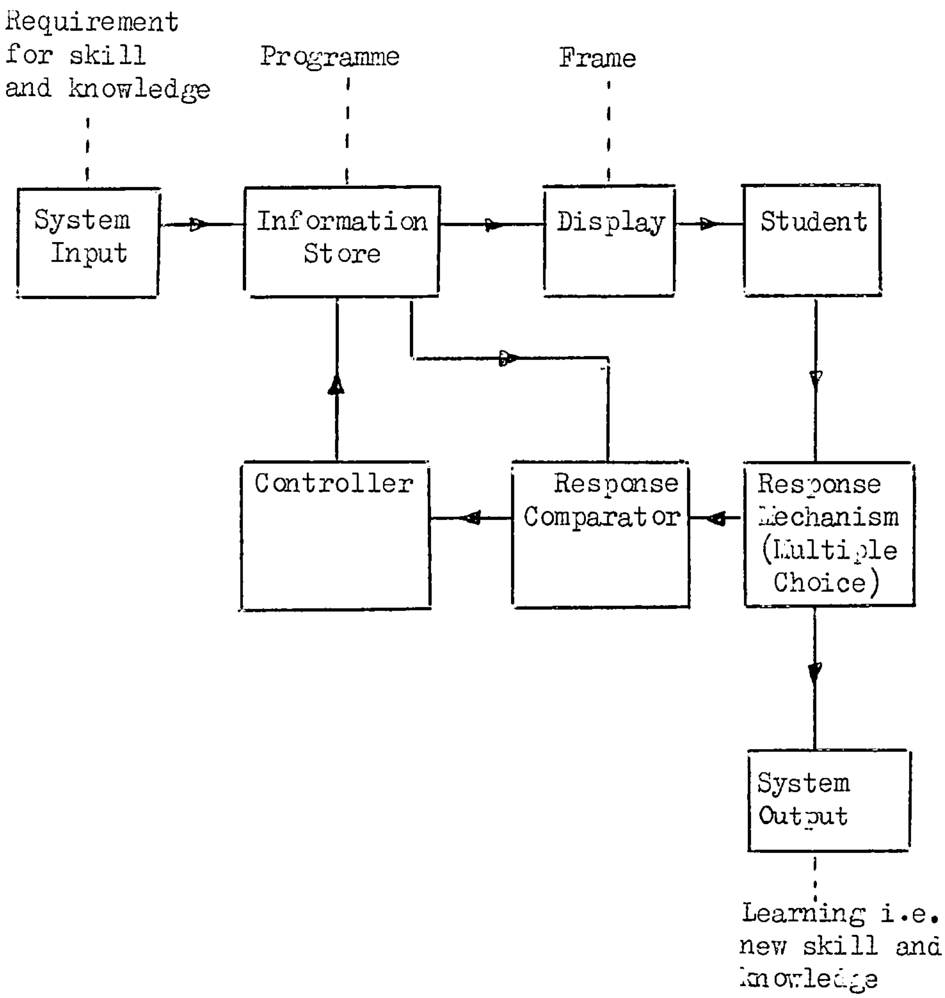
These remarks are included here as it is of interest to note the similarity between the method of approach used in the development of the fault finding programme, and the formalised method advocated by Wallis.

Having decided that programmed instruction offered the best chance of success with this course, the accepted precepts in the preparation of a programmed course were followed. Questions of space do not allow a general discussion on the principles, merits and organisation of programmed instruction in this work, and lies outside the scope of the reference. However, several references of standard works on this subject are included.

The model of an instructional system taken for the development of this course is shown in the diagram overleaf.

MODEL OF INSTRUCTIONAL SYSTEM USING PROGRAMMED

INSTRUCTION



This is a closed-loop system, analagous to a servo system, in which the feedback is immediate and continuous.

The stages in the preparation of a teaching programme to fit this model can be summarised as follows :

1. Task analysis
2. Declaration of objectives
3. Construction of criterion tests
4. Determination of knowledge and abilities among prospective students
5. Behavioural analysis
6. Construction of instructional system
7. Assessment of training effectiveness and efficiency. (cf 12, 20, 23)

The first step of task analysis had already been carried out by a study of the tasks of all ratings in the Royal Navy. The contents of this report are classified but deal very fully with the task of the ratings at sea. This in fact completed the first step in the production of the system.

The second step was to declare the training objectives for this particular course. Again, this had been considered previously in the task requirement given to the author and may be summarised as an objective that the trainee given this course would have a significantly better fault finding performance than the trainees who were given only conventional courses. (4 12, 14)

The first practical difficulty arose from the question of how to measure fault finding performance, and thus to judge in the objectives had been fulfilled. This constitutes the third step of the construction of criterion tests. The most obvious answer was to set the trainees fault finding tests on actual equipments in use in the Royal Navy, and to devise a method of marking performance in these tests. This was not found to be practicable. For the test to be valid, no error in results should occur due to insufficient knowledge of the actual equipment chosen. Also an equipment would have to be chosen which all trainees would have covered in theoretical courses, and with which there would be no sampling error due to differences in familiarity with the actual equipment. Moreover, the marking of performance on an actual equipment would be very tedious and involved, requiring a staff member standing over each trainee during his tests and marking his individual fault finding performance. With these difficulties in mind, a search was therefore instituted for a criterion test which could use an equipment simulator to eliminate these difficulties.

An almost ideal solution was found in a commercially produced simulator produced by Printechnic under the trade name of "Trainer tester sheets" (34). Examples of these sheets are submitted with the thesis to avoid lengthy descriptions, but a brief description is felt to be useful at this stage.

The actual sheets chosen were concerned with a superheterodyne radio receiver. This type of receiver is more usually called a superhet receiver, and is the normal type of radio sold commercially today. It first converts the received radio frequency to a standard frequency to enable a simplified cirquit with fixed tuning to be used in the majority of the receiver, and then detects the message being passed in the transmission.

The use of these sheets immediately eliminated any difficulty due to trainees not being familiar with the equipment used for the tests, as all members of the electrical branch of the Royal Navy cover this equipment in the basic course which they are given on entry. Also as the circuit was not one encountered in the normal events by personnel working on naval equipment, although the general type of circuit was fully understood, there would be no errors in the results due to differing amounts of familiarity.

The sheets consist firstly of a full circuit diagram of the receiver. This is complemented by a large scale photograph of the actual receiver, clearly showing all electrical components. A numbering system is used so that the circuit diagram can be related to the actual lay out of components in the receiver, thus including one of the first measurable parameters in fault finding - the ability to trace a circuit through an actual chassis.

Twenty different faults are covered by the series, each fault having a separate test sheet. The fault symptoms are given at the head of the sheet. Almost every test which could possibly be made on the circuit is listed on the sheet, with the answers to all of the tests covered with an overlay. If the trainee wishes to investigate the result of a specific test then he rubs out the overlay for that particular test. For example, the trainee might wish to measure the voltage at a particular point in the circuit. His first move is to find the exact point in the circuit diagram. He then attempts to match this point in the circuit with a numbered point in the lay out ... of the receiver.

out diagram of the receiver. This gives him the reference of the point in question. He then goes to the appropriate fault sheet, finds the reference number, enters the column for voltages against the particular reference number and rubs out that particular portion of the overlay. When the overlay is rubbed out, the answer to the test then appears, and a permanent record is left of the fact that the trainee attempted to find the fault with that particular test. It is recommended that each test is numbered in the order in which it was attempted.

The trainee continues these tests, numbering each test in turn, and attempting to gradually narrow down the faulty area, and eventually to determine the exact fault. When he considers that he has found the fault, he goes to the repair and replacement section of the fault sheet, finds the reference number of the suspected component by comparing the circuit diagram and the lay out photograph, and rubs out the overlay. Underneath the overlay is shown either "SR" i.e. symptoms remain, or "FC" i.e. fault cured.

A permanent record is left on the actual fault sheet used showing which steps were taken to rectify the fault, and the order of these steps. It is then extremely easy to go through the particular fault questioning the trainee as to his method of fault finding, and his reasons for making the tests he did in the order shown on his fault sheet. This gives a permanent record of fault finding technique which can be scored accurately, and which provides an excellent situation for remedial treatment. It is felt that these sheets are thus ideal for the testing of fault finding performance.

A preliminary test was carried out on these sheets to check their suitability, and to decide upon the best way of administering the tests. It was not thought necessary to give each trainee the whole series of tests, and after further investigation it was agreed that a pre-test consisting of three separate faults, and a post-test consisting of three separate faults would be adequate. Tests were then administered to individuals of a wide range of ability to discover the actual feasability of using these sheets with the target population. The results of this test showed that in fact these sheets were almost ideal for the purpose of criterion tests for a teaching programme, and that further detailed consideration could be deferred until the actual teaching programme was at a more advanced stage.

This successfully concluded the third stage in the development of the programme, namely the construction of criterion tests (Vide supra p. 26).

The next two steps in the production of the programme had both been previously covered by service investigations and thus no further work was necessary on them. Thus the next stage was the construction of the actual teaching programme.

CHAPTER 2.

PREPARATION OF THE PROGRAMME

The first consideration was the broad outline of the programme. It was decided that the most sensible attack would be to divide the programme into six sections to correspond with the six basic steps in the method of fault finding. These six basic steps are :

(a) Symptom Analysis

(b) Equipment Inspection

(c) Signal Injection and Signal Tracing

(d) Voltage and Resistance Measurements

(e) Repair and Replacement

(f) Performance tests.

Therefore the first six sections of the programme would have these titles, and each section would deal with one step in the method.

These six sections would then be followed by a further section which would mould the six basic steps into a composite method of fault finding. It was decided that this section would take the form of examples of fault finding in specific cases on a selection of electronic circuits.

Space does not allow for a full discussion on the merits of the various types of teaching programme, such (26,29) as the linear, branching, skip or adjunctive programmes, or to follow the ideas of early workers such as Skinner, Pressey or Crowder, but these topics have already been fully covered in a large number of publications. Moreover, the majority of teaching programmes written today bear little resemblance to the original, "Classical" ideas of Skinner.

Many of the early programmes were written in a linear style, possibly because this was thought to be easier to handle. However, it was the accepted opinion in the Royal Navy that linear programmes were not the best vehicle for producing programmed instruction courses. The main criticism of trainees given linear programmes was of boredom with the very slow progression of information. Research into programmed instruction in the navy therefore concentrated on multiple choice branching programmes.[1]

1. R.N. Programmed Instruction Memorandum 1/66
Department of the Director General of Naval Training.

In the light of this previous experience it was felt that a programme employing the techniques of multiple choice branching would be most suitable, and therefore development of the actual programme could proceed. (4 u)

In the early stages of production a close liason with the late Richard Goodman and his associates of the Department of Cybernetics and Computing of the Brighton College of Technology was maintained. The actual technique of writing may be summarised by the following main steps :

1. Analyse the criterion for terminal behaviour and check their validity.

2. Prepare detailed notes of course content to give the basis of a course which would produce this terminal behaviour.

3. Divide the course into well defined sections, each with a specific purpose in the break down of the teaching method.

4. Construct a criterion test for each section which would fully cover the contents of that section, placing the correct amount of emphasis on each topic.

5. Develop a logical and satisfactory progression of steps which would cover the section and which gives the correct information in an assimilable

fashion to enable a trainee to pass the criterion test.

6. Break down the progression of steps further to give the spine, or main frames, of the programme.

7. Revise the spine.

8. Produce subsidiary frames, including questions and answers.

9. Revise the subsidiary frames.

10. Scramble the frames.

11. Test.

Depending on the actual results obtained in step eleven above, a loop could develop in the progression the size of which, and number of tours, would depend on the actual circumstances encountered. It is not possible to give actual rules for this loop, but it should be maintained until a satisfactory result is obtained to the test. Assuming that a correct test sequence has been devised, it should be possible to discover the exact nature of the error in the programme which is causing the unsatisfactory test result. This may be a simple error in frame content, or a more serious error in development of ideas.

The first step in this production sequence had, as mentioned earlier, been already carried out, The terminal behaviour for this group of electrical trainees had been laid down by a Fleet Working Party. Therefore the first actual step carried out was to prepare detailed notes of the course content to give the basis of a course which would produce this terminal behaviour. These notes were based on the flow diagram giving the actual method of fault finding to be used[1].

When these notes had been produced, they were given as much circulation as possible amongst interested persons to assist with the revision. This principle of extensive circulation and revision was maintained throughout the production of the programme. It is considered important that this is done, as no matter how experienced the writer, the programme cannot failt to be improved by suggestions gathered from other workers in the same field.

Having satisfactorily completed this stage, it was then possible to proceed to the next step of dividing the

1. Vide supra p. 17.

course into well defined sections, each with a specific purpose in the break down of the teaching method. This was again completed very easily, as the course naturally broke down into sections to correspond to the six main steps in the fault finding method, each of which had a clear and specific purpose. Moreover, it had already been decided to follow these six basic sections with a problem section in which the main steps would be combined into a composite method.

Work then progressed through the production steps as far as production of the spine of the programme, continuing with the requirement that all work should be revised as much as possible by several persons, so that the end result was in the best possible condition. In particular, having decided upon a particular development of ideas to cover each section, it was very easy to check the spine against this progression in order to determine that the logical progression of the course was maintained.

When revision of the spine was complete, then work could begin on the production of the subsidiary frames. This included adding questions and answers to the completed spine frames. During this stage slight difficulties were encountered with several of the frames. The precepts of previous work done in programmed instruction all necessitated the response of the student, in this case by the question and answer technique. However, it was thought that to include questions on every frame if this was for the sake of asking a question rather than for the usefulness of the question was not a good programming tenet. Therefore a compromise solution had to be found where as many frames as possible had a question and answer technique. However, this was not allowed at this stage to be an absolute requirement.

Each frame for which a question and answer routine was not thought to be desirable then required further investigation. If the information contained on the main frame was not sufficient to warrant the inclusion of a question to check the effectiveness of the explanation, then there was a possibility that the frame did not contain enough information. There were obviously some bridging frames which did not need this consideration, but there were also some frames where the information given was not sufficient to ask a pertinent question. The obvious solution, and the easiest one, was to presume that these frames should be extended to be combined with the following frame thus containing sufficient information for the question technique. In most cases this was found to be possible, but there were a few frames where this was not thought to be a feasible solution.

One of the main considerations in the original writing was to limit the number of words, or the total content, of each frame to a size of the order of one hundred and fifty words, or its equivalent in content where diagrams were included. This was thought to be a very necessary requirement, as the experience gained from writing previous programmes was that facing a trainee with a seemingly large amount of material on a frame would produce a form of mental blockage against this information, or would more simply result in an unconcious refusal to assimilate all of the information contained on that particular frame. Although no absolute tests had been carried out to determine the exact amount of information on a frame to provide the most efficient form of communication, it could be said that this maximum of one hundred and fifty words per frame was an informed and well considered estimate. Looking forward to the conclusions of the tests carried out on this programme, this estimate would appear to be well founded.

A further consideration in the frame writing was to attempt to avoid the overuse of such terms as :- "Good, you are correct", or "Well done" . It is felt that in many programmes the use of these terms is overdone. Although reinforcement is required when the trainee gives the correct answer to a question, and encouragement is required for those who are not doing so well, there are many criticisms of this technique of always including a congratulatory phrase. The trainees have often felt that they were being talked down to. Sufficient encouragement should be given in most cases by the mere fact that the trainee gave the correct answer.

In this programme an attempt was made to give confirmation and encouragement without the overuse of these terms.

Furthermore, when a trainee selected the incorrect answer, it was not felt to be reasonable to continually say :- "No, you are wrong" , as this could have equally diasadvantageous results. Confirmation was given by the repeating of the question and the trainee's answer and showing that this was in fact the correct answer. The technique of repeating the question is thought to be extremely important as the trainee does not always remember the exact words of the question once he has passed on to the next frame. If the question requires a mathematical or a technical solution a repeat of the main facts of the question provides valuable reinforcement.

By omitting the constant repetition of the terms discussed above, a source of irritation was removed, but confirmation of results was retained. In cases where trainees were recording poor performances in the answers which they gave they were not overly discouraged by the constant repetition of the term "No, you are wrong", and the only true measure of performance was progress through the programme. Although this was not thought to be an ideal solution by everyone, it is believed that the results obtained by the use of this programme, discussed in following chapters, support the use of these techniques.

When the subsidiary frames were all prepared, a further final check on the frame sequence and content was carried out. The next step in the sequence would be to scramble the frames. However, before commencing the actual mechanics of scrambling, it was necessary to decide upon the format of the completed programme in order to allow for any special requirements of that particular format. (29,36,39)

It is possible to produce a scrambled programme either in a suitable form for electro-mechanical teaching machines, or in the form of a scrambled text. It had not been necessary up to this point to take a decision on which form to use, but now the advantages and disadvantages of the two main types of format had to be considered and a decision taken to produce the programme either for use in a teaching machine, or as a scrambled text.

A brief summary of some of the advantages and disadvantages for each particular method are as follows :

Advantages of machine presentation.

1. Good physical presentation is possible.

2. The machines generally have a high cheatproof aspect.

3. The machine gives an almost instantaneous presentation of the next frame in the sequence.

Disadvantages of machine presentation.

1. The machine is generally static.

2. The expense of the machine can be a limiting factor.

3. For machines which use various forms of film, production of the actual programme may be difficult.

Advantages of scrambled text presentation.

1. The text is very portable.

2. Production of the actual programme is usually very easy.

3. The cost can be very low, depending upon the actual form of production.

Disadvantages of scrambled text presentation.

1. The text is seldom cheatproof.

2. Good presentation is difficult.

3. In any scrambled text there is necessarily a lot turning back and forward between frames.

The various advantages and disadvantages had now to weighed against each other in order to discover the most acceptable form of presentation.

For a normal training course it is considered that the machine presentation is the most advantageous. However, in the case of this particular course the major disadvantage of the machine was its non-portability. Even though there are machines now in production which are reasonably portable it was not thought possible to tie the use of this programme to the availability of a machine. If the programme under development proved to be acceptable, then trainees in a wide variety of places and situations would be given the course, and in the vast majority of these occasions it would be impracticable to provide a machine.

The disadvantages of expense and technical difficulties in producing a film for the machine did not appear to be a limiting factor as the Royal Navy already had time available on the large number of machines already in use for existing programmes, and the technique of producing films had been mastered in the production of earlier programmes.

Therefore if the disadvantage of the book format could be resolved, then the major disadvantage of non-portability of the machine would mean that the programme was best produced in scrambled-text form. (cf 19)

The major disadvantages of the text format as outlined above are :-

1. Not cheat proof

2. Good presentation is difficult

3. There is necessarily a lot of turning back and forwards through the text.

Unfortunately, all scrambled texts suffer from the third disadvantage outlined above. Once the decision has been taken to produce a scrambled programme in text form there is no satisfactory way of surmounting this difficulty. However, it was thought that the first two disadvantages of the text form could be overcome.

Therefore it was decided that the advantages of the scrambled text outweighed its disadvantages, the machine presentation being discounted mainly on the grounds of non-portability, and the solution determined upon was to produce the programme in scrambled text form.

It was decided to produce the scrambled text in foolscap size, and it was calculated that three frames could be contained on each page. The principle of operation would be to read only the top frame of each page for the first third of the programme, the centre frame of the page starting again at the first page for the second third of the programme, and to once more start at the first page but to only read the bottom frame of the page for the last third of the programme. There were several reasons for this method.

The first of these was that as the programme was to be produced in a scrambled text format, the trainee would be given the complete programme as a book. If this appeared to be a very large book then he would become discouraged before even looking at the programme. This is a very viable point with scrambled textx as they are necessarily very much longer than a normal text book containing an equivalent amount of information. This is due to the large number of branching frames, and also to the fact that in many cases a frame need only contain a very few words. This produces an artificially extended book which can appear to be very daunting.

If the operating conditions of the programme are to be as ideal as possible, then it is vital that the trainee is not allowed to build up any personal opposition to the programme and thus the programme should appear to be as compact as possible.

The problem of some frames consisting of very small amounts of material is also very wasteful from a printing point of view. In some cases a frame may consist only of one sentence, and to have a whole page of the programme with only this amount of printing is not reasonable. With three frames on each page, compensation could be made for this by ensuring that a very small frame was balanced by a larger frame so that each page was used as efficiently as possible.

Although there were to be three frames to each page, it was not considered reasonable to have these frames reading sequentially down the page. As both sides of each page were to be used for printing, there would be six frames visible at any one time. When scrambling the frames care would have to be taken to ensure that none of these frames would interfere with the frame being considered, i.e. there would be five frames visible on the page as well as the one being considered, and none of these five frames should have a direct relationship with the frame being read. Any of the frames leading from one particular frame would have to be at least one page different from the original frame. Thus the scrambling would have to be at least at six frame intervals, and a page would have to be turned to accomodate this. There would be exactly the same amount of page turning if the frames were read across the top of sequential pages, and the difference in frame numbers of associated frames would be much smaller, thus giving a neater effect to the scrambling.

The technique of scrambling employed was to prepare a mock up of the completed book, and to insert into this mock up the completed frames, arranging the scrambling so that any associated frames were at least one page different. At the same time an attempt was made where possible to ensure that correct answers resulted in a progressive movement through the book by pages, to correspond to the progress through the programme. Care was taken to ensure that the actual amount of page turning was kept to a minimum as this can prove to be a major source of irritation, and should be avoided if at all possible. A running check could also be maintained on the scrambling to see that no mistakes occurred resulting in the appearance of any unused frame numbers. In the production of commercial scrambled books, this task is usually performed by the publisher, when the publisher has specialised knowledge of these techniques. In this case the scrambling was all completed by the author, both to ensure a close control on various factors as described above which could affect the efficiency of the completed programme, and because the scrambled book was to be produced by service printers who had no previous knowledge of this type of book.

An addition to the actual teaching programme was made at the beginning of the scrambling to ensure that no one was attempting to work through the programme by reading the frames sequentially, instead of following the correct scrambled route. Although it may be thought that this is not a matter to be safeguarded against, in fact it is fairly prevalent amongst trainees with no previous experience of this type of programme, and who are not sufficiently well motivated.

This addition took the form of an extra frame printed on the page immediately following frame 1. Anyone attempting to read the book in the normal text fashion would come to this frame, whereas following the scrambling it was impossible to arrive at this frame.

The contents of this frame were as follows :-

FRAME 2.

> You should not have arrived at this point. Nowhere have you been told to go to FRAME 2. Now go back to FRAME 1 and use this book properly.

The inclusion of this checking frame was justified when the results were analysed, as a very high proportion of readers turned directly to frame 2 upon completion of frame 1, instead of following the scrambling which would have taken them further through the programme. This was in spite of detailed instructions for using the book given on an insert page at the beginning of the programme.

On completion of the writing of the first section of the programme, the mock up was closely inspected to ensure that no further improvements could be made. This was done by again circulating the work among interested personnel. It cannot be stressed too strongly that the writing of a programme such as this is a task which can be performed by one man working entirely on his own. The more opinions and suggestions that can be gathered together the better. When a concensus of opinion considered that this first section was in a suitable condition, and no further improvements could be made, then it was deemed to be completed for the moment, and work could commence on the second section of the programme. In fact, whilst the mock up of the first section was undergoing distribution, work was started immediately on the first stages of production of the second section, in order to keep delays in completion of the programme to a minimum.

The technique employed for the writing of this second section and all subsequent sections was identical to that employed in the first section of the programme. This has already been fully described.

On completion of each section, it was included in the mock up of the scrambled book, to keep a running check on the suitability of the layout. All sections were not necessarily of the same size. In fact there were large discrepancies between the sizes of the six basic sections of the programme. This was because the sections had been taken from the six basic steps of the fault finding method, and were not necessarily of equal status or complexity. The actual lengths of the six basic sections are as shown below :

1.	Symptom analysis	60 frames
2.	Equipment inspection	26 frames
3.	Signal injection and signal tracing	53 frames
4.	Voltage and resistance measurements	26 frames
5.	Repair and replacement	19 frames
6.	Performance tests	5 frames

This gave a total length of 189 frames for these six basic sections of the programme.

The length of each section does, however, give a reasonable value of the estimated difficulty of each section. In writing the programme, no preconceived limitation was placed on the number of frames which could be included in each section. Instead, the ideas in that section were developed until it was thought that an acceptable standard of understanding would be achieved by the trainee upon working through the programme. Although involved testing of programmes can be carried out in an attempt to discover the correct amount of time required for each section, the only acceptable criterion in the final situation is whether the programme actually accomplishes its stated task.

As an absolute measurement, this is the only (cf 19) criterion of the standard of the programme. Regardless of criticisms concerning programme format or frame lay out, if the programme achieves its stated objectives with its target population, then it can be said to be a successful programee. Tests on frame content and other methods of checking the development of the frames can only be aids to production, and cannot be mandatory to the programme as a whole. It is the end product which must be tested, not the method of producing it, and thus the actual production of programmes must still be dependent upon a certain measure of intuition on the part of the author or authors.

When the six basic sections of the programme were completed, consideration was given to the fault finding problems which were to come next, and whose purpose was to mould the six basic steps of the fault finding method into a composite method. For these problems an electronic circuit was required, and it was decided that the best vehicle for this purpose would be a simple superheterodyne radio receiver with which the trainees would already be familiar. It was planned that this circuit would be printed on a fold out sheet at the end of the scrambled book, so that it could be viewed in conjunction with whatever frame was being considered. It would have been simpler to produce this circuit as a separate hand out sheet, but this was inherently unsuitable as it could be lost, and would become an awkward ancillary to the programme.

Three suitable faults were chosen on this circuit, based on their training value, authenticity and general usefulness in their task of moulding the basic sections into a composite method. These three faults were investigated in the actual circuit being used to determine the exact symptoms which should be obtained with these particular faults. Also the various test voltages and signals were determined which would be obtained with that particular fault in the circuit.

The actual faults chosen were as follows, exactly as they are presented to the trainee :-

1. There is no sound output across the entire receiver tuning band even with the gain control set at maximum gain.

Through the vents in the receiver cabinet, you can see that at least some of the valves are lit.

2. A receiver has an output which varies considerably from station to station across the tuning band.

Other receivers in the same frequency range are working properly, which eliminates atmospheric conditions as the source of the trouble.

An equipment inspection fails to show anything wrong.

3. The output of a receiver is normal across the entire tuning range except that, in addition to the desired output signal, a loud noise signal is present.

The fault was presented to the trainee as the immediately apparent symptoms which would be observed with this fault. The branching technique of the programme was then to be employed to provide the trainee with a choice of moves in his attempt to rectify the fault. The trainee would be gradually advanced through the techniques of fault finding by the branching programme, until he could make an estimate of the possible fault. This was all based on the method of fault finding which had been taught in the first six sections of the programme.

The production of these sections of the programme was along similar lines to the earleir sections. However, the first requirement was to investigate each fault and to determine the correct series of tests to rectify the fault. This had to be the sequence of tests which a trainee would follow if he were following the programme method implicitly, and not the steps which would be followed by an experienced fault finder.

The next step was to take a sample batch of trainees and to give them the actual faults in an attempt to discover the more usual and important mistakes which they would make in attempting to find the fault. If possible, these had to be rectified in the programme, as well as showing how the six basic steps could be welded together to form a composite method of fault finding.

The main steps in the production of these three fault sections were then as before. Since a logical development of thought had already been produced in determining the correct method of fault finding to be used, the next step was to write the spine of the programme. This was followed by revision, subsidiiary frames with questions and answers, revision, and then scrambling. The three problem sections could then be inserted into the mock up of the programmed text.

On completion of these three sections concerning actual faults, the first draft of the programme was complete. Extensive consultation then took place with various authorities in an attempt to rectify any mistakes in the programme before classing the programme as ready for testing. This task took several months and could be divided into two stages.

The first of these was consultation with technical experts in the electronic field to check the accuracy of the technical content. The second stage was to check the actual programming technique.

The accuracy of technical content can be split into two sections. The first of these was to check the actual theoretical accuracy, disregarding fault finding as such. All examples and problems were checked to verify that correct values had been supplied, that the electronic theory was correct and that all statements concerning electronic theory were in fact true. The second part of checking the accuracy of technical content was to confirm the fault finding technique. The basic method of fault finding had already been agreed, and this was a check to see that the development in the programme followed this method correctly, and that all tests and results were factual and accurate.

Checking the theoretical accuracy was extremely easy as there were a large number of officers with expert electronic knowledge serving in H.M.S. Collingwood, several of whom were extremely interested in the project. Any technical points raised by these officers were discussed and annotations made to the draft before the programme was passed for the second stage of checking. The purpose of this second stage was to check the actual programming technique.

The investigation for this stage was headed by Mr. D. Wallis, of the Senior Psychologist's Department of the Director General of Naval Training. Mr. Wallis at this time was the leading authority on all Programmed instruction in the Royal Navy.

The delay in completing this stage of final revision was mainly due to circulation difficulties amongst the various interested persons. In fact interest was so high that it was extremely difficult to retain the draft programme long enough for production to take place.

The general response to these checks was extremely encouraging, and only a few minor revisions were suggested. These revisions were made after consultation between the author and those making the suggestion. In fact, only four frames needed revision, and there were no large scale revisions suggested. This should be true of programme writing in general if the correct sequence of steps in the production of the work is followed, and if sufficient revision is carried out at each stage in the production.

The mock up of the programme was then given to a number of trainees in a small scale test for which no detailed results were kept as the numbers were too small for analysis. Twelve trainees worked through the programme in their own time and each was interviewed. The results of these interviews were unanimously encouraging.

Therefore considering the opinions expressed by those given the programme to evaluate it, and the trainees' response, it was decided that a large scale test could be carried out, as the programme appeared to be substantially successful.

CHAPTER 3.

FRAME PROGRESSION ARRANGEMENTS

The method of progression through the individual frames of the programme was given a great deal of thought. For ease of production, the mock up of the programmed text had been made with the route given in the normal manner, that is with the relevant frame or page numbers shown directly against the various answers to the question, or given at the end of the frame.

At the time at which this programme was being written, there was evidence that the cheating aspect possible in this form of instruction was large enough to merit serious attention. Cheating a programme can be done in several ways, dependant upon the actual format of the programme and the means by which it is presented. One of the easiest methods of cheating with a programmed text is to look up all the possible answers and to check which is the correct solution, without attempting to work out the answer, or to follow the route given for this answer.

Any trainees who were reasonably well motivated would have no incentive to cheat in any way. However, the type of trainees under instruction in this particular case were not necessarily adequately motivated. Cheating was known to occur in the other programmes in use at this time in the navy, and it was possible that it would also occur in the fault finding programme under development, particularly as it would be easier to cheat with a programmed text than with the teaching machines in use for the other programmes.

The standard answer to cheating is that if the material to be taught is properly programmed and presented, designed for the target population specifically, then cheating should not occur. However, it was still considered that even with the best possible programming and presentation, cheating would still occur. This was especially true considering the special circumstances in which this course would be given, where many trainees would be required to work on the programme without supervision.

Cheating in the existing courses was found to be particularly prevalent towards the end of a necessarily long session, when the trainee had reached saturation. In the cases in which this cheating did occur in the existing programmes, then almost invariably it would be detected by the class supervisor. If the cheating did happen to elude the suoervisor, then it would be discovered at the next criterion test, which would never be at a greater interval than one or two days, thus enabling remedial action to be taken in time to avoid the wastage of the course.

As the proposed course in fault finding would have to be given in a more informal way, with trainees working without close supervision and strictly controlled periods, then the cheating aspect might become more important. As discussed earlier, the existing tight training schedule for these electrical trainees did not allow for the inclusion of extra formal courses, and thus the amount of control occuring in other programmed instruction courses would be lacking in this course.

It was felt that however much the programme was trainee orientated, and however much effort was put into motivating the trainees, cheating would still occur at this training level. This cheating would have to be cut down as much as possible.

Therefore a method of frame progression external to the programme, with built in cheat-proof facilities, was designed. This tokk the form of a "Clue Board", which is in use today for several programmes. This clue board was in fact developed independently of other workers in this field, originally in 1964. However, it is not now unique.[1]

Examples of the various types developed for use with this programme are submitted with the thesis.

The first design attempt was to produce a wooden clue board which was laid out as shown in the diagram on the following page.

1. K.D. Duncan, Experiments with an inexpensive device for programmed instruction in the multiple choice style. Programmed Learning, Vol I, 3. November 1964. 145-155

J. Annett, A low cost cheat proof teaching system. Programmed Learning, Vol I, 3. November 1964. 155-158

(2, 13)

DIAGRAM SHOWING LAY OUT OF CLUE BOARD

Frame	A	B	C	A	B	C	Frame
1	7	8	5	52	58	-	56
3	10	9	-	54	60	57	59
4	11	13	-	63	65	64	61
5	10	9	3	62	66	68	64
9	6	4	-	71	72	70	68
13	15	19	17	71	74	-	
14	12	16	18	71	74		
15	19	17	-	67			
20	24	25	-	79			
21	24	25					
23							
25							

The actual board measured approximately 15" x 12" and was numbered on both sides to save space.

The numbers were produced with a "Dymotape" machine and were stuck on to the board with their self adhesive. In use, the columns of numbers under the headings "A", "B" and "C" were covered by a sheet of paper which was clipped to the board. This sheet had blank squares printed in appropriate positions to correspond to the positions of the hidden numbers. This left the two outside columns of figures visible. These outer two columns contained lists of all the frame numbers in which there was a multiple choice. The covered numbers under the headings "A", "B" and "C" give the correct frame to progress to for that particular choice on that particular frame. Of course, each question in the programme had the answers to the question only identified by the labels "A", "B" and "C".

The method of use was for the trainee to enter the board at the frame number which he was working on, assuming that this was a choice frame, and to move across the board until under the column which corresponded to the choice of his answer. He would then black in the appropriate square on the covering sheet, using a soft pencil, and the number which had been hidden underneath the sheet would appear in a similar manner to taking a brass rubbing. The number which appeared would indicate the next frame in the sequence. No other choices would be visible to him, and he would thus have no option but to proceed to the frame indicated. This system cut out the cases where a trainee could cheat by looking at all the possible answers to a question frame, and simply look for the one which told him that the answer was correct. This cheating could damage the correct use of the programme, and this is what the clue board was designed to overcome.

However, this was not the only use of the clue board. In working through a branching programme using a machine presentation, or using a scrambled text in the normal fashion, the trainee leaves no record of his passage through the individual frames, unless he is specifically asked to keep a record of his movements. The keeping of this record is tedious, and also introduces a spurious effect into the programme as the trainee has the impression that he is very much under test conditions at each question, and that each individual choice may be counted against his performance.

In using the clue board method, a trainee leaves a complete record of every choice as he works his way through the programme,,and at the same time he does not feel that he is being asked to do something which is out of the ordinary, or a special form of test, as using the clue board is the normal, and in fact the only, method of working through the programme. Thus the clue board is an extremely useful aid in the testing and validation of the programme, as well as a method of measuring individual performance.

In actual use of the programme, very few attempts have been observed of trainees trying to cheat, and the clue board had obviously been instrumental in preventing these attempts. However, in operation of the programme the main use of the clue board was found to be as an aid in the testing and validation of the programme.

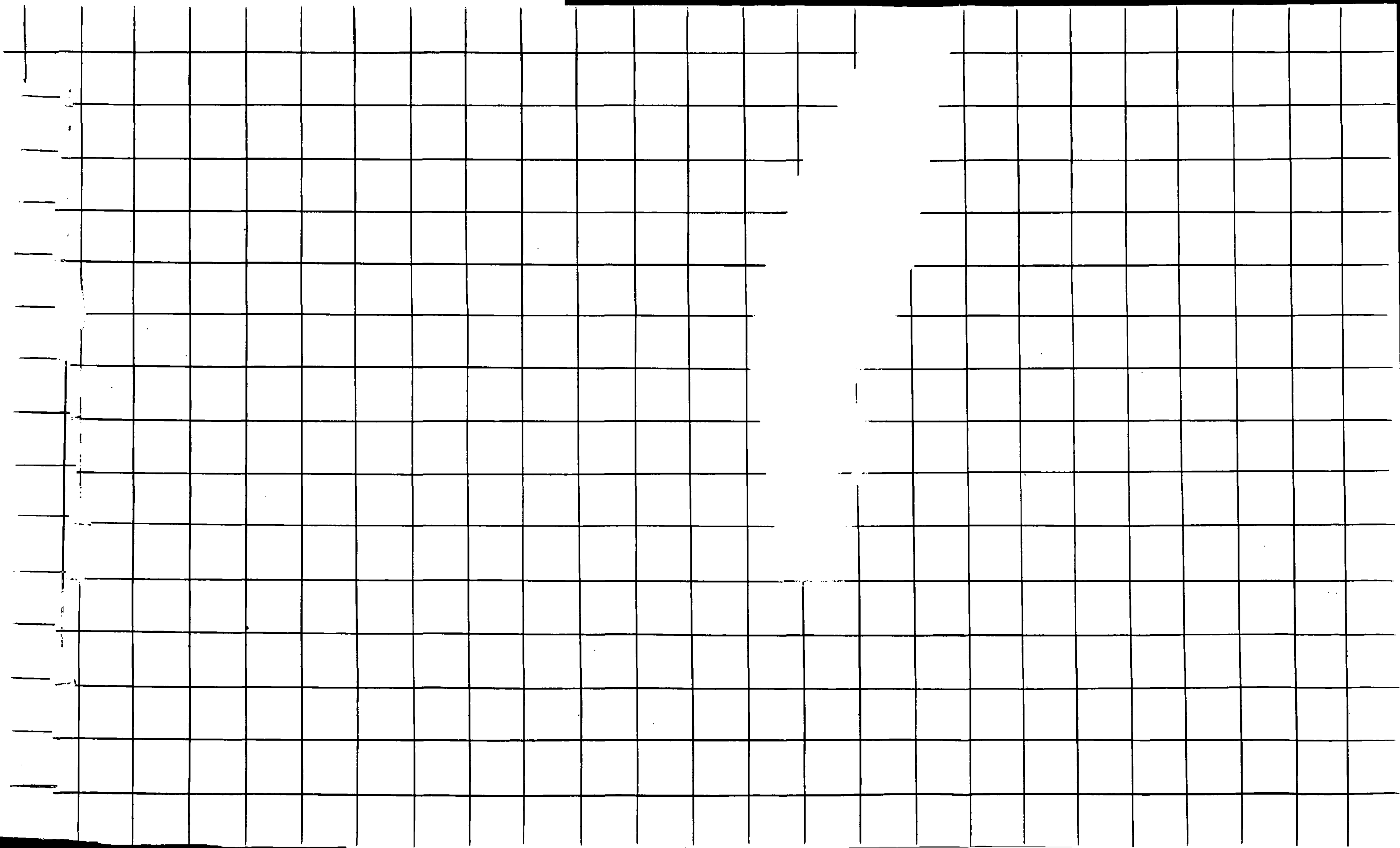
Although this board was found to work satisfactorily, it was felt that further improvements could be made in the design. The main drawback to this original board was that it appeared to have a rather poor finish, and to be amateurish in manufacture. This detracted from the overall impact of the programme. In producing a viable programme, one of the most important considerations is that it should be produced as attractively as possible. This is so that there is no inherent reaction of a detrimental nature from the trainees.

Therefore an attempt was made to produce a more professional looking board. This was produced in the workshops of H.M.S. Collingwood, to the design of the author. The material used for the board was traffolite, a proprietory sandwich material of five or three layers. These layers are alternately black and white. The outermost layer can be removed by an engraving process and will then reveal the other colour underneath. The board can be engraved in this way on both sides.

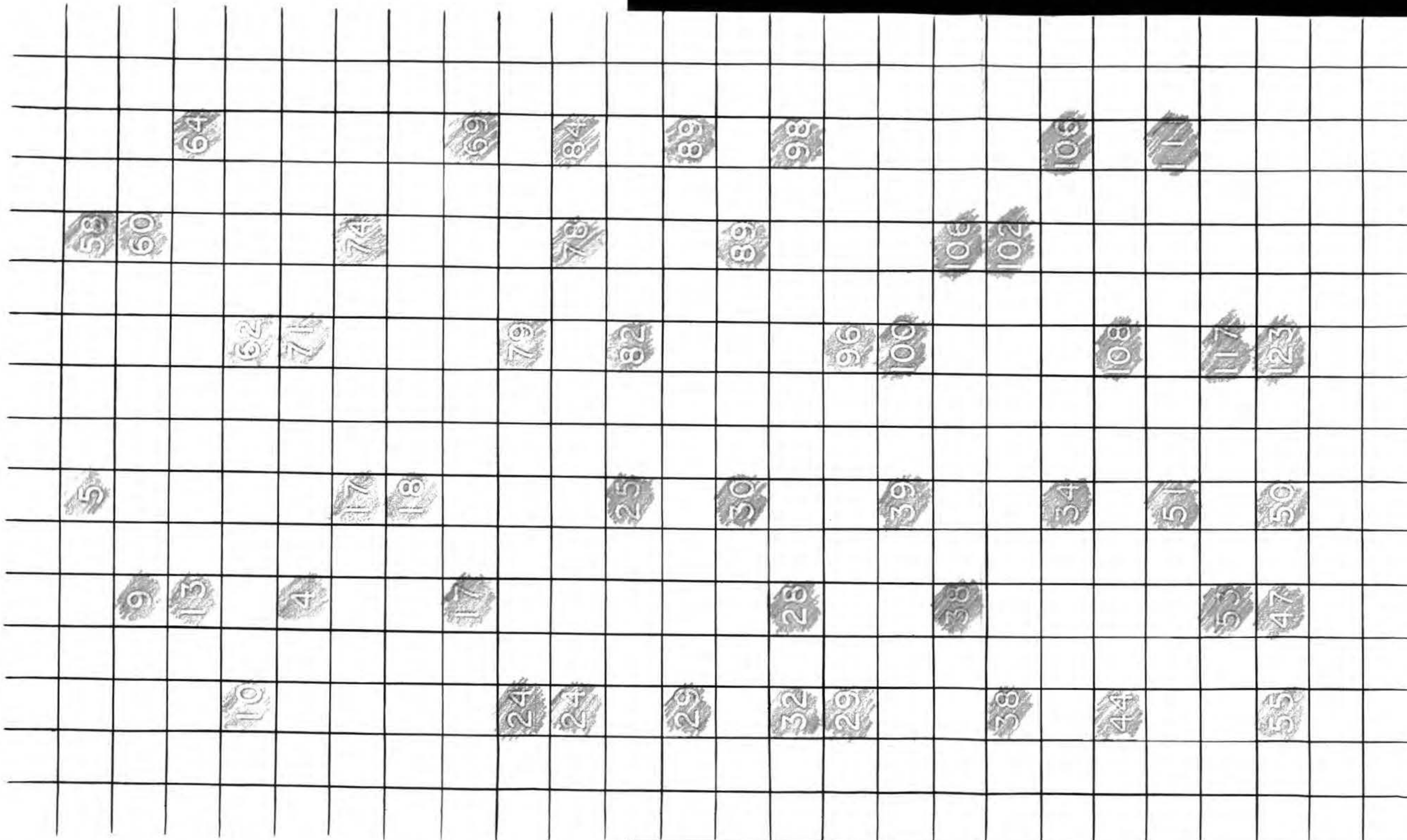
The lay out of these boards was essentially similar to the original board produced with the dymotape. Once again the centre of the board was covered with a clip on sheet of paper, marked with appropriate squares, the frames which had a choice of route having their numbers visible in the columns on either side of the board.

Examples of an unused sheet and a completed sheet are shown over, and an example of this board is also submitted.

EXAMPLE OF UNUSED COVER SHEET FOR TRAFFOLITE CLUE BOARD.



COMPLETED CODE SHEET FOR TRAFFOLITE BOARD



This traffolite board was found to be excellent. The appearance was first class, and the ease with which the hidden numbers appeared when rubbed with a soft pencil meant that there could be no possibility of errors occuring in the use of the board. Unfortunately, it was considered that these boards were too expensive to produce for large scale use, and after the first production batch were completed no more were ordered.

Meanwhile, the search for suitable substitutes was continued. The most reasonable method of those experimented with was to use a sheet of aluminium alloy, of the same type as is extensively used for the chassis of electrical equipment. This was easily obtained as large quantities were in use in H.M.S. Collingwood in the workshops. The method of producing the appropriate numbers on the board was to use a conventional hammer punch. This could be used by any available person, who was not even required to be semi-skilled, and thus the actual production of these sheets was very easy.

The lay out of the board and the size of the board was kept exactly the same as for the earlier boards, so that the existing cover sheets could be retained, and so that there would be no difference between the completed cover sheets using any of the three different types of clue board. An example of this aluminium alloy clue board is also submitted.

The three types of clue board described above were, in fact, those used during testing of the programme. However, while this was taking place a further development of the clue board took place, and it is more convenient to discuss it at this stage than in the correct time sequence.

None of the clue boards designed so far were completely satisfactory. It was still thought that the use of some form of external clue board was essential, but it was hoped that a more convenient type could be designed. The use of these large boards was not always particularly convenient, especially as it was found that there were a large number of requests for copies of the programme to be distributed by post.

However, a completely satisfactory type of clue board was finally discovered. This final type was produced on a special type of tracing paper by the following method.

The grid for the table of numbers is printed on the front of the sheet of paper, and the appropriate numbers are then printed on the reverse of the sheet, in mirror fashion. Because of the type of paper used these numbers show through to the front of the sheet. The "A" , "B" and "C" choice columns are then overprinted on the front of the sheet with a solid layer of a special type of ink. This layer of ink is sufficiently dense for the numbers covered by it to be invisible when viewed from either side of the paper.

An example of this form of clue sheet is shown on the following page.

EXAMPLE OF FINAL TYPE OF CLUE SHEET.

SYSTEMATIC FAULT FINDING SCRAMBLED BOOK CLUE SHEET

D.P.65/6635

FRAME	CHOICE		
	A	B	C
1			
3			
4			
5			
9			
13			
14			
15			
20			
21			
23			
25			
27			
29			
31			
33			
34			
36			
40			
42			
49			
51			
53			

FRAME	CHOICE		
	A	B	C
56			
59			
61			
64			
68			
70			
72			
73			
77			
80			
84			
87			
91			
93			
94			
98			
99			
100			
103			
106			
109			
114			
115			

FRAME	CHOICE		
	A	B	C
117			
119			
121			
122			
123			
126			
127			
128			
141			
144			
147			
149			
151			
153			
155			
157			
159			
161			
166			
175			
176			
180			
185			

FRAME	CHOICE		
	A	B	C
191			
194			
199			
201			
203			
204			
205			
210			
214			
218			
220			
222			
224			
227			
230			
232			
234			
239			
245			
247			
250			
252			

The use of the clue sheet is exactly as before. When a trainee wishes to make a choice of answer, he enters the table at the frame number of the point at which he wishes to make the choice, using the frame numbers visible in the columns which are not blacked out. He then moves across the sheet until he is in the column of his answer choice, either "A" , "B" or "C". He then rubs off the overlay ink from the front of the sheet using any normal type of eraser, and the number printed on the reverse side of the sheet becomes visible. This tells him the frame number of the next frame in his sequence.

This again leaves a permanent record of the trainee's progress through the programme, and enables both his performance to be checked, and the programme to be validated. From the cheat proof aspect, this type of clue sheet was far superior to the earlier types, as the underlying numbers are completely invisible until the overlay is rubbed off. On the earlier types of clue board, the trainee could always remove the overlay sheet to discover the underlying numbers on the board. Although this was never observed in practice, it was a drawback of the original boards.

This final type of presentation was found to be very successful, and the other types of clue boards were kept only for demonstration purposes. The paper sheet was found to be particularly useful when it was necessary to send a copy of the programme by post.

To simplify the use of the programme by class instructors, and to increase the efficiency with which it was used, a further set of information was produced. This took the form of a supplement to the programme and contained the following sections :

1. A brief description of the fault finding method as taught in the programme.

2. A revision sheet and flow diagram of the method.

3. A table showing all possible multiple choices.

4. Flow diagrams of the entire programme, produced to correspond to the sections of the programme.

A copy of this supplement is also submitted with this work.

When these items were ready, a final check on the programme was carried out to determine whether there were any factors which would affect the way in which it would be used. This was effected by giving the programme and clue board to individuals of widely differing abilities and standards, both to check the programme for inconsistencies, and to check the mode of operation. This test proved to be completely satisfactory, and the next stage of detailed testing of the programme was instigated.

CHAPTER 4.

VALIDATION OF THE PROGRAMME.

It was considered to be good programming practice to test the programme itself for internal cohesion before carrying out detailed tests on whether the programme produced a satisfactory improvement in performance. Therefore the first part of the testing of the programme dealt with the programme only, and did not use criterion tests.

In this first test the programme was checked for the presence of any discrepancies, any points at which excess errors occurred, or remedial frames which were in fact left unused. It was carried out with a group of 107 trainees in four different categories as follows :

Radio Electrical Mechanics

Leading Radio Electrical Mechanics

Radio Mechanician Apprentices

Radio Electrical Artificer Apprentices.

There are now three main categories of ratings in the electrical branch of the Royal Navy. These three categories are titled "Radio" , "Ordnance" and "Control". The title does not necessarily describe their duties to a non-specialist. The radio ratings do not only deal with radios, they also have responsibility for radar, navigation aids, direction finding equipment, teleprinters computor equipment, recording devices, and many other associated equipments. They have no responsibility for what might be termed "heavy" electrics including generators and electrical supplies, but do have various responsibilities for weapon systems. All the four groups of ratings used in this test come into this radio category.

The Radio Electrical Mechanics are the junior entries to the radio branch, and are undergoing their first electrical training. These mechanics, whose title is usually abbreviated to "R.E.M." , are mostly of secondary school standard, and will become the semi-skilled tradesmen of the navy on completion of their training. Their task is to work under the direction of more senior ratings, and they would only be given comparatively simple tasks to perform without supervision. The length of their basic course depends upon the age of entry, and the course includes an introduction to service subjects, as well as specialist electrical training. The specialist part of the course lasts approximately six months, and the actual length can depend upon their performance. The equivalent army rank of these ratings is "Private".

After gaining experience at sea, and passing a preliminary examination in technical subjects, the R.E.M. can be rated up to be an R.E.M. First Class. This is the equivalent rank to a Lance Corporal in the army.

The rating then returns to a shore based school for further professional training after a suitable length of service at sea to gain practical experience. An R.E.M. could expect to spend between two and four years at sea before returning for this further professional training, which is held at H.M.S. Collingwood, the Royal Naval Weapons and Electrical School. The length of this course is again approximately six months.

On satisfactory completion of this course, and after satisfying various service requirements, he may be rated up to a "Leading Hand", in this particular case a "Leading Radio Electrical Mechanic", usually abbreviated to "L.R.E.M.". This rating is the equivalent of a

Corporal in the army, and the second group of ratings involved in this test were in this category.

The last two groups in the test population are slightly different from the two groups described above. Also, although they are both classed as apprentices, there is a difference between the two groups. The Radio Mechanician Apprentice can either enter the navy direct, or he may be transferred from another category whilst already serving. He will usually have at least two passes in the Ordinary Level of the General Certificate of Education. If a rating already serving in the navy wishes to transfer to this category, but does not have the necessary qualifications, then there is a means of entry by the successful passing of a service examination of a corresponding level.

The length of the basic course for these ratings is approximately two years, and, on successful completion, they may expect speedy advancement, certainly to Petty Officer, and most probably to Chief Petty Officer. For convenience, the title of this group is usually abbreviated to "R.M.A." .

The Radio Electrical Artificer Apprentices are the most highly skilled group in the test. Artificers are the skilled tradesmen of the navy, and receive long and intensive training. They will all reach the rating of Chief Petty Officer in the course of a normal service career. Entry is by means of interview and selection from the results of the General Certificate of Education Ordinary Level examination, and a high standard of entry is required. The basic length of apprenticeship is four years, and the group used in this test were in the third year of their apprenticeship. They had covered all the basic electrical and electronic theory in the course, and were in the stage of passing on to specific equipments. The title of this group is normally abbreviated to "R.E.A.A." for ease of reference in the service, and the same practice will be used here.

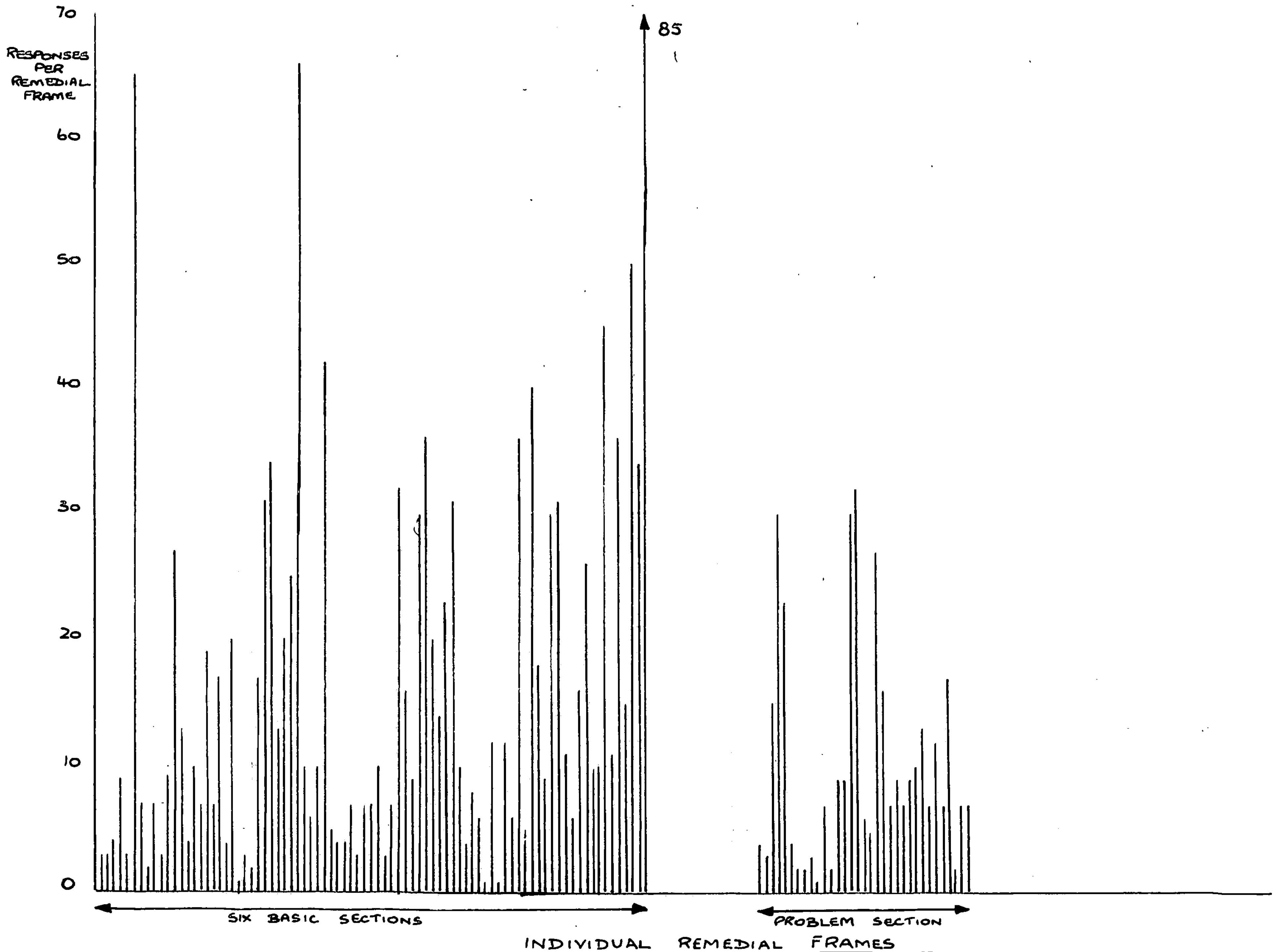
In fact a significant proportion of these R.E.A.A.s will reach commissioned rank in the Royal Navy, as an average of one in three officers are commissioned from the lower deck under various schemes.

For the first stage of this test the completed overlay sheets were used which each trainee had produced from the clue board whilst working through the programme. These clue sheets were studied to discover the frequency of response on each frame of the programme.

Initially the test was carried out by keeping a straight tote of the numbers of trainees using each frame. It was decided that the numbers using each correct frame need not be counted, and the list of frame numbers was amended so that it only included remedial frames. At the same time a record was kept of the time taken to work through the programme.

The diagram overleaf shows the number of responses for each remedial frame in the programme, given in the order of completion, i.e. with the trainee's result who took the least time on the extreme edge of the left hand side, and the result of the trainee taking the longest time on the right hand side. For convenience, the results are split into the first six basic sections of the programme, and the problem section. These results are for a total of 107 trainees. (Fig 4.1)

Fig 4.1


70
60
50
40
30
20
10
0
RESPONSES PER REMEDIAL FRAME
85
SIX BASIC SECTIONS
PROBLEM SECTION
INDIVIDUAL REMEDIAL FRAMES

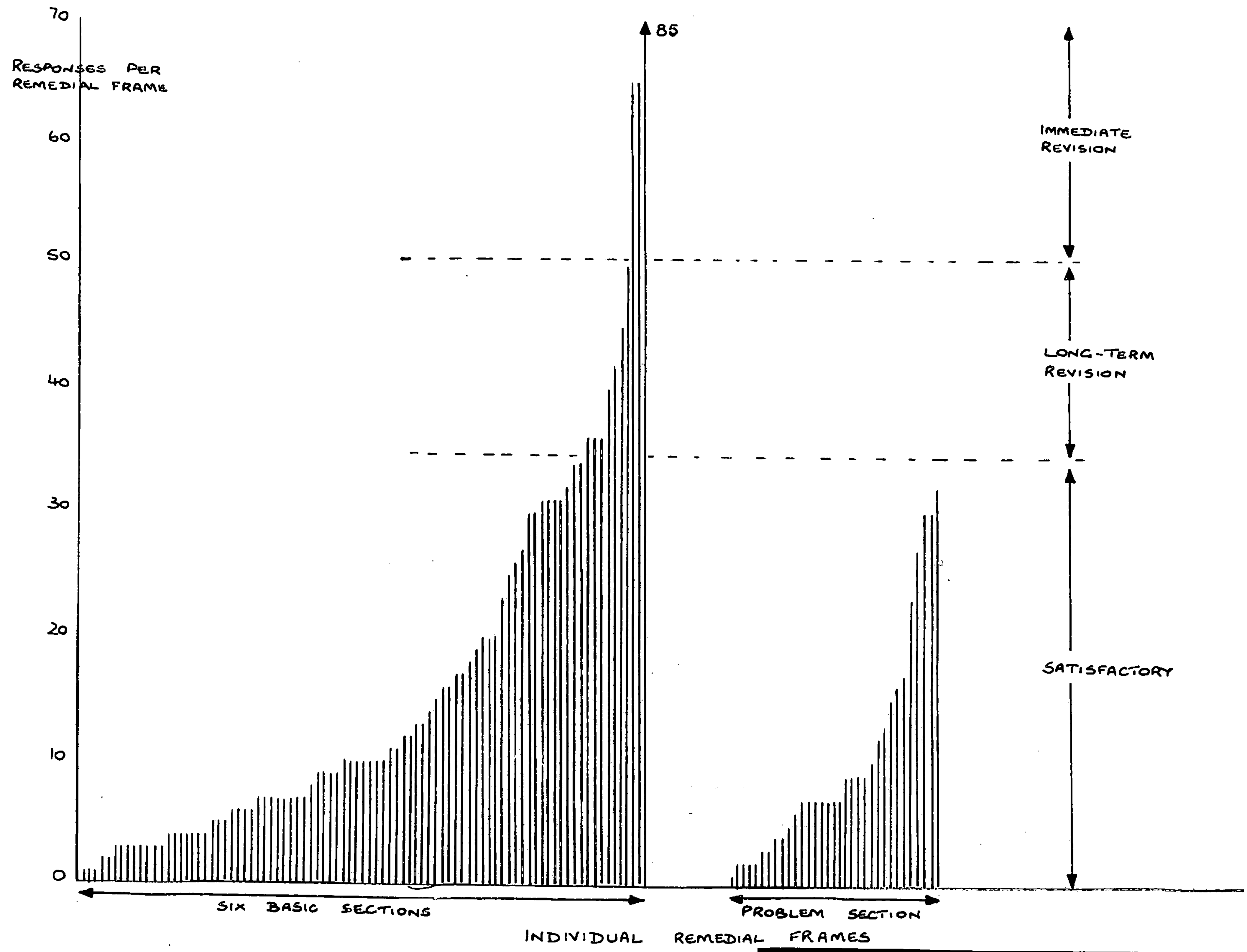
The results were then re-plotted in ascending error rate, as shown in fig. 4.2 overleaf.

It should be remembered that as well as the division of the programme into sections to correspond to the six basic steps of the fault finding method, there was also a section after this where three actual fault finding problems were posed, the trainee being led through the solution of these problems to consolidate the six basic steps into a composite fault finding method. It was hoped that if the six basic steps were understood, then the error rate in the section of the programme dealing with these three problems would be less than the error rate for the first six sections of the programme.

In order to show the results separately, the results up to and including frame 189, which are those concerned with the six basic steps, are shown on the left hand side of figures 4.1 and 4.2, and the results from frame 190 onwards are shown on the right hand side of the diagrams. The frames from 190 onwards deal with the three problems given in the programme.

It appears from these two diagrams that the error rate

Fig. 4.2


70
60
50
40
30
20
10
0
RESPONSES PER REMEDIAL FRAME
85
IMMEDIATE REVISION
LONG-TERM REVISION
SATISFACTORY
SIX BASIC SECTIONS
PROBLEM SECTION
INDIVIDUAL REMEDIAL FRAMES

of the problem section is lower than the error rate for the first six basic sections. However, the total possible errors on the problem section are rather lower than on the previous sections, and thus direct comparison is not possible. This will be considered later.

The first diagram showed the error rate for each remedial frame in the programme in order, and no immediate pattern appears to emerge.

There are a total of 87 remedial frames in the first six sections of the programme, and 35 remedial frames in the problem section. In each case the figures are for a sample of 107 trainees.

As an immediate measure, frames which had a response rate of greater than 50% were considered for revision. There were only three of these frames in the first part of the programme, and none at all in the problem section. This was the first real indication that the programme could be successful. (Fig 4.2)

The three frames in question, 11, 54 and 187 were examined in an initial attempt to discover reasons for this high error rate.

The first frame with a high error rate was frame 11. The error rate on this frame was 65 incorrect responses out of a total of 107 trainees, or approximately 61%. This frame required trainees to distinguish between considering all the symptoms of the fault collectively, or considering the symptoms one at a time. The programme had in fact taught that all the symptoms should be considered collectively. However, the answer that they should be considered one at a time was not completely incorrect, and it was felt that this mistake was comparatively unimportant for the overall purpose of the programme, and it was decided that this did not require immediate revision.

The second frame with a high error rate was frame 54. Again there were 65 incorrect responses from a total of 107 trainees, or approximately 61%. This was in part a trick question, in that earlier in the programme an almost identical set of circumstances had been shown to have a certain solution. On this frame the circumstances were very slightly altered, necessitating a different solution.

However, it was thought reasonable to leave this frame as it stood, as it showed an extremely important facet of fault finding in that circumstances are never exactly the same in two cases, and that the approach to the solution of the problem must be accordingly modified in each separate fault finding problem.

The third frame with a high error rate was frame 187 with 85 incorrect responses, the error rate being approximately 80% . This frame was definitely felt to require revision to make the programme fully effective.

However, as there were only three frames on the whole programme with a high error rate, the decision concerning revision was taken out of the author's hands. Superior officers decided that the pressure to have this programme in the field as soon as possible precluded a revision and reprint of the programme at this stage for only three frames. The solution chosen was to place particular emphasis on these points when the programme was followed up with live instruction.

Therefore it was considered that this simple test provided strong evidence of the basic suitability of the programme, and that further testing should be carried out.

However, before proceeding with further tests, it was now convenient to consider long term revision of the programme. For this purpose it was decided to take a figure of one third total response rate as the limit at which to undertake revision. Thus all frames with a response rate of greater than 34 should be investigated.

In the first six sections of the programme, the basic method, there were ten such frames, and in the problem section there were no frames which had an error rate greater than 32. (Fig 4.2, page 88) Even with this smaller error rate the programme was written in such a way that the revision necessary was minimal, and the programme in its present state was a suitable vehicle for further tests.

It was not possible to carry out revision down to this one third error level at this time, but a note of frame numbers requiring this revision, and of possible revised versions and additions, was kept ready for a second edition of the programme, if it proved to be successful in the primary object of improving fault finding performance amongst electrical ratings in the Royal Navy.

Before leaving this first test, two further diagrams can help to summarise the results, shown overleaf.

Fig 4.3 Histogram showing the error rate for 107 trainees on the first six sections of the programme.

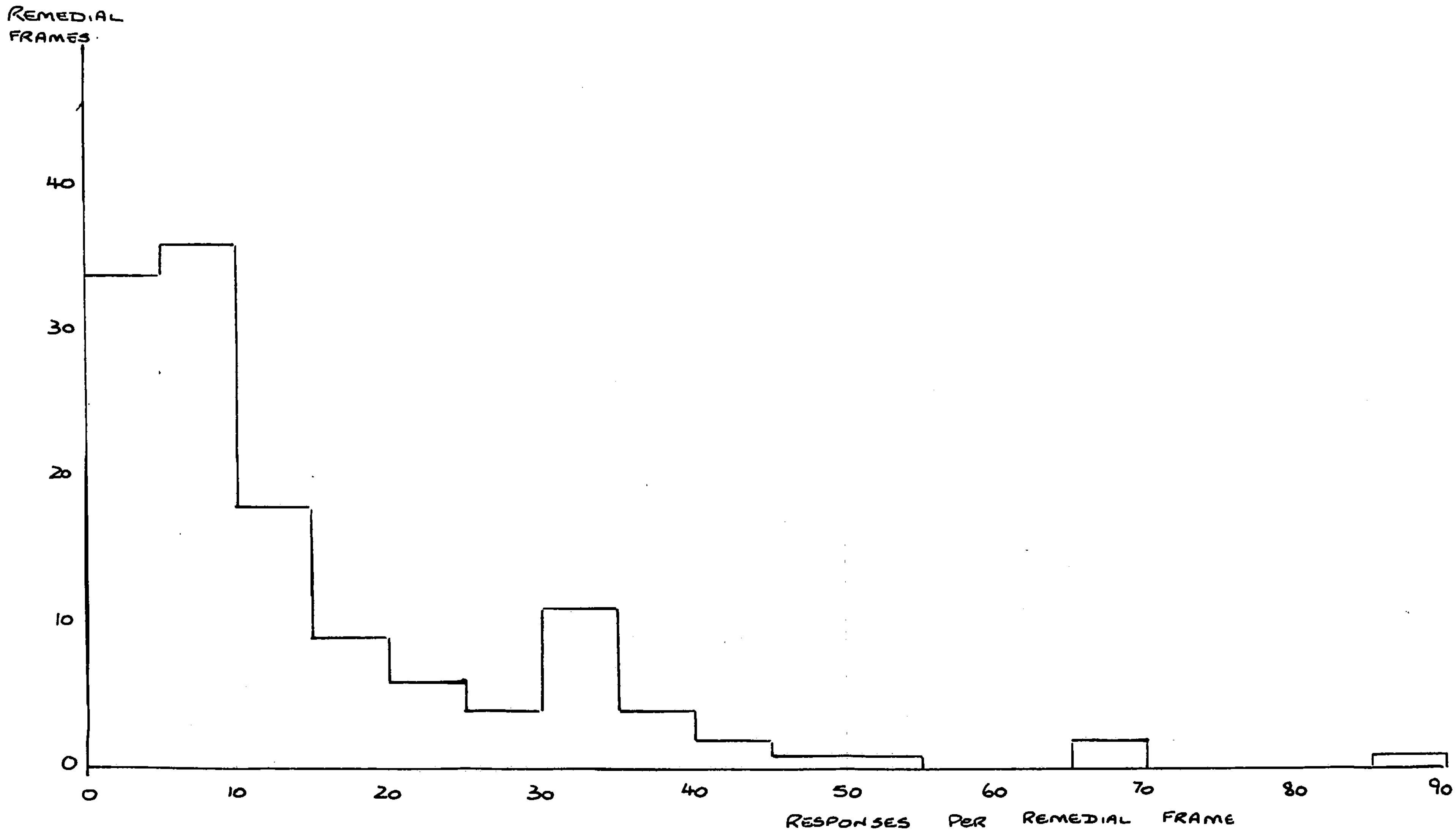
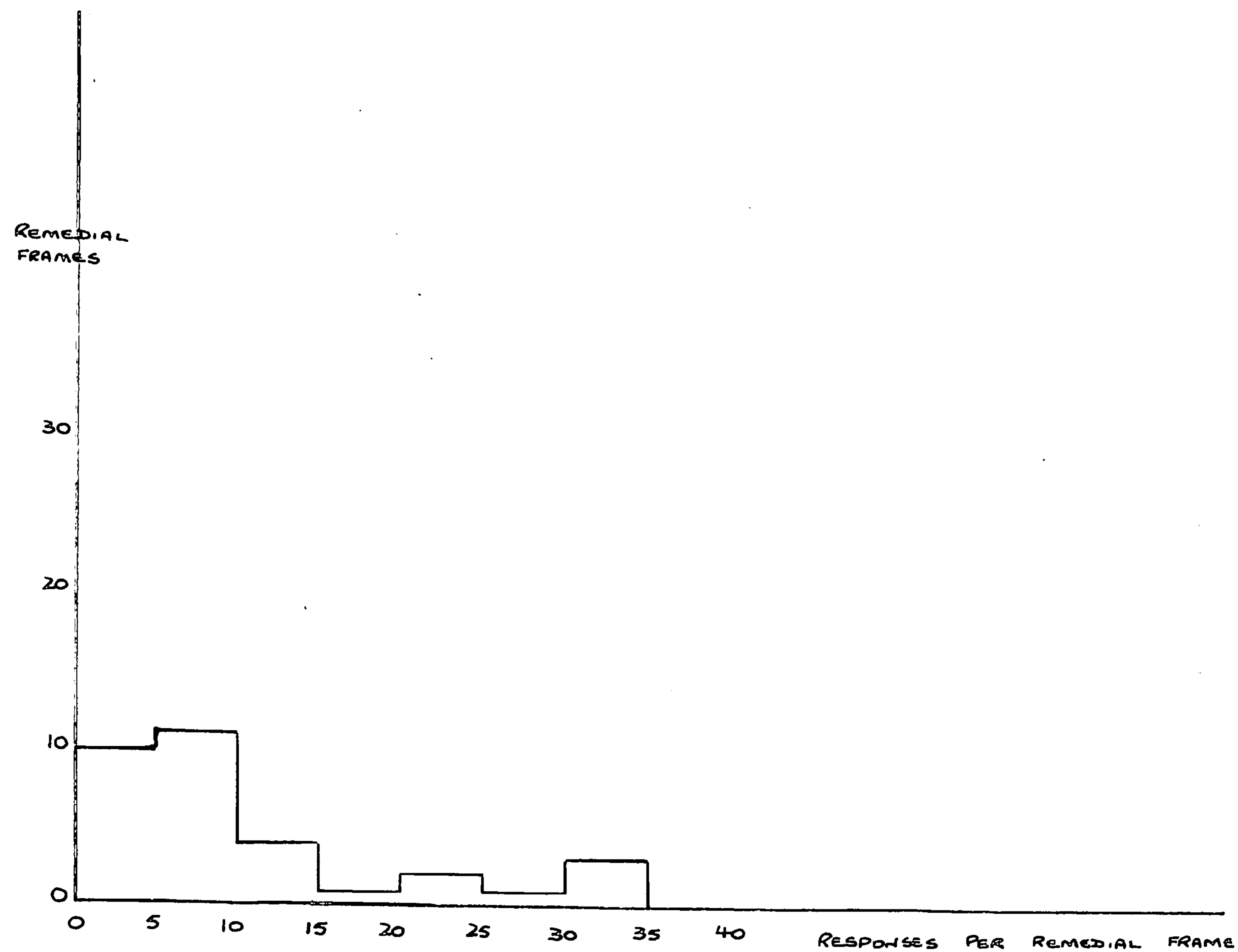


Fig. 4.4 Histogram showing the error rate of 107 trainees on the problem section of the programme.



It has already been stated that this programme would be given to different types of ratings if it proved to be successful. Therefore it was felt to be important to investigate the error rates for each separate group of the different categories which would be working through the programme. These categories would in fact be the four groups already named as being in the test population. The purpose of this test was to ascertain if the programme was suitable for all these different levels. An investigation into comparative error rates was therefore carried out. The figures obtained during this investigation are summarised in the following table.

Group	Number in Group	Average error rate	Standard Deviation	Highest error	Lowest error
REM	70	20.2	6.9	35	7
LREM	14	14.4	5.5	26	8
RMA	27	14.9	5.1	33	2
REAA	22	12.4	6.6	26	2

It can be seen that there is remarkably little difference between the different groups for this test.

A comparison of the different groups was undertaken to see if there was any significant difference in the error rates for the different groups in the test population.

For this purpose, the two types of apprentices, Radio Mechanician Apprentices and Radio Electrical Artificer Apprentices, were taken as one group, and the two types of mechanics were taken as the other group. The courses taken by trainees within these groups were essentially similar.

The comparison was based on a chi-squared test for two independant samples.

The categories used were levels of performance in the programme taken from the error rates. These rates were split into four groups as follows :-

Group 1	0 - 10	error frames used
Group 2	11 - 20	error frames used
Group 3	21 - 30	error frames used
Group 4	31 - 40	error frames used

The sample was then summarised for the two groups, apprentices and mechanics, according to these categories.

The following table shows the results obtained in this way :

	Apprentices	Mechanics	Total
Group 1	12	9	21
Group 2	30	42	72
Group 3	7	24	31
Group 4	0	9	9
Total	49	84	133

The hypothesis is that the two groups differ with respect to some characteristic of their training, and therefore to the relative frequency with which group members fall in several categories.

For the above results, chi squared equals 10.7 for three degrees of freedom, with a significance level of 0.02 .

Thus the null hypothesis is rejected, and it would be expected that a trainee in an apprentice group would have a lower error rate than the trainee in a mechanic group. This is borne out by the average error rates of the various groups.

This result comes as no surprise, but it is interesting to note the comparatively small difference between the groups. It is considered that these results do not provide evidence that the programme was not suitable to give to all members of the experimental population. In all cases the number of error frames used by the trainees in working through the complete programme lies within acceptable limits.

As well as the classes of trainees on career courses used as the experimental group in this series of tests the programme was given to several other individuals. These were ratings and officers who could be given the programme on an opportunity basis, some of them being on other courses, and some being on the staff of the school or part of the ship's company.

Some of these individuals could be included with the classes under test because of their category of rating, level of training and practical experience in electrical and electronic work in the Navy. However, some of these individuals were not capable of being fitted into the four categories of the test population. These individuals consisted of senior ratings and officers, but the number involved was too small to allow statistical results to be obtained. However, there were several results obtained with individual ratings which can be included in the test population, as well as the actual test classes, and these have been included where appropriate, making the actual total greater than the 107 trainees involved in the detailed tests.

Detailed results of the individual error rates obtained from the completed clue sheets of the total sample are shown in the following four diagrams. In each group, the first diagram shows the individual error rate in answering the questions included in the programme in the order of completion of the total programme. The second diagram in each case shows the individual error rates drawn in ascending order.

The results from the small number of officers and senior ratings working through the programme fall within the general limits of these detailed results.

Fig. 4.5 R.S.M. test group. Individual error rates in answering questions in the programme.

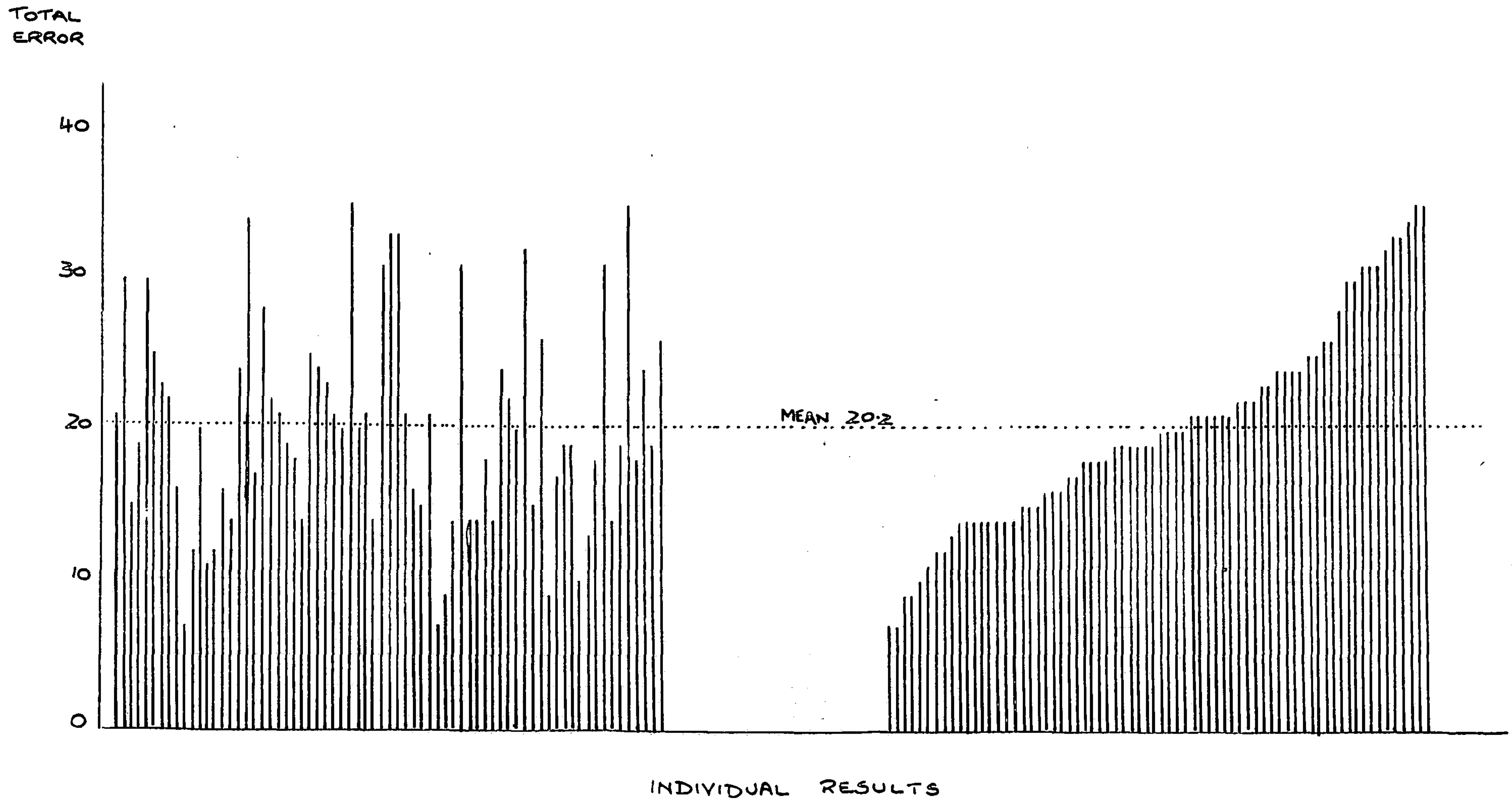


Fig. 4.6   L.[illegible].E.[illegible]. test group.   Individual error rates in answering questions in the programme.

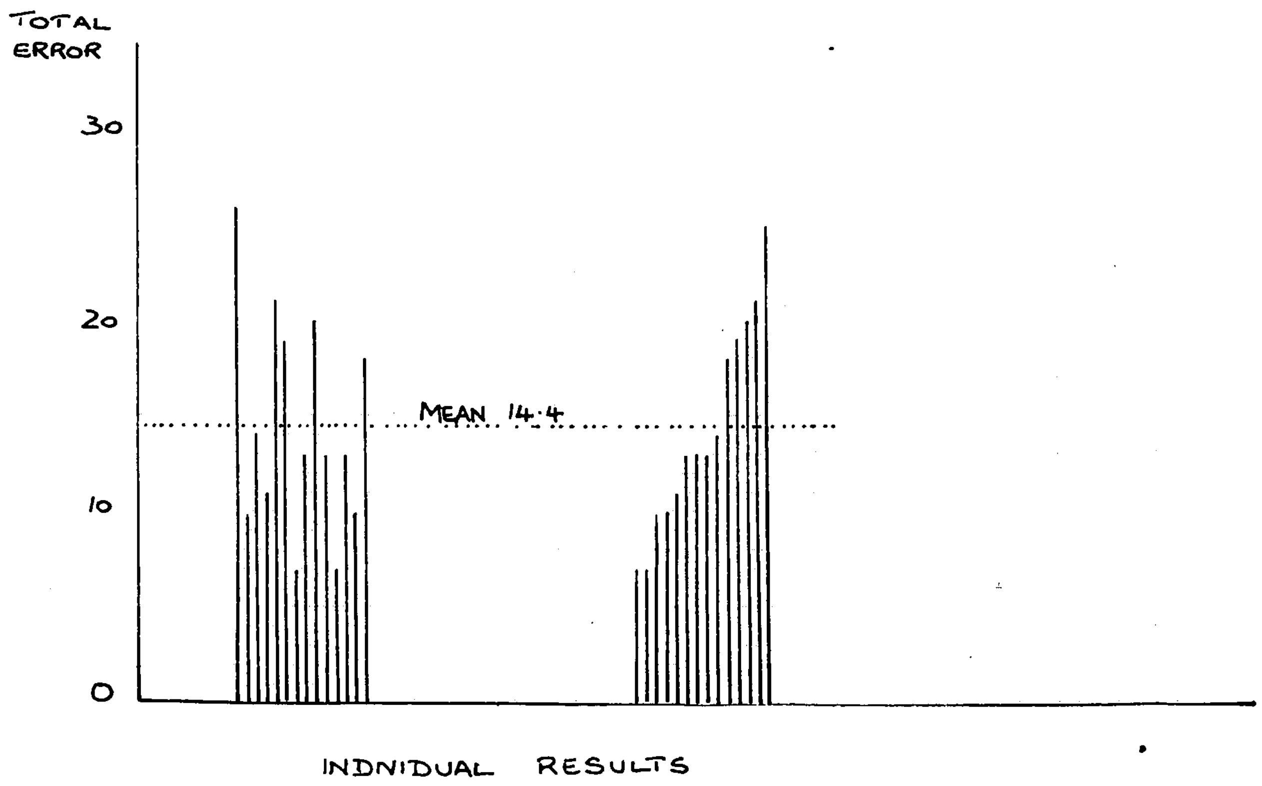


Fig. 4.7 R.M.A. test group. Individual error rates in answering questions in the programme.

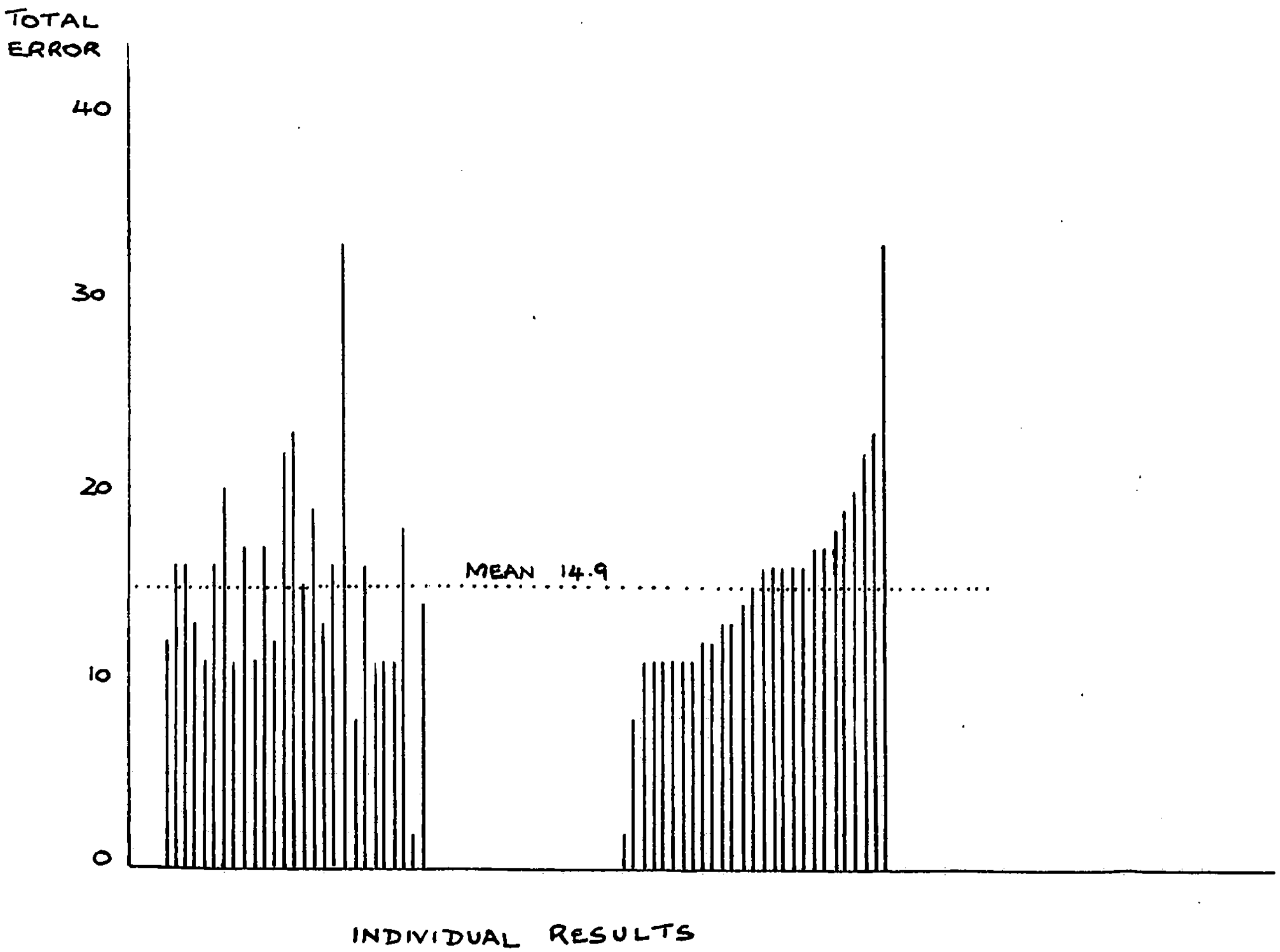
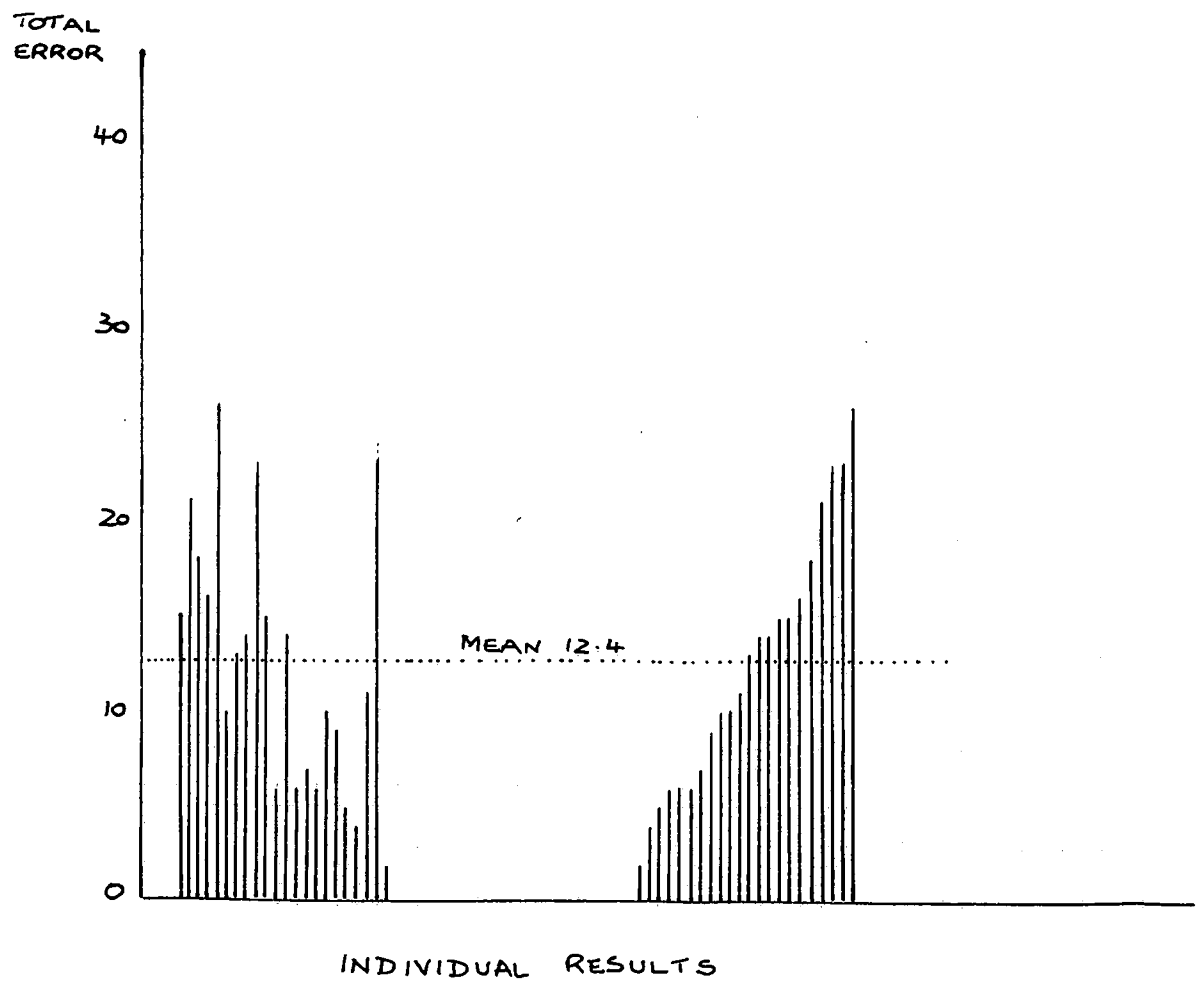


Fig. 4.8 R.E.A.A. test group. Individual error rates in answering questions in the programme.



It has already been described how a check was kept on the time taken by each trainee to complete the programme. This time was measured to the nearest ten minutes. All trainees were instructed that the time taken to complete the programme was relatively unimportant compared to the full understanding of each frame. The time taken was measured by noting the time of issue and the time of return of the programme during lesson periods. Thus the trainees were unaware that they were being timed and there was no particular incentive to rush through the programme. All measurements of time taken should therefore be true measurements, unaffected by external factors.

The results of this test are summarised in the following table.

Group	Number in group	Average time in minutes	Standard deviation	Longest	Shortest
REM	69	182	47.8	260	70
LREM	14	134	41.1	230	80
RMA	27	137	43.8	210	40
REAA	19	149	37.6	220	60

Longest and shortest times are measured in minutes.

The individual results for all trainees participating in this test are shown in the following diagrams, (Fig. 4.9 to Fig. 4.12 inclusive) The results are shown according to the four groups involved in the test, i.e. Radio Electrical Mechanics, Leading Radio Electrical Mechanics, Radio Mechanician Apprentices and Radio Electrical Artificer Apprentices. The first diagram in each group shows the time taken in order of ascending numbers of remedial frames used during the programme, and the second diagram in ascending time taken to complete the programme.

These diagrams are shown overleaf.

The time taken by the different groups of trainees show surprisingly small variations considering the differences in ability and experience. The R.E.M.s took the longest time, as would be expected from the group with the smallest amount of training and experience. However, the spread of the results, and the total variation of each group are fairly similar. This provides a further argument in favour of the possibility of using the programme to equal effect on a range of trainees with differing amounts of training and experience.

Fig. 4.12 Time taken by [illegible].E.A.A. group.

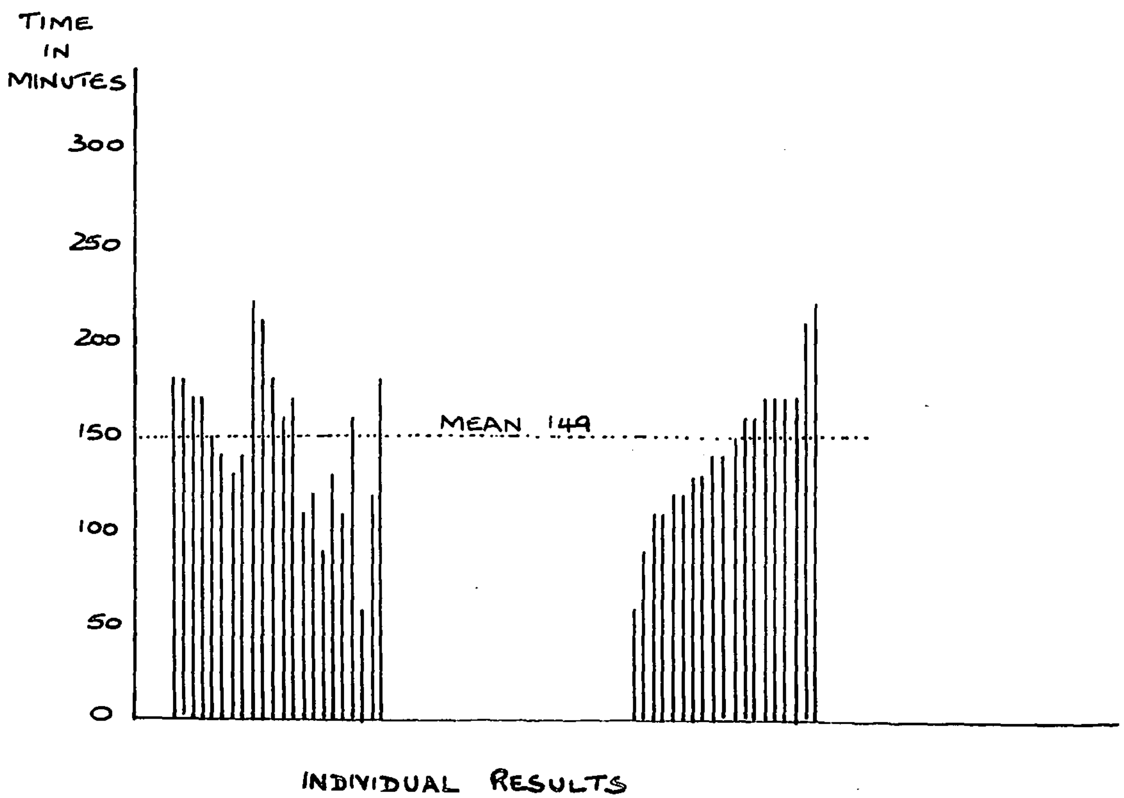


Fig. 4.11 Time taken by R.M.A. group.

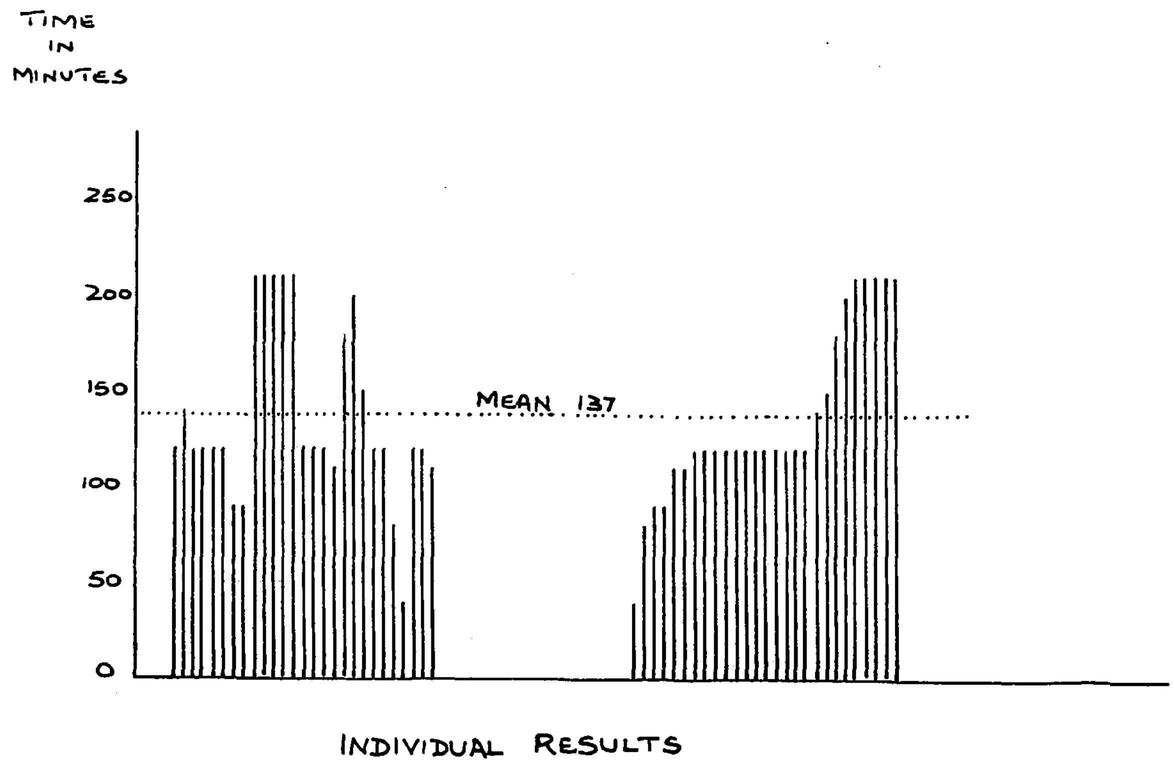


Fig. 4.10 Time taken by [illegible] group.

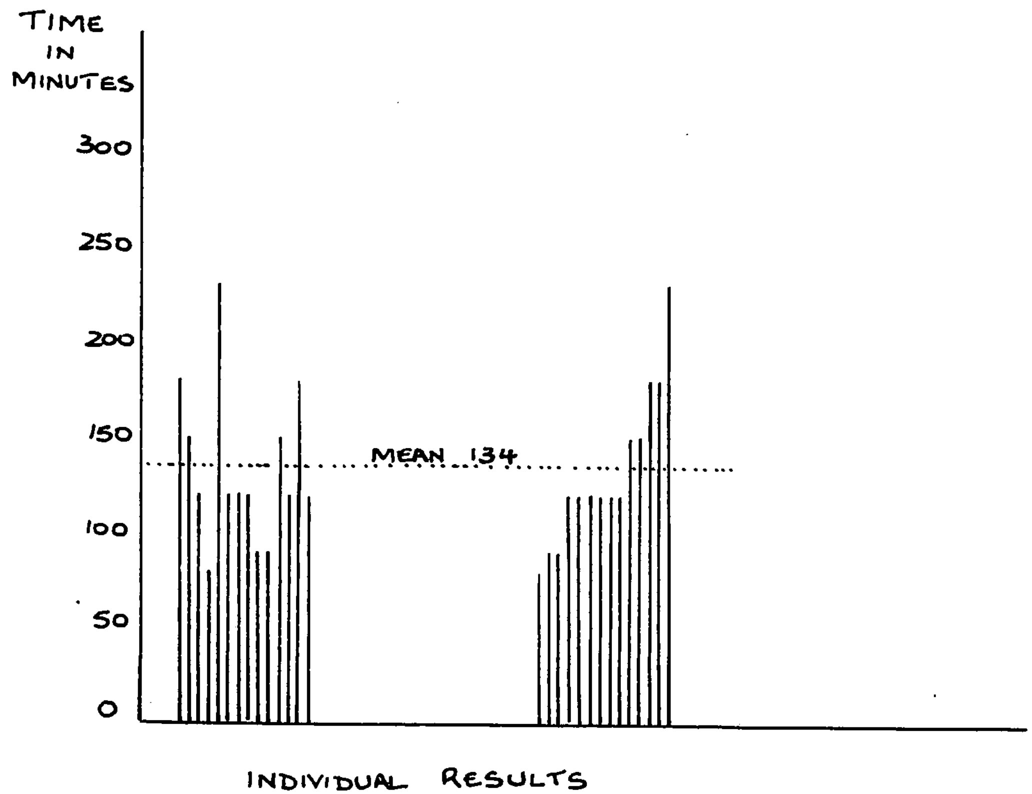
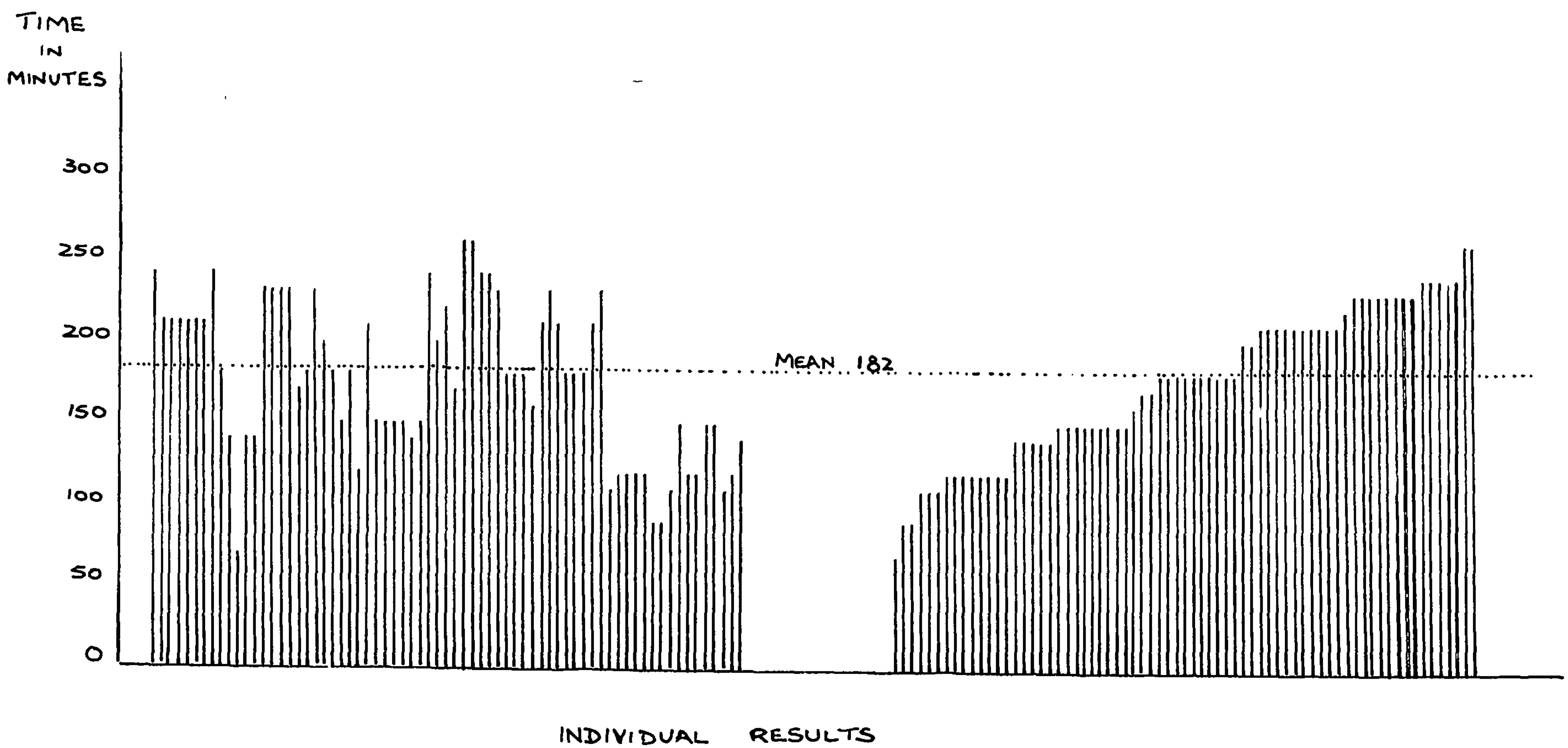


Fig. 4.9 Time taken by R.E.M. group.



As for the raw error rate on the programme, a comparison on performance was carried out for the two basic groups involved, the mechanics or semi-skilled personnel, and the apprentices or skilled personnel. The parameter was the time taken for each individual to work through the programme.

A chi squared test was carried out to determine the probability of the two groups having a different level of performance produced by intrinsic factors of the groups rather than the programme.

The categories used for the chi squared test were taken from the number of minutes each trainee took to work through the programme. Having regard to the average time for each group, and the spread of the times, the categories decided upon were four in number, with the following composition :

Group 1	0 - 75 minutes
Group 2	80 - 150 minutes
Group 3	155 - 225 minutes
Group 4	230 minutes and above

As the times were only measured to the nearest five minutes, there were no intervals of less than five.

The test population was then summarised for the two main groups, the apprentices and the mechanics, classifying each individual according to the four categories shown above. The following table shows the results obtained in this way.

	Apprentices	Mechanics	Total
Group 1	2	1	3
Group 2	29	38	67
Group 3	18	28	46
Group 4	0	16	16
Total	49	83	132

A value for chi squared was now computed at 11.7 for three degrees of freedom, giving a level of significance of $p<$ 0.01 . Thus a difference of performance on the time taken was to be expected. This can also be suspected from the average times of the four groups of the orginal test population.

Although the apprentices had a better performance, the most important factor is whether the programme was suitable for all groups in the test population. The results for the time taken do in fact show that the parameter as measured was satisfactory for all groups.

However, it was decided that these tests did not completely specify the internal cohesion of the programme, and the level of performance of each trainee who worked through it. A further test was therefore prepared to test the error rates of trainees in the programme by a second check on the remedial frames used.

For this test a scheme of weighting each remedial frame was produced. This weighting scheme gave each remedial frame a certain score, termed the weighted error, which depended upon the extent of the mistake which led the trainee to that particular remedial frame. There would obviously be different levels of lack of understanding of the content of main frames, and this would be shown by which actual incorrect response was given when working through the programme. Some answers to the questions on the main frames would be slightly incorrect, whilst others would be grossly incorrect.

If the programme was correctly written, then the extent of the error in giving an incorrect answer would be shown by the amount of remedial action deemed necessary to correct the mistake. A general measure of the amount of remedial action given could then be measured from the extent of the remedial loop in that part of the programme.

This would only be so if the programme had already been shown to be satisfactory in content and progression. Any remedial frames which were used by too large a proportion of the trainees would show an inherent fault in the programme, either due to incorrect question techniques or to lack of explanation. In this case a false estimate of the performance of the trainees would be given, and it would be impossible to use this weighting scheme.

However, by keeping a straight forward record of the numbers of trainees using each remedial frame, as discussed above, it had already been shown that there were no points in the programme where excess error rates occurred. Therefore the progression of the main frames, and the extent and content of the questioning, had already been shown to be satisfactory. It was thus felt possible to proceed with this weighted error scheme.

Weighted scores were then worked out for each remedial frame, based mainly upon the amount of remedial action given in the programme to correct this mistake. This score actually varied between one and twelve.

Detailed results were then obtained from the test groups, and a record kept of ech trainees' total weighted error score on the programme. This record was kept in two sections, the first being the weighted score on the first six basic sections teaching the fault finding method, and the second being the weighted score on the three worked examples of actual faults designed to tie the method into a composite series of actions. It was hoped that this would show the relation, if any, between the amount of error made in learning the basic method of fault finding, and the amount of error made in learning how to apply the method to an actual fault.

However, a total weighted error for each trainee would show little more than the straight forward count of errors made during the programme. In general, if a remedial frame had a high weighted error, and thus showed a more serious mistake, it would be hoped that fewer trainees would give this answer than the number using a remedial frame which had only a small weighted error. A simple formula was therefore devised which would show the severity of each remedial frame, depending both on the number of trainees using that frame, and on the weighted error for that remedial frame. In fact the total weighted error fro each remedial frame was considered as the weighting of the frame multiplied by the number of trainees using that frame. This meant that six trainees using a remedial frame with a weighting of four was held to be equivalent to twenty four trainees using a remedial frame with a weighting of one.

In the first test on the programme, where a straight total of remedial frames used by each trainee, and the numbers of trainees using each remedial frame, was kept, it was considered that frames which were used by 50% or more of the trainees required immediate revision. Using the weighting system, this could be modified so that the total weighted error for each remedial frame should not exceed this value.

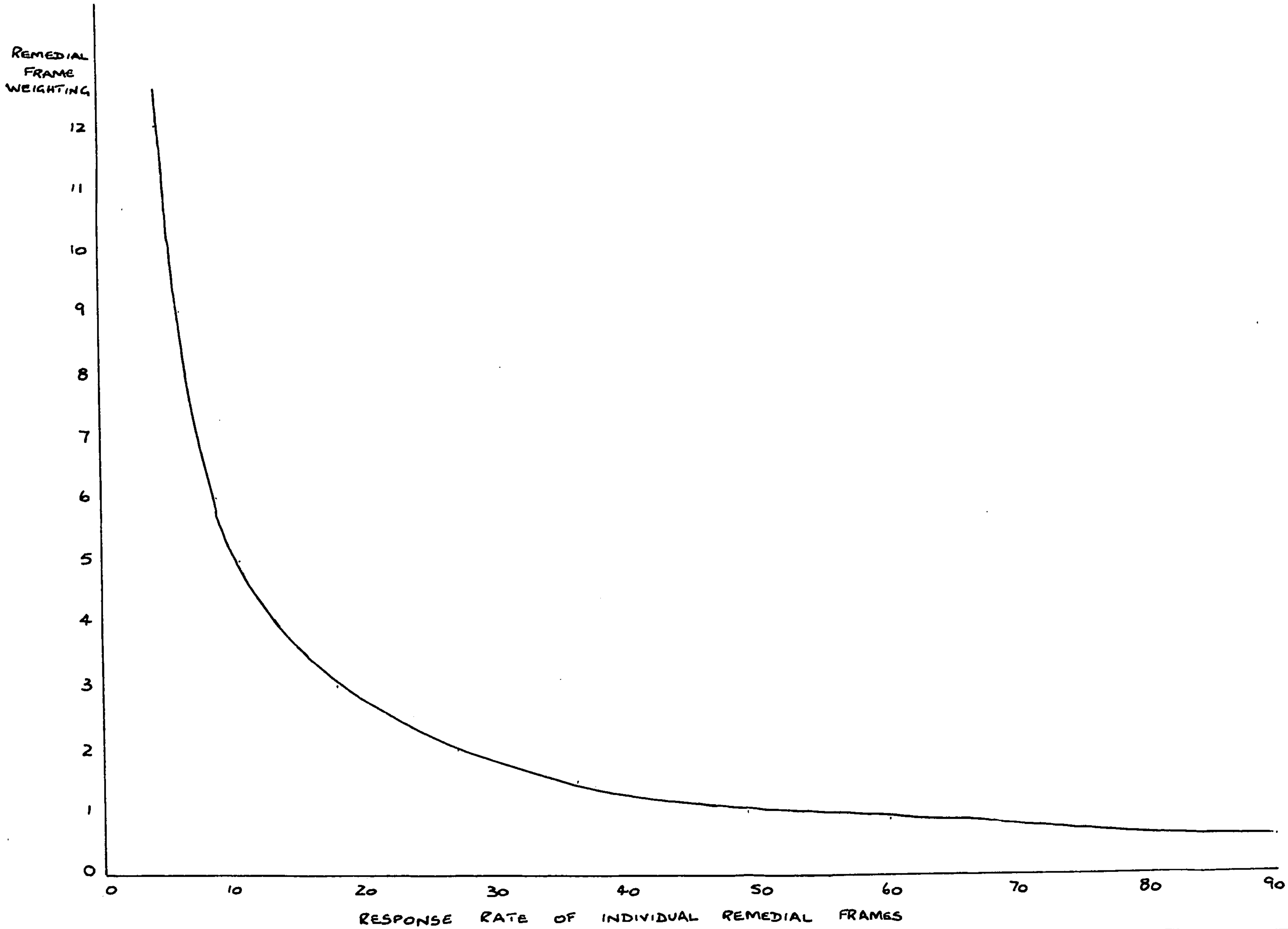
There were 107 trainees involved in this test, and therefore for the remedial frames which had a weighted error of one, not more than 53 trainees should use that particular remedial frame if the programme was to be considered successful in this test. Similarly, for a remedial frame with a weighting of two, not more than 27 trainees should use that remedial frame; for a remedial frame with a weighting of three not more than 18 trainees should use the frame, and equivalent numbers could be worked out for each weighting. These values can be plotted on a graph, which we can term the curve showing the norm of responses. This graph (Fig. 4.13) is shown on the following page.

The results for each remedial frame in the programme could now be plotted on this graph. Any points which fall below the curve are satisfactory, and any points which fall outside the curve can be considered as needing further investigation with a view to possible revisions.

For ease of reference, the results were divided into two groups. The first group contained the results for each remedial frame in the first six basic sections of the programme, and the second group contained the results for the section of the programme which dealt with the three actual problems on fault finding in specific circuits.

Two graphs of results were then plotted. In each case the remedial frames are divided into groups corresponding to their weighting, and the number of

Fig. 4.15 Curve showing the "norm" of response rate for different weightings of remedial frames.



trainees using that particular remedial frame. The first graph, (Fig. 4.14 on page 114), shows the responses for the first six sections of the programme. The second graph, (Fig. 4.15 on page 115), shows the responses for the section of the programme dealing with the three fault finding problems. Those remedial frames whose results are above the norm are marked with the actual frame number.

In the diagram for the fisrt six sections of the programme, (Fig 4.14), nine remedial frames lie outside the curve for the norm. Their frame numbers are 11, 21, 24, 46, 54, 65, 91, 99, and 187. Of these nine frames, three requiring revision were picked out in the first test on the straight forward incidence of trainees on remedial frames in the programme, and thus this test has discovered six more frames requiring revision. These six further frames had then to be investigated with a view to necessary revisions.

Before looking at the actual frame content, it was necessary to know how far each frame deviated from the norm of weighted responses. This deviation was therefore calculated for each of these frames.

Fig. 4.14. Weighted response for each remedial frame in the first six sections of the programme.

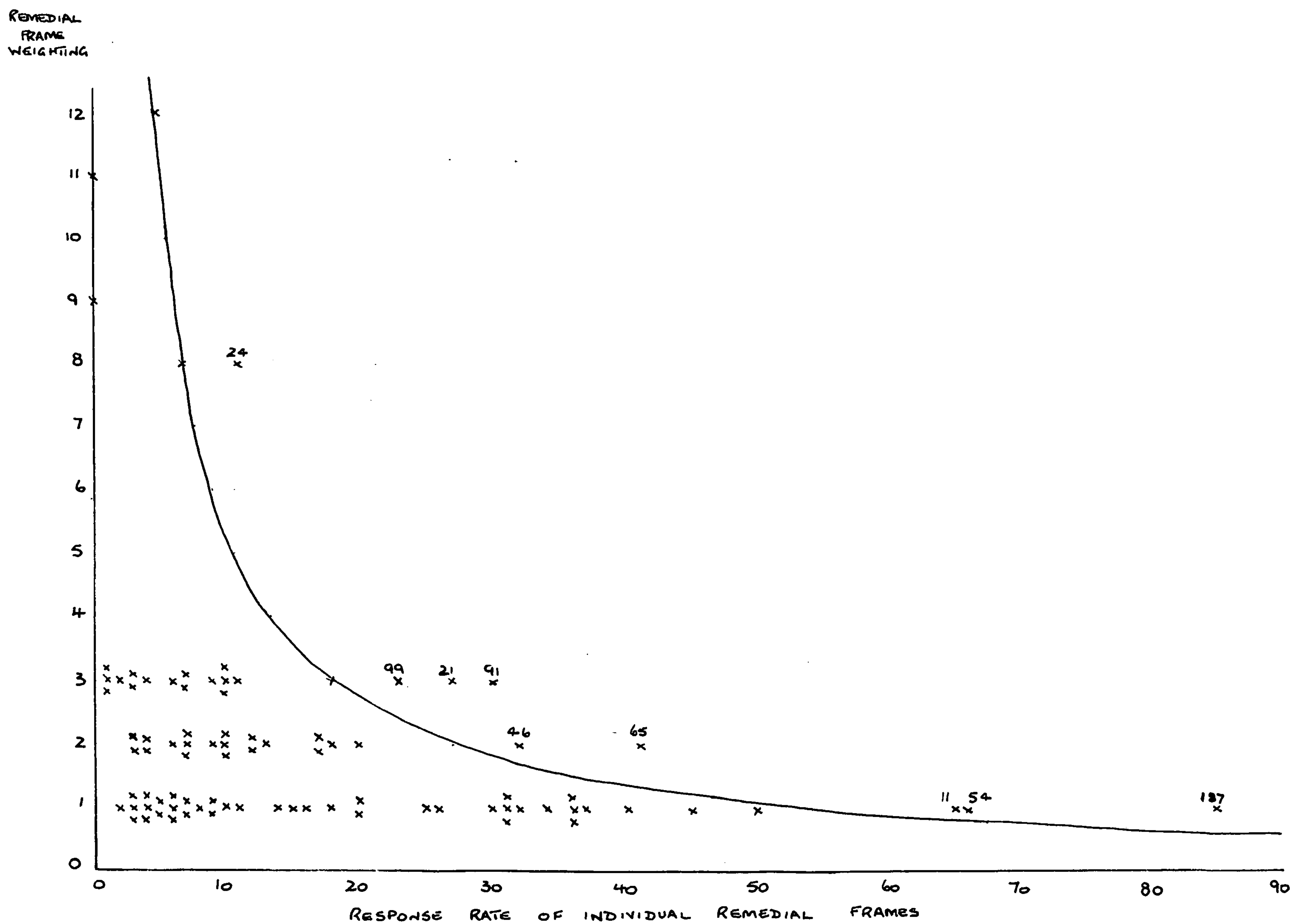
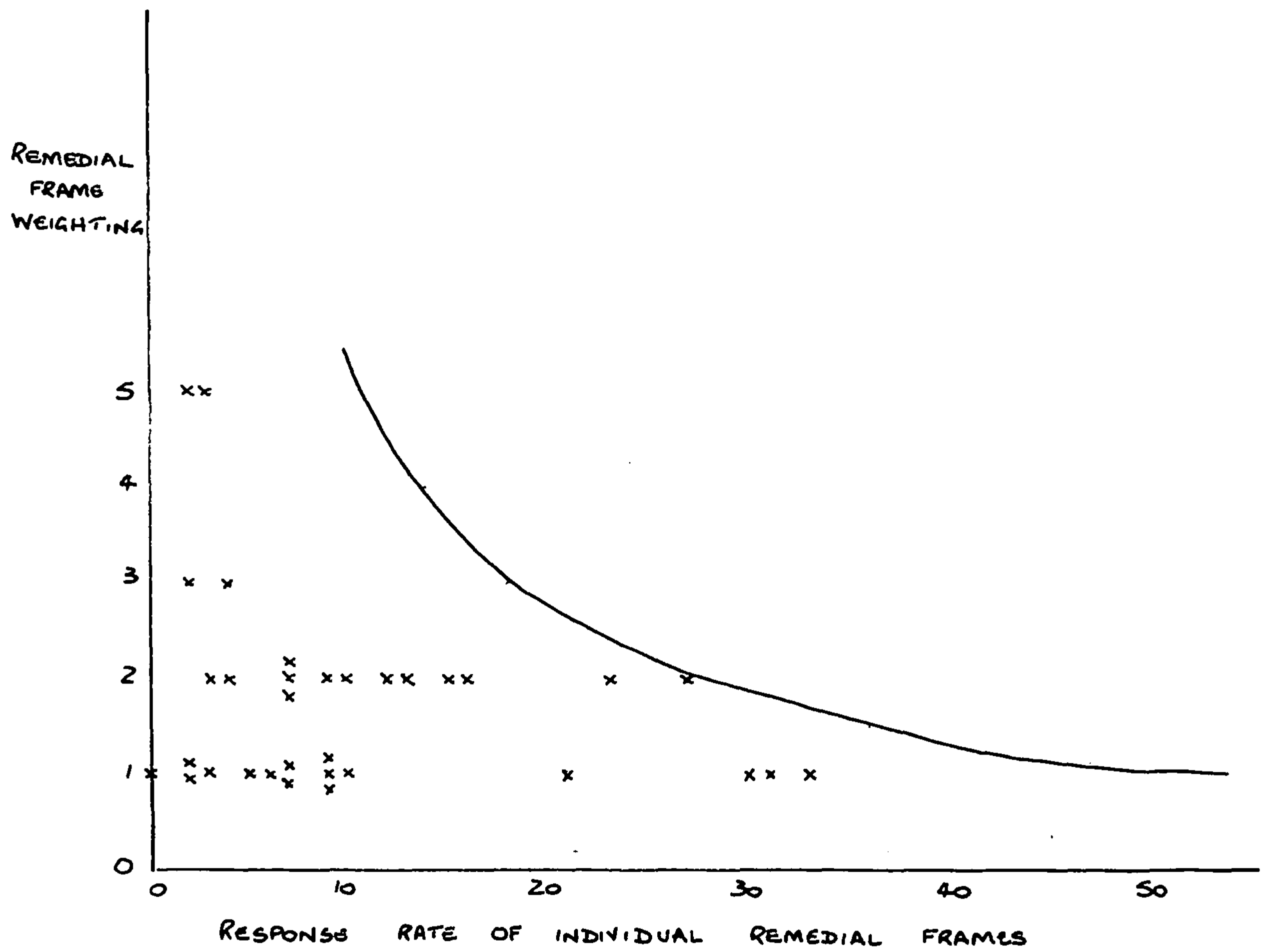


Fig. 4.15. Weighted response for each remedial frame in the section of the programme containing the three fault .



The results for each of the nine frames outside the curve of the "norm" are shown in the table below.

Frame number	Weighting	Responses	Norm	Deviation from norm	Percentage deviation from norm
11	1	65	53.5	11.5	21.5
21	3	27	17.8	9.2	34
24	8	11	6.7	4.3	39
46	2	32	26.7	5.3	16.6
54	1	66	53.5	12.5	19
65	2	41	26.7	14.3	35
91	3	30	17.8	12.2	41
99	3	23	17.8	5.2	23
187	1	85	53.5	31.5	37

The three frames which had already been discovered as requiring revision can be omitted from this discussion, as they have already been reviewed. These three frames are 11, 54 and 187. This leaves six other frames which could require revision.

At this stage in the testing proceudre, it was decided only to apply revisions if absolutely essential.

The highest percentage deviation from the norm was the 41% of frame 91. Ignoring the three frames found already, there were also three other frames with a high deviation. These were 21, 24 and 65. Frames 46 and 99 were not considered to have such a high deviation that they required drastic attention. Thus a decision had to be taken on four frames, as to whether immediate revision should take place, or whether revision could safely be left to the next edition of the programme.

The deciding factor on this revision was the amount of pressure being applied to bring the programme to a final stage of testing. Revision of these frames, and producing a new edition of the programme would have taken at least three months, mainly due to the work load of the printers. Therefore the unfortunate decision was taken that further revision could wait until all tests had been completed.

It is not considered that leaving these six frames in their original state made any significant difference to the final performance of the programme, as the number of frames involved was small, and the amount of error apparent on each frame was also small.

On the section of the programme containing the three worked examples, there were no cases of remedial frames with errors greater than the norm. Thus no cases of revision were necessary in this section.

This weighting of remedial frames is thought to be an extremely useful tool in the testing of programmes. It is not known whether this device has been used before, but it is suggested that it is a test having much more bearing on the effectiveness of the programme than a straight count of the error rate of the sample population working through the programme.

The weighted errors of individuals were now tabulated to investigate the comparative performance of the various groups involved in the test. These results are presented firstly by the total weighted error of each trainee on working through the programme. In each group, the first graph shows the total weighted error in ascending order of time taken to complete the programme. The second graph in each case shows the total weighted error in ascending order. Any extra results obtained for individuals in any of these groups are included in the results. The graphs are on the following four pages.

Fig. 4.16 Weighted errors of R.E.M. group on working through the programme.

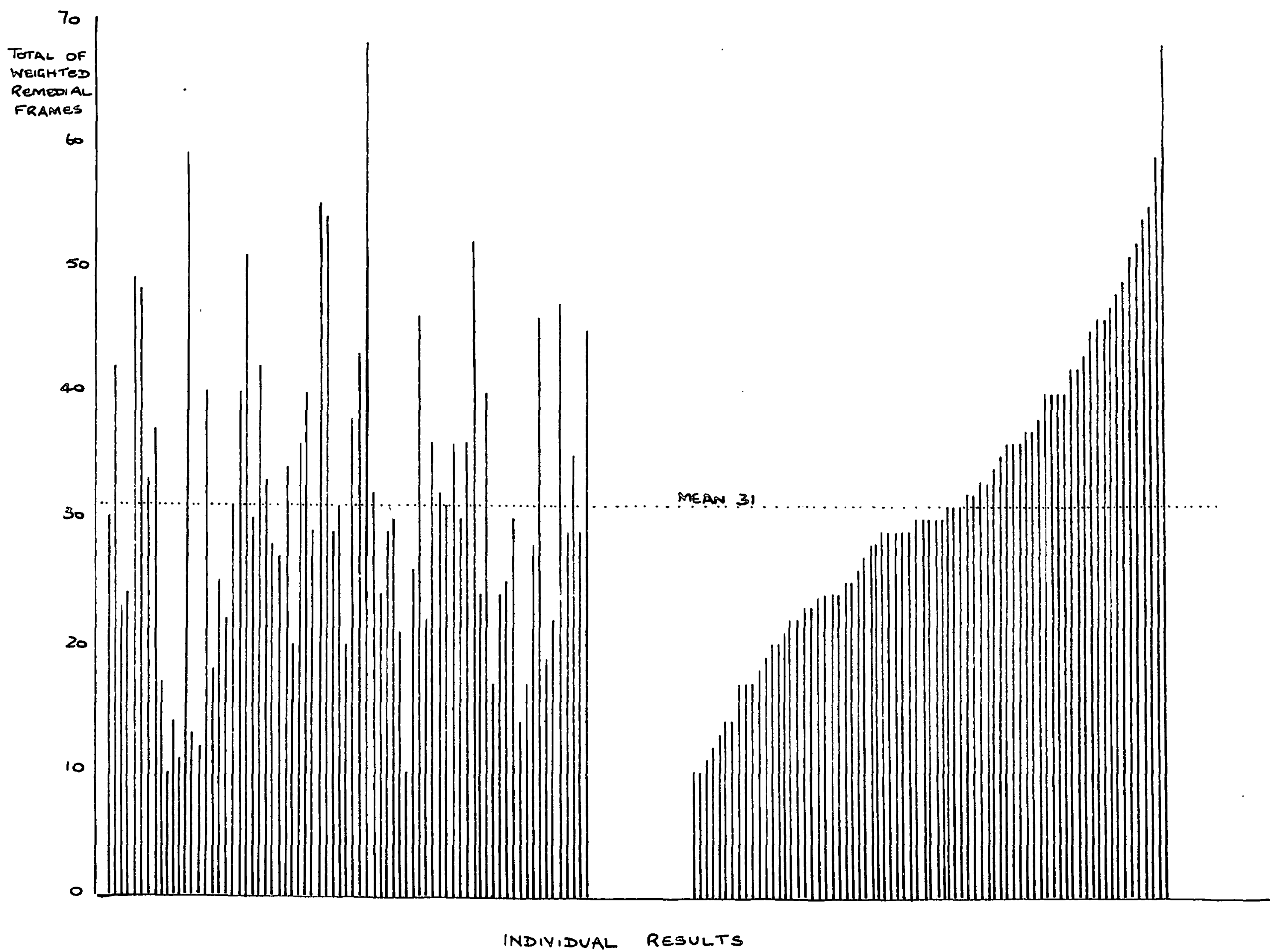


Fig. 4.17. Weighted errors of L.R.E.M. group on working through the programme.

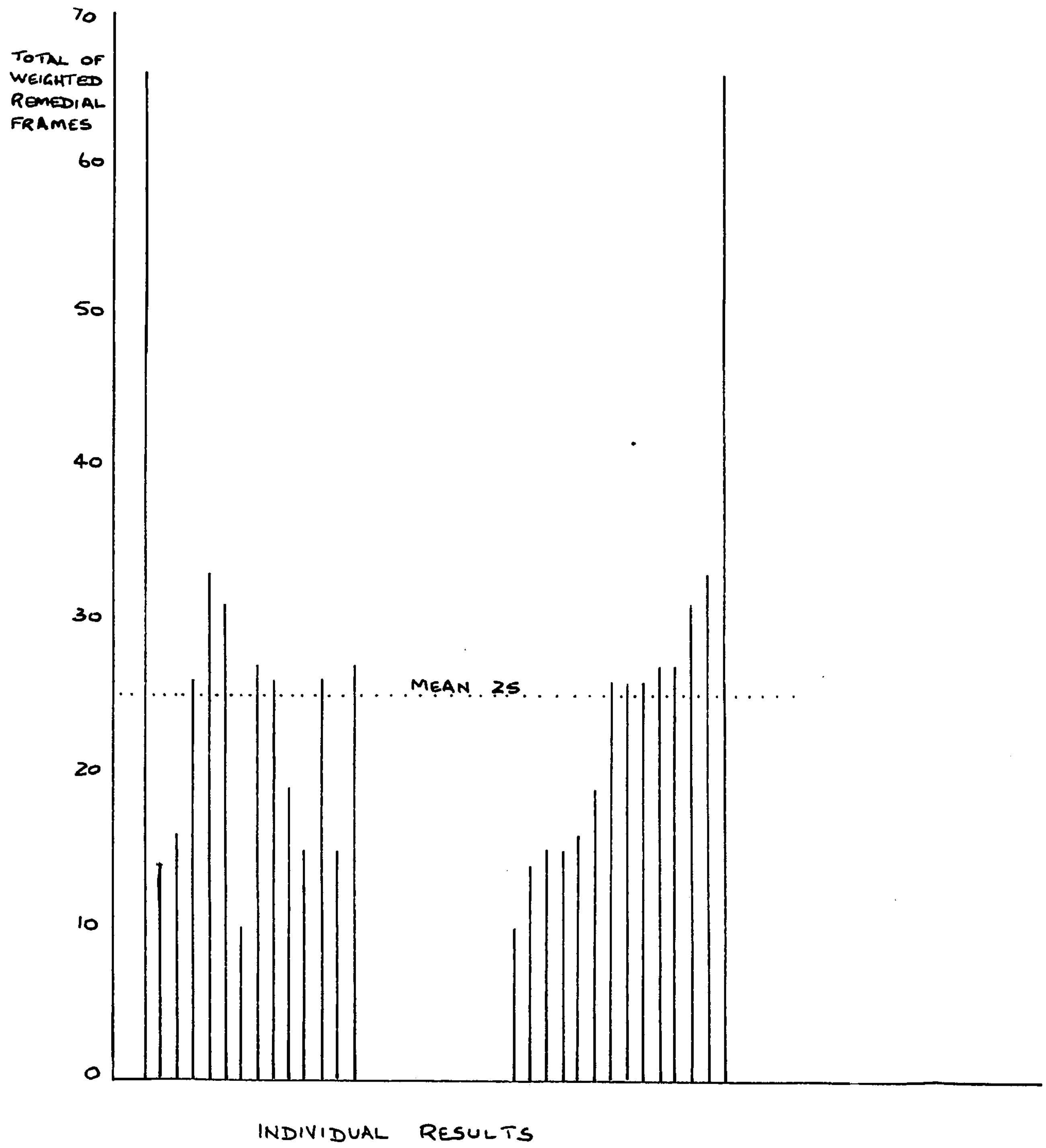


Fig. 4.18. Weighted errors of R.M.A. group on working through the programme.

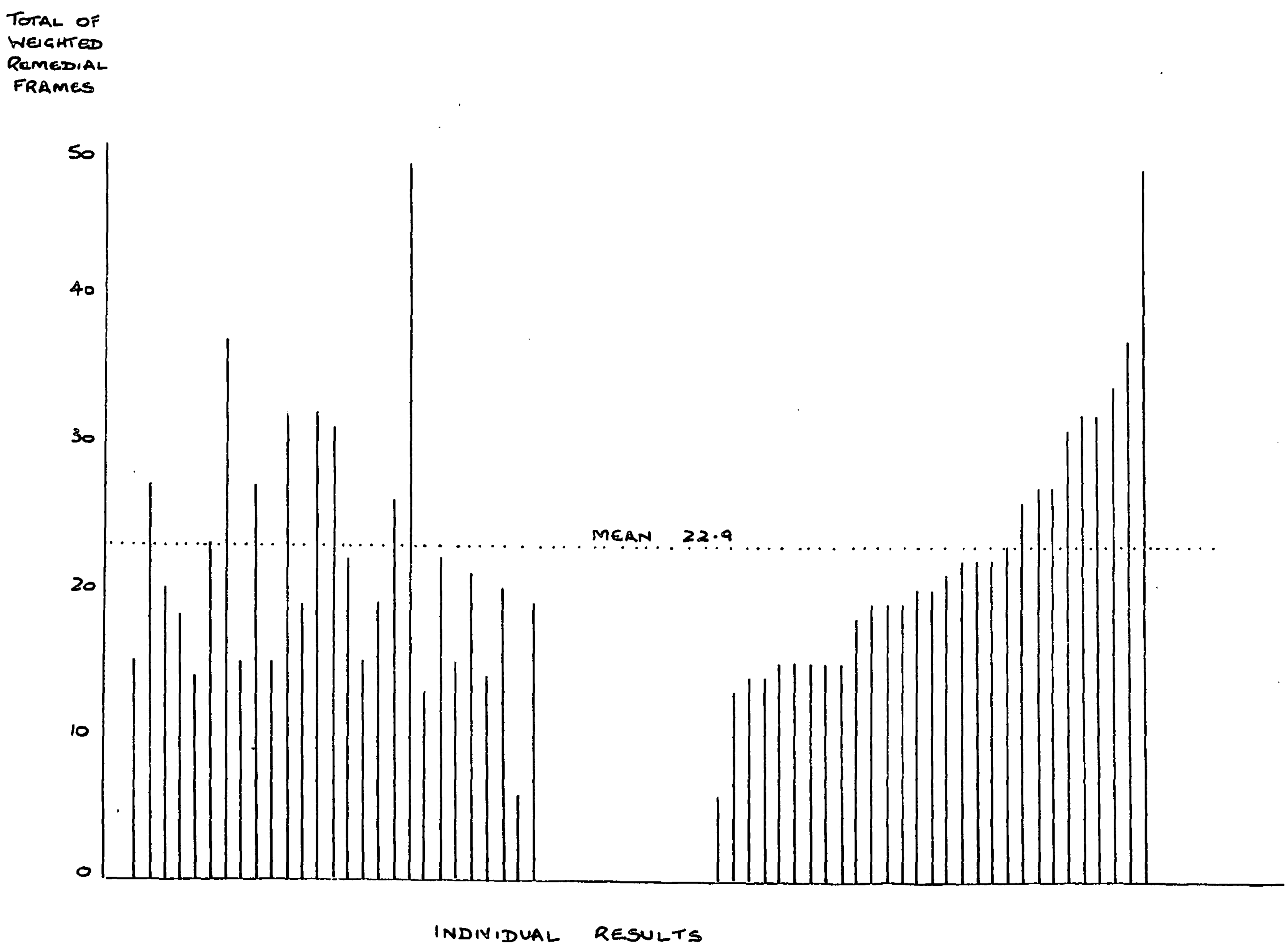
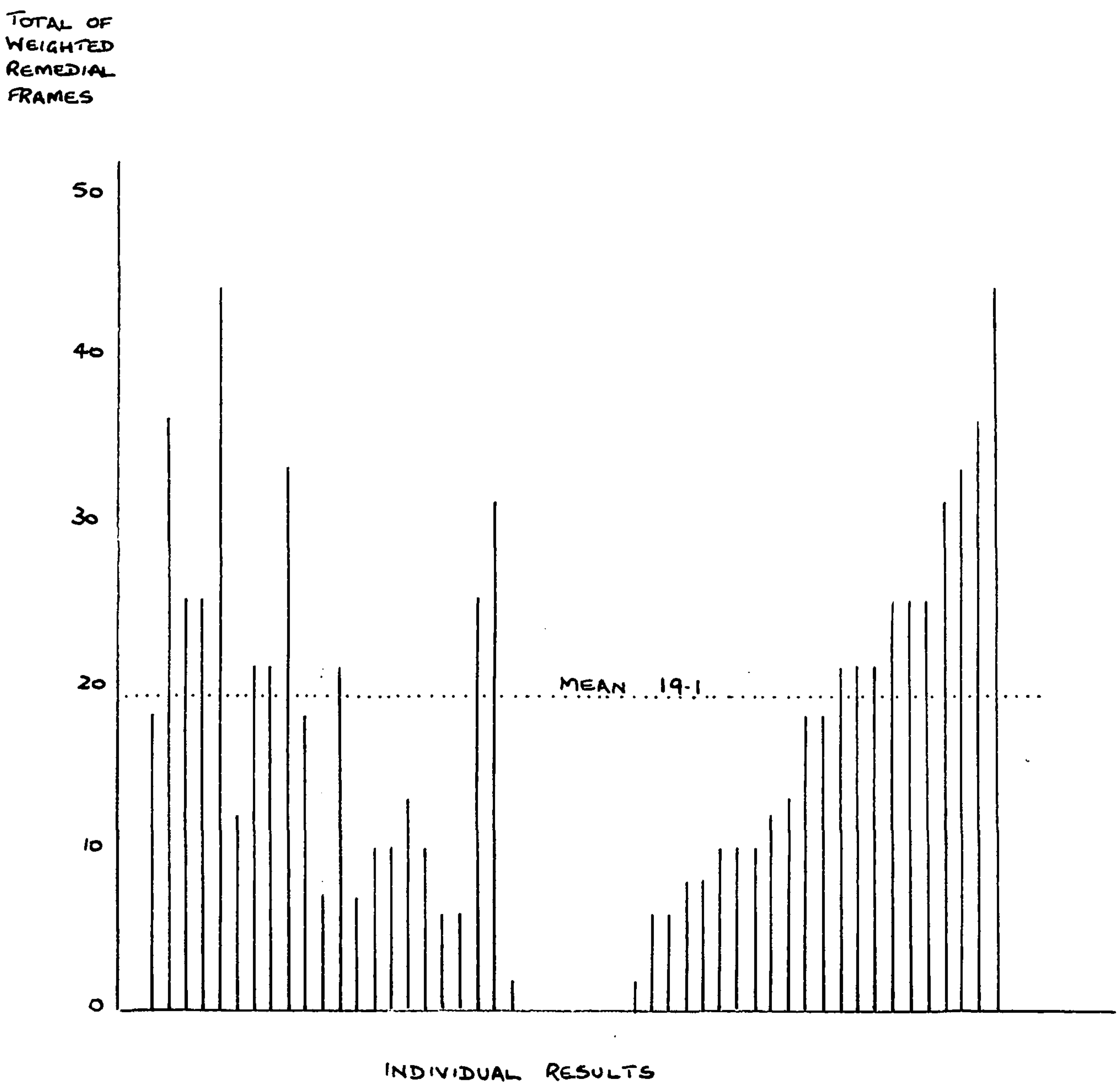


Fig. 4.19. Weighted errors of R.E.A.L. group on working through the programme.



These graphs can be summarised in the following table.

Group	Number in group	Mean weighting	Standard deviation	Maximum	Minimum
REM	73	31	12.3	68	10
LREM	14	25	13.3	66	10
RMA	27	22.9	8.7	49	6
REAA	22	19.1	10.9	44	2

The results for the four different types of trainees show a remarkable degree of cohesion, considering the differing levels of training and experience.

The results of all trainees taken together are shown on the two histograms on pages 124 and 125. The first histogram shows the weighted response rate for the first six basic sections of the programme, and the second histogram shows the weighted response rate for the problem section of the programme.

The results for any individual trainees falling within the groups for this test are included in the table and the diagrams, thus the total number of results is slightly larger than than the original content of the test population.

Fig. 4.20. Histogram showing the weighted responses on the first six sections of the programme.

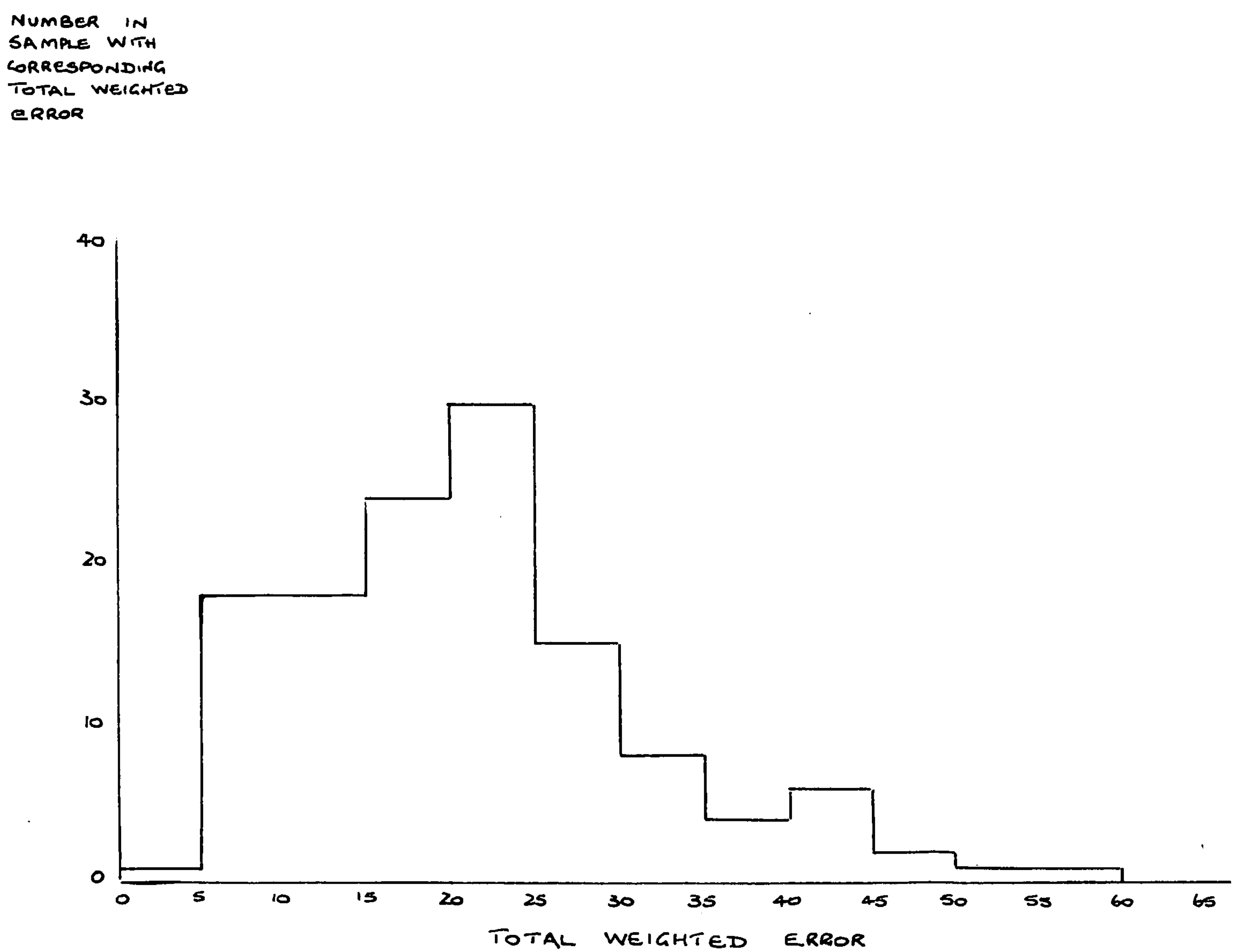
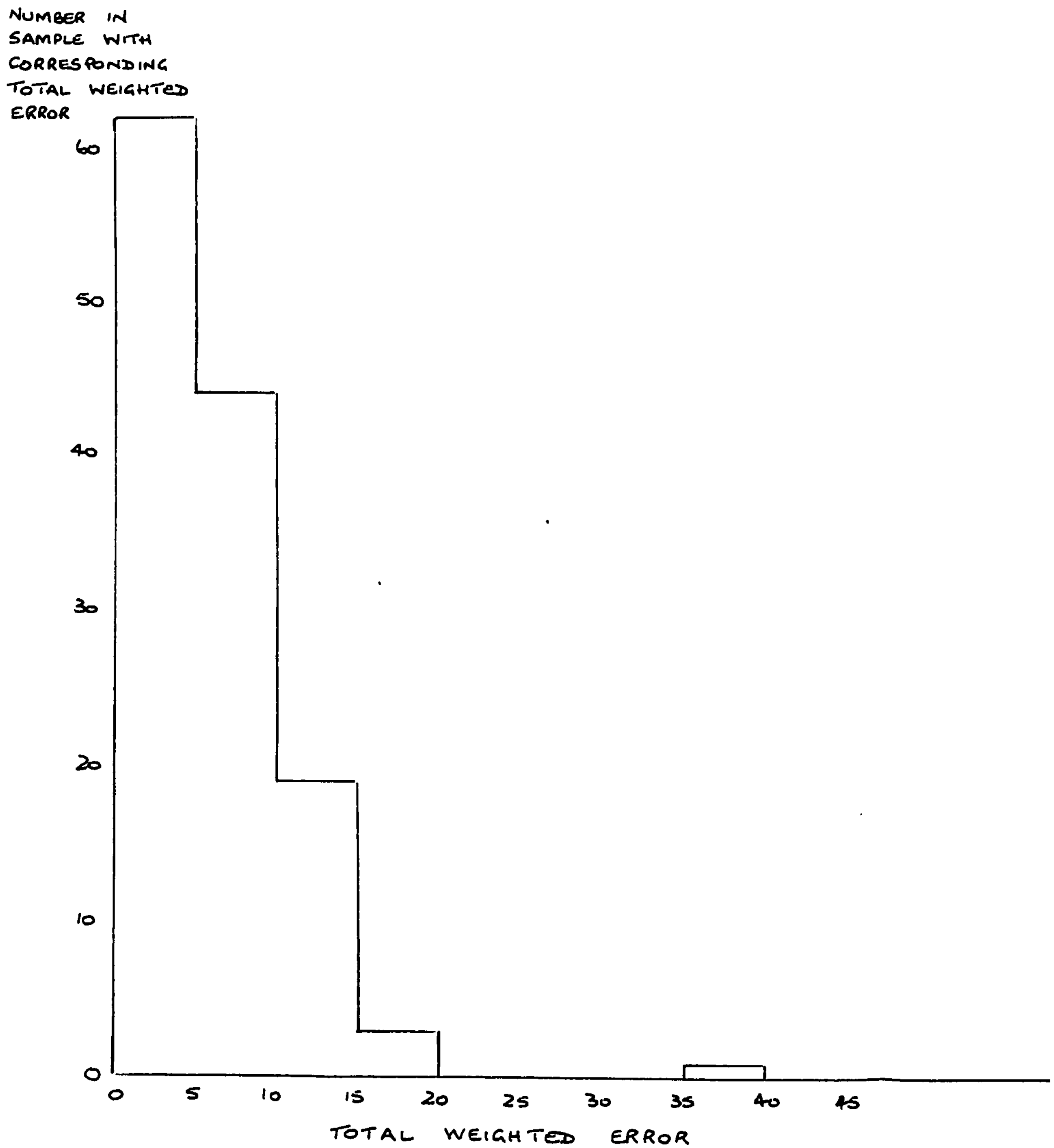


Fig. 4.21. Histogram showing the weighted responses on the problem section of the programme.



The distribution on these histograms is regarded as being satisfactory, and furnishes further evidence that the programme is viable. The overall weighted error in responses on working through the programme, for a total of 138 trainees, gives a value of 26.7 for the complete text. This value, and the values of mean weighted error for the different groups, is well below the figure taken for a satisfactory level before revision was required. In fact, the weighted error is actually below the figure taken as the maximum total error measured as a straight count of remedial frames used. Therefore the results of this test are very satisfactory.

One further test was carried out on the viability of the programme. This test compared the weighted error on the first six sections of the programme, and the weighted error on the section of the programme containing the three worked examples of actual faults. It was hoped that the error rate on the problem section would be lower than on the programme for the basic method, as the trainee should have been able to apply the method which he learnt in the first six sections to the problems.

The results of this test are shown in the following eight diagrams, fig 4.22 to 4.29 inclusive.

Fig. 4.22. R.E.M. weighted responses on the programme in order of completion.

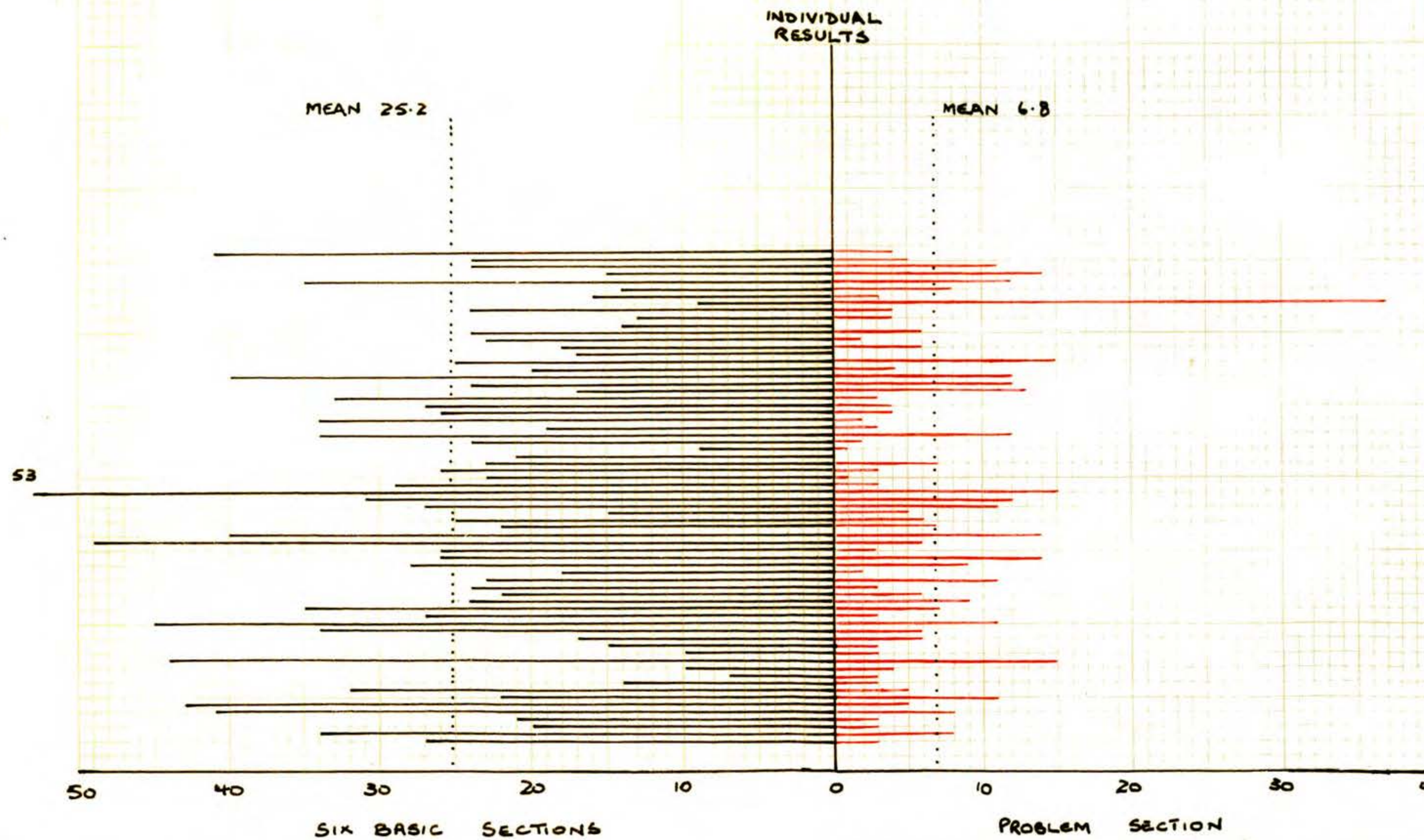


Fig. 4.23. R.E.M. weighted responses on the programme in descending order of response.

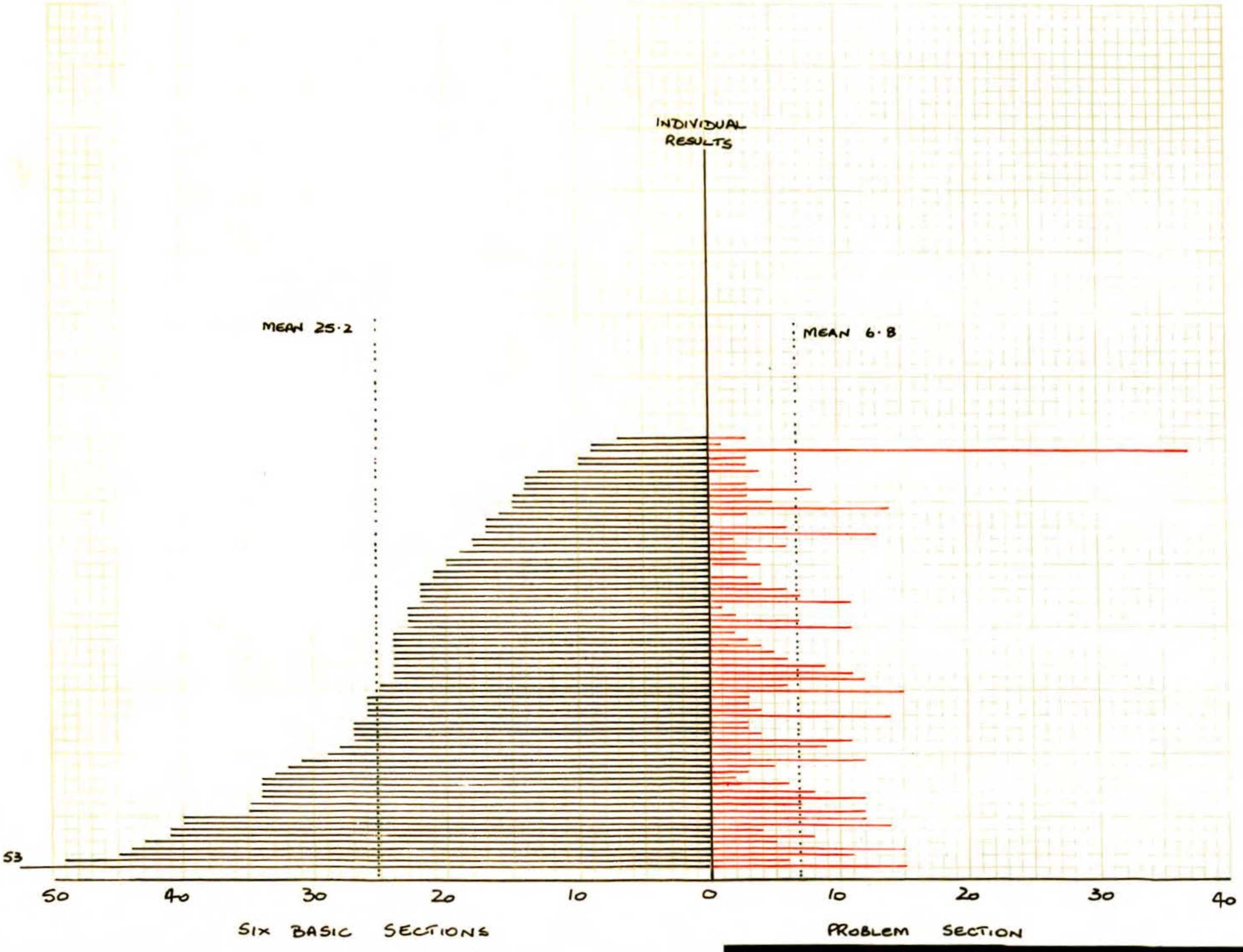


Fig. 4.24. L.R.E.M. weighted responses on the programme in order of completion.

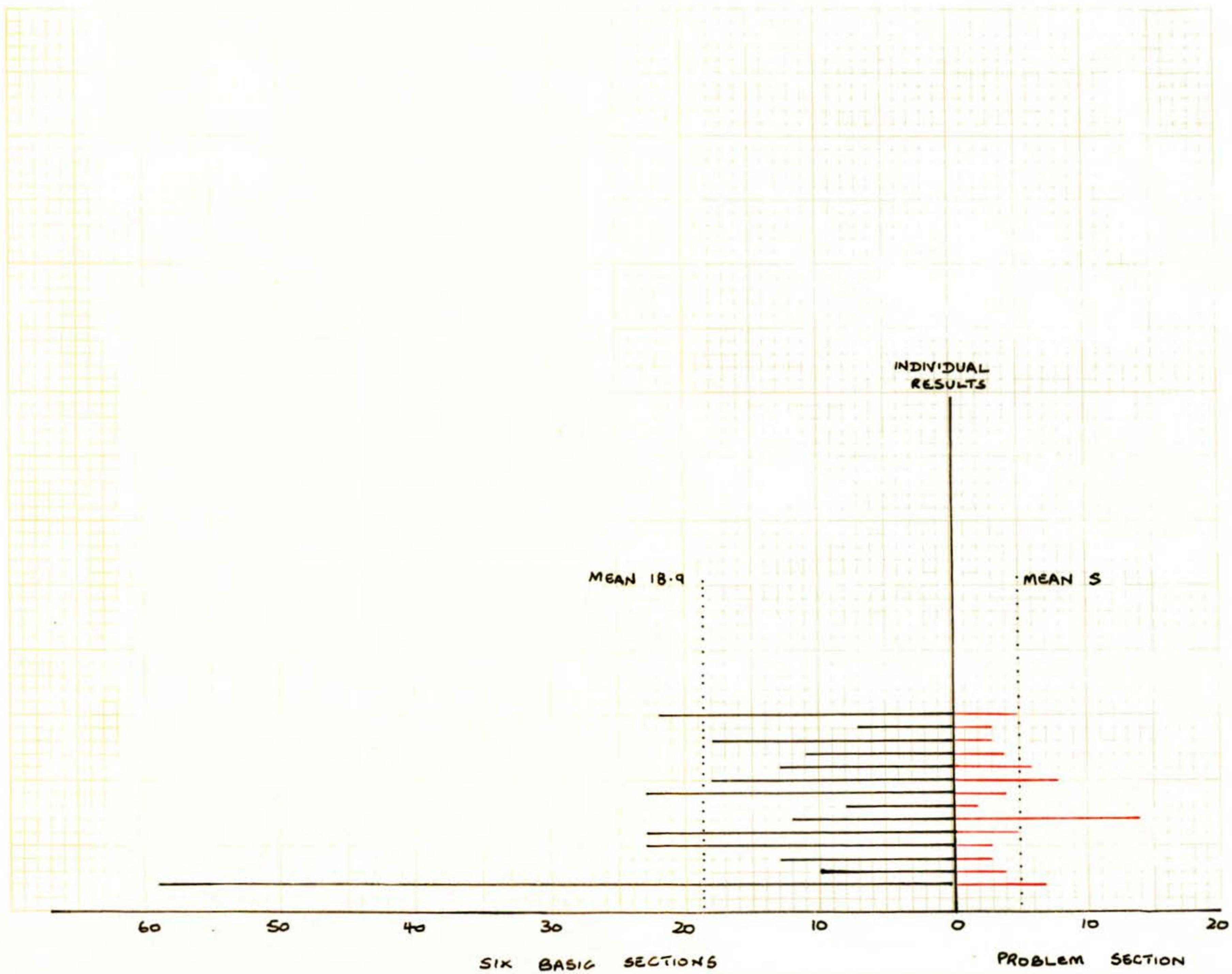


Fig. 4.25. L.R.E.M. weighted responses on the programme in descending order of response.

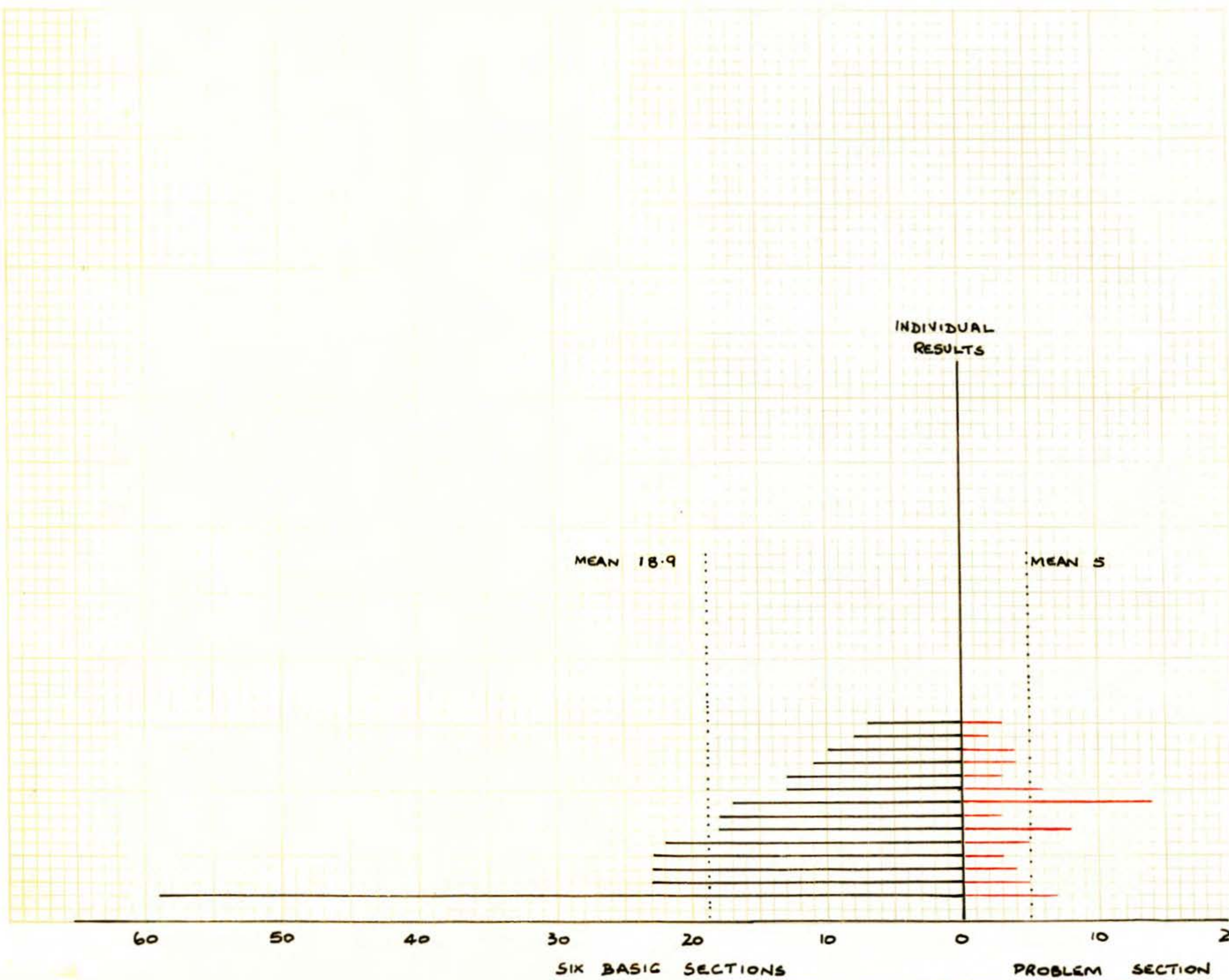


Fig. 4.26. R.M.A. weighted responses on the programme in order of completion.

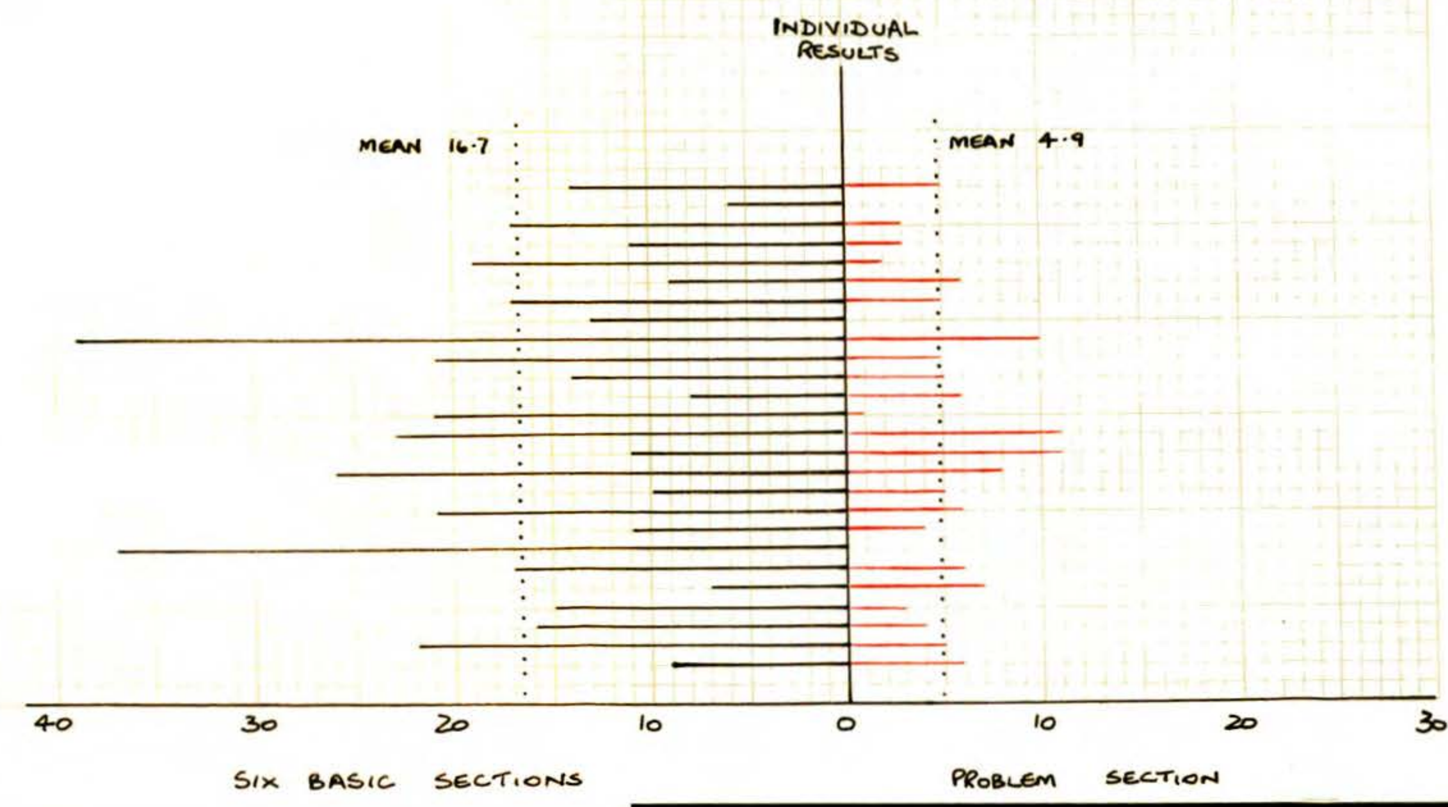


Fig. 4.27. R.M.A. weighted responses on the programme in descending order of response.

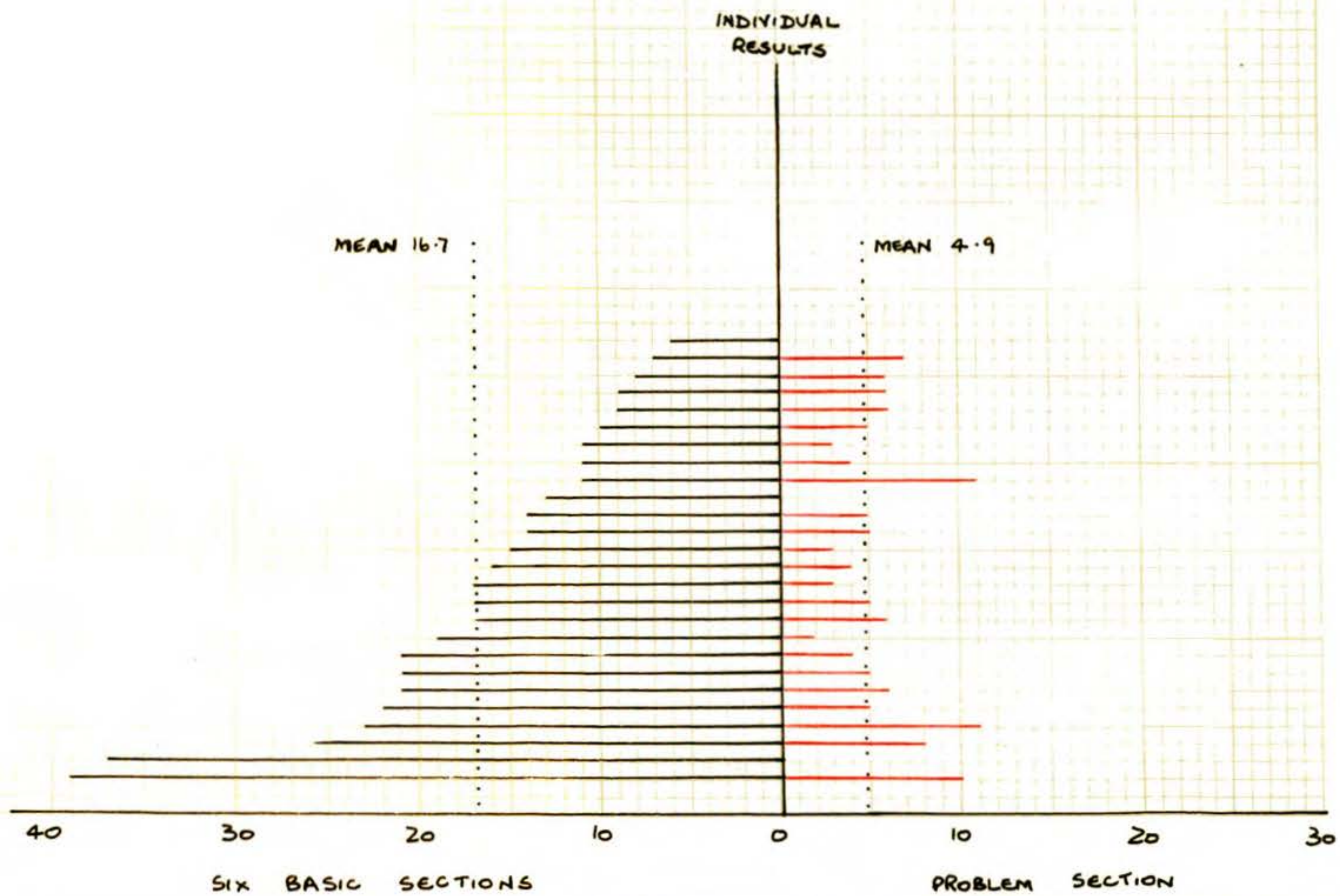


Fig. 4.28. R.E.A.A. weighted responses on the programme in order of completion.

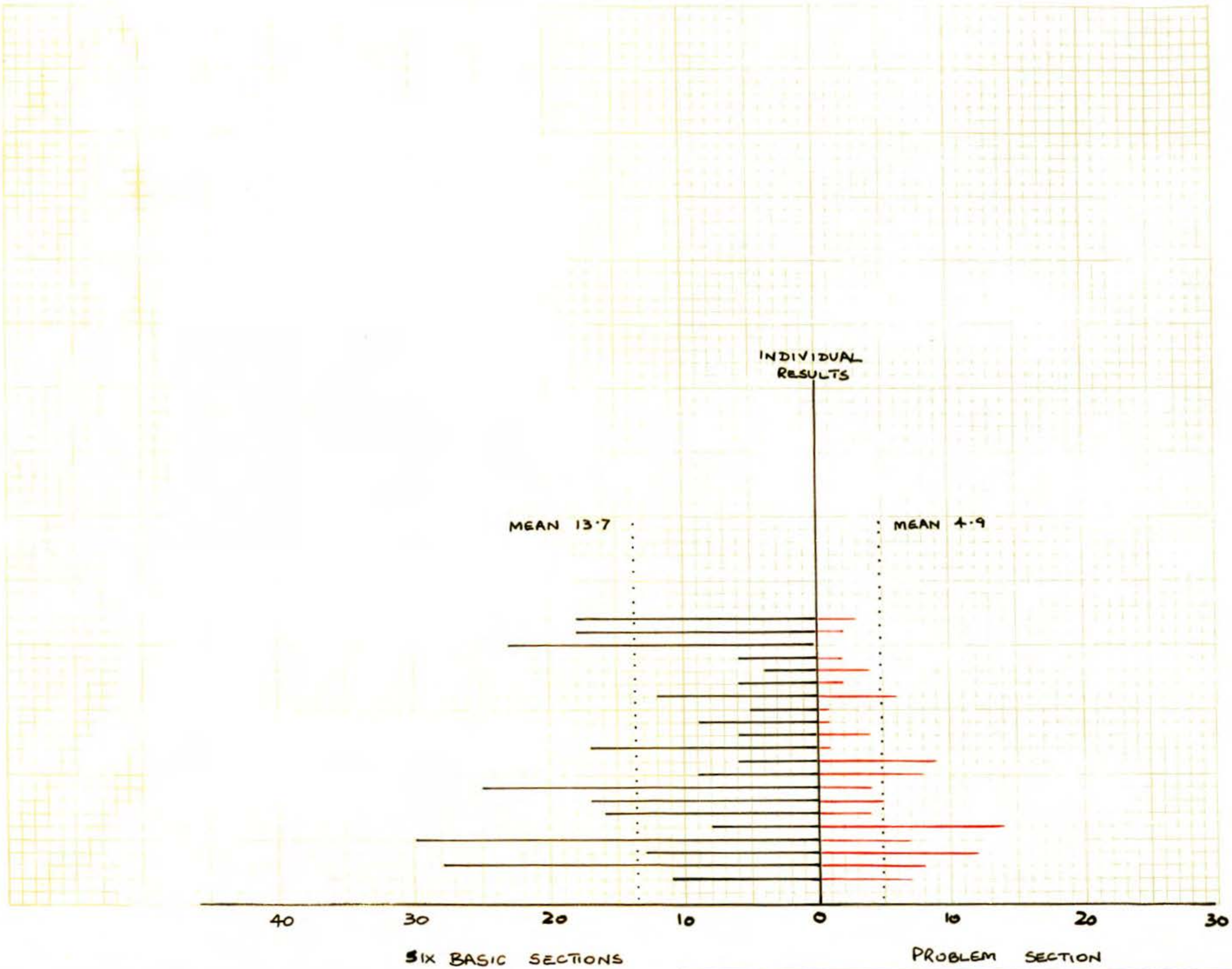
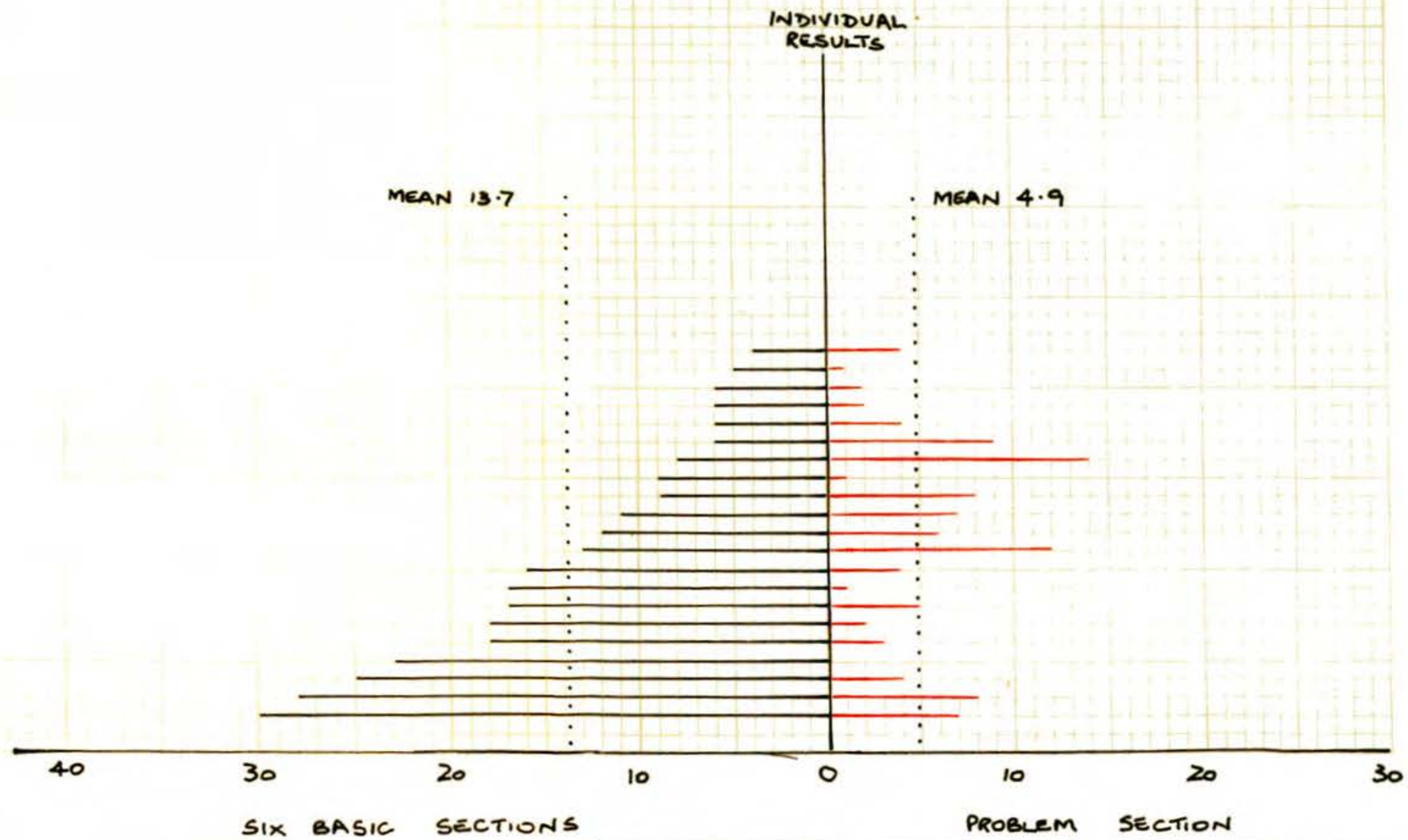


Fig. 4.29. R.E.A.A. weighted responses on the programme in descending order of response.



These graphs may be summarised by the following two tables of results .

Results for first six basic sections of the programme.

Group	Number in group	Average weighted error	Standard deviation	Maximum	Minimum
REM	69	25.2	10.0	53	7
LREM	14	18.9	12.4	59	7
RMA	26	16.7	8.1	39	6
REAA	21	13.7	7.7	30	4

Results for the problem section of the programme.

Group	Number in group	Average weighted error	Standard deviation	Maximum	Minimum
REM	69	8.0	5.6	37	0
LREM	14	5.0	3.0	14	2
RMA	26	4.9	2.3	11	0
REAA	21	4.9	3.6	14	0

It should be noted that although the maximum weighted error for the R.E.M. group as shown in the second table is 37, the next highest is 15, which is more in agreement with the maximum weighted error in the problem section for the other three groups.

As for the test on the raw error rate, and the test on the time taken, a chi squared test was carried out for the parameter under consideration. This was carried out, as before, using two main experimental groups, apprentices and mechanics.

The categories used for this test were not the same as those used for the raw error rates, as the weighted errors are necessarily higher than the straight error counts. Considering the total theoretical weighted error and the total theoretical raw error, a close approximation is to take a 1.5 conversion factor.

This then gives the following categories :

Group 1	0 - 15 weighted error
Group 2	16 - 30 weighted error
Group 3	31 - 45 weighted error
Group 4	46 - 60 weighted error

There are, however, three results which do not fall within these categories; those of trainees with weighted errors of higher than 60. Thus a further category was included for this group, making five categories in all.

The following table shows the results for weighted error rates, split into apprentice and mechanic populations, for each of the five categories :

	Apprentices	Mechanics	Total
Group 1	19	11	30
Group 2	21	39	60
Group 3	8	25	33
Group 4	1	9	10
Group 5	0	3	3
Total	49	87	136

The value of chi squared for these results was calculated to be 16.4 for four degrees of freedom, giving a level of significance of 0.01 .

Therefore it would be expected that the two types of trainee would differ in their respective performances, and it would be expected that the apprentice group would have a lower error rate than the mechanic group.

However, this does not disprove that the programme could be given satisfactorily to the different classes involved in these tests. It is expected that a difference in performance would occur with different levels of trainee, the main criteria is that the extremes of these groups do not find the programme too difficult or too easy.

The group finding the most difficulty is, as would be expected, the group of Radio Electrical Mechanics. This group had a mean weighted error calculated to be 31. The group finding the least difficulty is the Radio Electrical Artificer Apprentice. This again is as expected, and this group had a mean weighted error calculated to be 19.1 .

The question must now be whether these extremes of value are satisfactory. This must be a matter for judgement, coupled with a close study of the results. It would appear that the results of the two extreme types of trainee are, in fact, satisfactory, the weighted error rate of the Radio Electrical Mechanics not being disproportionately large, or the weighted error rate of the Radio Electrical Artificer Apprentice disproportionately small.

It can therefore be said that this test shows that the programme is suitable for all the members of the test population, with regard to this parameter.

At this stage in the discussion of the testing of the programme, a summary of the various parameters tested will simplify later discussion. These tests are listed below :

1. A straight count of the number of trainees using each remedial frame occuring in the programme.
2. A straight count of the number of remedial frames used by each individual trainee.
3. The total weighted error for each remedial frame in the programme.
4. The total weighted error for each individual trainee in working through the programme.
5. The time taken by each trainee to complete the programme.

These can now be summarised.

The first test on the programme was to check the number of trainees using each remedial frame in order to find any frames which obviously required revision. For immediate revision a figure of 50% of trainees using a particular remedial frame was taken as the maximum allowable. No frames were found where this was found to be necessary, although three frames were found with error rates in excess of 50%. These three frames were examined and were not thought to require immediate revision. For long term revision it was decided to investigate remedial frames which were used by greater than one third of the trainees. Ten such frames were found. In neither case were any frames found on the problem section of the programme which required revision.

The error rates on the programme for individual trainees were now summarised. It was found that the results for the four groups taking this test were compatible. Thus from the results of this test, the programme should be in a suitable condition to be given to any of the four different groups in the test population. At the same time, the error rates for each group were compared with the time taken to complete the programme. No satisfactory connection could be found between the number of errors made on the programme, and the actual time taken to complete the programme.

The time taken by each trainee to complete the programme was then noted, and the results summarised by test groups. The results for each of the four test groups show that the programme can equally well be given to any trainee of the four main groups taking the test. Thus the programme is again proved to be satisfactory for the whole spectrum of the test population.

For the next test, a weighted error was assigned to each remedial frame, depending upon the extent of the error which led the trainee to that particular frame. The first consideration was to investigate the total response for each weighted remedial frame. As shown earlier, a system was devised of considering both the number of trainees using each remedial frame, and the wieghting of the frame, to decide whether revision of the frame was necessary. A "norm" result was obtained within which all the frame results should fall. Nine frames were found to fall outside this norm, and thus required revision. However, it was impossible to undertake extensive revision at this stage, and after investigation, it was decided that the revision of these nine frames could safely be left until the next edition of the programme. The fact that only nine frames in the entire programme required revision should make very little difference to the performance of the programme as a whole. This fact was substantiated by the errors recorded on the problem section of the programme. No frames were found on this problem section which required revision, and thus the performance on the trainees in the actual fault finding situation had been shown to improve from working through the fault finding method as explained in the first six sections of the programme.

The weighted errors on the programme were then summarised for each of the four groups in the test population. A comparison of these results showed that all four groups were compatible, and that once again it was true to say that the programme could be given to each of the four groups with equally advantageous results. Although the results are very similar for the four groups, there is a steady reduction in errors from the R.E.M. group to the R.E.A.A. group. This is to be expected, as the four groups are listed in the theoretical order of ability and experience. However, the divergence of results for the four groups is not so great as to preclude the advantage of being able to give this programme to any trainee within the four test groups.

Two histograms were then drawn, showing the weighted errors for the trainees in the first six sections of the programme and the problem section of the programme. Although there is a smaller actual weighted error on the problem section than on the first six sections, the distribution of both histograms is satisfactory.

Diagrams were then drawn to show the weighted error on the first six sections of the programme compared with the weighted error on the problem section. These were summarised firstly in order of completion, and then in descending order of weighted error. No satisfactory connection could be found between the time taken to complete the programme, and the weighted error of the trainee.

The raw figure of weighted error on the problem section cannot be directly compared with the weighted error on the programme section because of the different number and weighting of error frames in these two sections. A correction factor of 2.636 has been computed for the problem section to make the two sections comparable.

This produces results as shown below :

Group	Number in Group	Number not Improving	Average Saving
REM	69	12	5.2
LREM	14	5	5.3
RMA	26	6	3.8
REAA	21	8	1.0

The average saving refers to the difference in weighted error on the first six sections compared to the corrected weighted error for the problem section. A "saving" is effected if the performance on the problem section, after correction, is better than the performance on the previous sections.

In the REM group, a proportionately small number did not improve their performance on the problem section compared to the programme proper, but the average saving is small, of the order of 5.

In the other three groups, a proportionately larger number did not improve, and although the saving of the LREM group is approximately the same as the REM group, the other two are lower. The REAA group in fact can hardly be said to have improved at all.

However, improvement on the latter half of the whole programme is not necessarily to be expected.

To check the significance of the changes in performance, a Wilcoxon matched-pairs signed-ranks test was carried out for each group. Again a corrected weighted error was taken for the problem section.

Weighted error rates were compared for each individual trainee in all groups for weighted error on the programme section and corrected weighted error on the problem section. The results are shown below :

		Small sample treatment		Large sample treatment	
Group	T	N	α	Z	α
REM	-220	68	-	5.4	n.s.
LREM	-25	13	sig	0.098	sig
RMA	-99	25	<.05	1.709	0.0436
REAA	-96.5	20	sig	0.673	0.25

T is the smaller of the sums of like signed ranks

N is the total number of independently drawn cases

Z is the deviation of the observed value

α is the level of significance

Although the numbers of LREM and REAA trainees are not really large enough for large scale treatment, the result can be informative. However, no particular pattern emerges from these results. The REM group show a significant change in performance. The RMA group have a level of significance just below 0.05, the standard level, but it is not low enough to be conclusive.

The other two groups of LREM and REAA, did not ~~the null~~ differ significantly ~~hypothesis is significant~~, and thus any change in performance cannot be taken as relating to a particular set of circumstances.

However, this is not a drawback of the usefulness of the programme, as the performance of all groups on the problem section was satisfactory.

This completed the tests on the actual programme and showed that :

(a) The programme itself is in a satisfactory condition to proceed to tests to discover and evaluate the increase in fault finding performance accrued as a result of working through the programme.

(b) The programme was suitable for the whole spectrum of the test population used in validation of the programme, and these four groups could again be used for the evaluation tests.

The next stage was therefore to instigate tests to evaluate the increase in fault finding performance accrued as a result of working through the programme.

CHAPTER 5.

EVALUATION OF THE PROGRAMME.

The main analysis to discover the teaching efficiancy of the programme was carried out with a pre-test / post-test system. These two tests used the fault finding simulator sheets produced by Printechnic under the title of "Trainee Tester Sheets". The series on the superheterodyne radio receiver which consists of twenty separate fault sheets was chosen as the standard, and their contents were considered to be exactly right for this test. The variety of faults included in the series of twenty also provided a means of measuring a wide field of fault finding performance.

These tests were described in Chapter 1, and a series of them are submitted with this work, therefore further description is not necessary.

There were two main divisions in the sample population taken for these tests. These were the experiemntal group and the control group. The experimental group took the pre-test, followed immediately by the programme, and then took the post-test. The control group took the pre-test and took the post-test after an interval equal to the average time taken to work through the programme by the experimental group. The control group did not have any instruction in fault finding techniques in the interval between the two tests.

The content of the experimental group was as follows :

(a) one class of Leading Radio Electrical Mechanics

(b) one class of Radio Mechanician Apprentices

(c) two classes of Radio Electrical Artificer Apprentices

(d) three classes of Radio Electrical Mechanics.

As has been shown earlier, career course classes in H.M.S. Collingwood are strictly comparable, and can be considered as matched. (36,37) Therefore, although the classes used for the evaluation were not the same actual trainees as those who took part in the first series of validation tests, the results of the classes used for evaluation can be taken in context with the classes used for evaluation.

The control group consisted of a ~~cross section~~ sample of twenty one trainees.

To obtain an entirely unbiased result, both the control group and the experiemntal group were marked on the same strict scheme, and to the marking agency there was nothing to distinguish the two groups. To assist with this policy of providing strict marking control, a marking scheme was prepared in which there was no possibility of producing different final marks because of extraneous causes during the marking. Moreover, the tests were all marked at the same time and by the same person.

The strict control of the marking situation was dependent upon an ideal set of solutions for each of the twenty faults in the series chosen for evaluation. These soluti ns were not ideal in the sense that they were the best possible solution to the fault, but were ideal in the sense that they were the solutions to be expected from a trainee following implicitly the method of fault finding taught in theprogramme. It had already been established that this particular method of fault finding was considered to be desirable for the trainees in question, and thus measuring the fault finding performance in the pre-test and the post-test based on the criterion of this fault finding method, would produce a direct result of the training value of the programme.

Thus the first step in the evaluation of the programme as a training aid was to produce this "ideal" set of solutions for the faults in the test series, and to produce a write up of these solutions ready for use in the evaluation tests.

At the same time investigations into the exact method of marking the fault finding simulator sheets were carried out. The possibility of using actual equipments for the evaluation tests on fault finding performance had already been discounted because of the difficulty of producing a sufficiently viable and strict marking scheme. The fault finding simulator sheets had been chosen because they offered an extrmely good solution to this problem. When using the simulator sheets, a permanent record of each step in the fault finding method used by the trainee is left in the rubbed out portions of the sheets. Moreover, as the trainee is required to number his steps in the order of completion, a complete record of his progress through the fault can be obtained.

Another advantage of these sheets is that no artificial aspect is introduced into the trainees' fault finding by requiring any other records to be kept of his fault finding performance. In any situation requiring the use of actual equipments, the record could be kept by an observer, but this would be very wasteful in manpower, and impossible for large numbers of trainees. If the trainee was required to keep a personal record then this would introduce an artificial aspect into the fault finding situation.

In fact no artificial aspect due to the use of the simulator sheets as a criterion test was introduced, as preliminary trials of these sheets had proved to be so successful that they were in large scale use in the training establishment in normal fault finding situations, and in fact a fairly large number of sheets of this kind had been made in the establishment. These sheets dealt with specific naval equipments. Thus the trainees were familiar with this sort of simulator, and no spurious effect would be produced by unfamiliarity with the type of test.

Once the "ideal" set of solutions to the tests had been determined, the next step was to lay down a marking scheme. This scheme had to be sufficiently rigid for there to be no discrepancies in marking, if trainees' solutions were marked at different times or indeed by different persons.

To do this, a decision was required on the most important factor in good fault finding, and the comparative emphasis to be given to the different aspects of fault finding performance which could be marked. For example, it would be possible to mark the trainees' solutions solely on the time taken to repair the fault. However, it can be argued that this is not always the most important criterion of good fault finding. It could be argued from a purely logical viewpoint that the most important criterion was that the fault should be repaired in the smallest number of steps, as this should be the most efficient solution. Unfortunately, this is not always the case, and it is impossible to state categorically which is the most important criterion.

To give the broadest possible picture, it was decided that the following parameters should be used :

(a) Number of steps taken to cure the fault.

(b) Time taken to cure the fault.

(c) Number of components replaced or repairs made.

However, it was obvious that a direct measurement of the number of steps taken, or the number of components replaced, would not give a direct measurement of the efficiency of the fault finding performance. It might be several times more complicated, costly and wasteful, to carry out a certain test or component replacement than to carry out others. In electronic terms, checking a voltage would be amongst the simplest tasks, whereas replacing certain components such as a transformer could involve a substantial amount of work in unsoldering, unbolting, rebolting and resoldering. If the component replaced did not in fact repair the fault, then the operation would be even more costly, both in terms of material used, and in terms of the man hours required, as well as the inconvenience of the fault not being repaired correctly.

Therefor a "weighted" score was given to each step in the fault finding method, depending upon its complexity and the approximate time it would take to carry out. This produced two further parameters :

(i) "Weighted" score for the number of steps taken to repair the fault.

(ii) "Weighted" score for the number of components replaced during the fault finding sequence.

There were thus a total of five parameters which could be used to measure fault finding performance. These were :

(a) The number of steps taken to cure the fault.

(b) The weighted score for the number of steps taken.

(c) The number of components replaced or repairs made.

(d) The weighted score for the components replaced.

(e) The total time taken to cure the fault.

As stated above, it was found to be impossible to state categorically which of these five parameters was the most important. In the special circumstances of repairing faulty electronic equipment in a ship of the Royal Navy at sea, this situation becomes even more complicated. There will be occasions during which different parameters will be of prime importance. For example, if a radar equipment sustained a failure at an inopportune moment, then the most important criterion would be that the fault was repaired in the shortest possible time, regardless of the number of components replaced, or indeed whether the sequence of steps was logical. On the other hand, a ship at sea can only carry a certain number of spares, and these must be conserved as much as possible.

However, it was decided that for this evaluation test, one particular requirement should be that only one component was replaced. If the trainee was following the logical method correctly, then the steps of the fault finding method should indicate exactly which component was at fault. Thus one, and one only, component should be replaced. Also if the logical method was followed, then the time taken to repair the fault, and the number and weighting of steps, should be at a minimum for most of the faults cured by the test population. This would not always be so if the trainee was experienced but the level of experience of the test population was such that their optimum performance should be attained by following the method given in the programme, if this was followed faithfully. It should be remembered that the programme under test was attempting to teach a basic method of fault finding which could be followed by a person with no previous experience.

Thus the actual marking scheme had to be considered collectively, rather than quoting one particular test result for a group. Unfortunately, this collective consideration has to be carried out objectively rather than subjectively, as it has been shown that the circumstance of a particular fault may govern the best solution of it. This objective consideration produces a certain amount of complexity in the detailed analysis of results.

With the above points as a basic set of criteria, the marking scheme and ideal solutions were prepared. These were produced in a separate booklet, a copy of which is submitted with this thesis. The marking scheme provided for weighted scores to be given for different steps in the fault finding method, depending upon the relative complexity of the step. Weighted scores were also produced for the repair and replacement of components. The weighting varied between one and five for different steps, and full details are given in the supplementary booklet.

It is realised that this weighting scheme imposes a further condition on the marking scheme, as steps may have relative complexities in excess of this difference in mark. However, it was not considered practical to pursue this weighting scheme too far as it would introduce false conditions. The weighting scheme, used in moderation, should be better than a straight count of steps, as long as it was used without an excess of zeal.

In examining the large numbers of trainees involved in this trial, it was thought that to give each class exactly the same test would produce discrepancies, as there was bound to be some collusion between the classes, and this would invalidate the results. Therefore a series of criterion tests was prepared, and the actual test given to each group was varied.

However, these tests had to be strictly compatible in order that the test results should be comparable. In order to do this a series of tests was prepared in which each test contained three faults out of the twenty faults available from the simulator sheets. Each test of three faults was selected so that it contained one fault from each of the three main areas of the circuit used for the examples. These areas were the radio frequency stages, the intermediate frequency stages and the audio frequency stages. Each test was also selected so that the total number of steps necessary to cure the fault as shown by the ideal solutions, and the total weighted score of these steps, should be similar for all the tests. It was not found possible to make these totals exactly the same, but each test was selected so that there was a discrepancy of only one unit in the total scores, and in fact the majority of the tests had exactly the same totals. It is not considered that this difference of one in the total scores for the tests introduces any noticeable variation in the results.

For ease of reference, the ideal score for each fault was termed the "bogey" score.

The classes of Radio Electrical Mechanics, Leading Radio Electrical Mechanics and Radio Mechanician Apprentices, were each given one group of three faults as the pre-test, and one group of three faults as the post-test. The class of Artificer Apprentices was given two groups of three faults as the pre-test, and two groups of three faults as the post-test.

The control group, consisting of twenty one trainees, took one group of three faults as the pre-test, and one group of three faults as the post-test, without having any fault finding instruction in the period between the two tests.

For each fault in which a solution was found, the five parameters listed above were measured. A separate record was kept of faults which were not successfully diagnosed and repaired.

All five parameters were then compared for the pre-test and the post-test. The net results of these comparisons was found to be very favourable. Each experiemntal group showed a significant increase in fault finding performance after working through the programme. Moreover, although there were quite a lr e number of cases where the trainee was unable to cure the fault before working through the programme, this was very much reduced after the trainee had completed the programme. Details of these results are shown below, and each is discussed separately before drawing more general conclusions as to the improvement in fault finding due to the programme.

Fig. 5.1

NUMBER OF FAULTS NOT COMPLETED IN PRE-TEST AND POST-TEST

GROUP	NUMBER IN GROUP	TOTAL FAULTS IN EACH TEST	PRE-TEST		POST-TEST		ACTUAL IMPROVEMENT	PERCENTAGE IMPROVEMENT
			TOTAL UNCOMPLETED	PERCENTAGE UNCOMPLETED	TOTAL UNCOMPLETED	PERCENTAGE UNCOMPLETED		
REM 1	16	48	11	23	0	0	11	100
REM 2	16	48	7	15	3	6	4	60
REM 3	10	30	7	23	0	0	7	100
RMA	23	69	20	29	5	7	15	76
LREM	17	51	5	10	0	0	5	100
REAA	11	66	15	23	7	11	8	53

Completion of faults.

Although this is not a true parameter of measurement it produces some interesting results.

There were a total of 42 Radio Electrical Mechanics, each taking a pre-tesr of three faults, and a post-test of three faults. There were therefore a total of 126 faults to be cleared in each test. In the pre-test, a total of 25 faults were not successfully diagnosed, and 101 faults were correctly cleared. Thus approximately 20% of the faults in the pre-test were not diagnosed correctly. In the post-test of the same possible total faults, two classes successfully cleared all the faults, and one class left three faults uncompleted. This gives a marked improvement in fault finding performance, and the actual figures for the three classes are shown in Fig. 5.1 on the previous page. Taking the three classes together, with 25 faults unsuccessfully attempted in the pre-test, and only three faults unsuccessfully attempted in the post-test, a positive improvement in fault finding performance of 88% is obtained. On this basis alone, the programme would appear to be successful, if it produces consistent results of this level.

The next largest group is the class of Radio Mechanician Apprentices, there being 23 in the class. In this case a class of 23 gives a total number of faults in each of the two tests of 69. In the pre-test, a total of 20 faults were not correctly diagnosed in the pre-test, and five in the post-test. This gives an unsuccessful rate in the pre-test of 29%, and an unsuccessful rate in the post-test of 7%. Both of these rates are higher than the comparable rates for the classes of Radio Electrical Mechanics. This is rather surprising, as the Radio Mechanician Apprentices are considered to be at a higher level of training than the Radio Electrical Mechanics. However, for the Radio Mechanician Apprentices, the simple percentage improvement of faults completed in the tests works out to be 76%, which is in itself a substantial improvement.

The Leading Radio Electrical Mechanics have already had fault finding experience in the performance of their duties at sea. However, they have had little formal training in fault finding methods, and tend to have confused ideas due to possessing a mixture of fairly sophisticated pratical know-how picked up from senior ratings with whom they have been working, and the simple theoretical knowledge that they gained whilst on course as a R.E.M. Out of a possible total of 51 faults in each test, 5 were uncompleted in the pre-test, this being 10% approximately, whilst all faults were correctly diagnosed in the post-test, a percentage failure rate of zero. A straight gain of 10% therefore resulted, but the percentage gain could be worked out to be 100%. In either case the fact that all faults were cleared in the post-test is a very satisfactory result.

The LREMs are the senior fault finders of the test population, and the senior rating is the man to whom the junior rating will turn when in difficulty. Thus the senior man should be able to clear all faults. It is also most efficient if he solves this fault in the best possible way, but it is in some ways more important that he can always find the answer to a problem which is baffling a junior rating. This requirement is amply satisfied by this test, as the group of Leading Hands solved every fault in the post-test.

The last and smallest group in the test were the Radio Electrical Artificer Apprentices. This group should be the most intelligent and highly trained of the four groups in the test. At this stage in their careers, They have no practical experience of equipments, having concentrated on the theoretical aspect of electronics during their course.

This group had a total of 66 faults to clear in each of the two tests, as they were given six faults in each test. A total of 15 faults were not cleared in the pre-test, an approximate percentage of 23%, and this reduced to a total of seven unsuccessful attempts in the post-test, an approximate percentage of 11%. This comparatively high result in the post-test was a little disappointing, in view of the higher standard of the group. However, this improvement still represents an average increase in performance of 53%, although this is the smallest improvement of the four groups.

An explanation for this comparatively low increase in performance was pursued by interviewing individuals in the class. From the results of this interview, it became apparent that those members of the class who did not show a satisfactory increase in performance had tended to ignore some of the methods of fault finding taught in the programme. The reason for doing this was that they considered as a result of all their previous training that they already had sufficient training to be able to fault find satisfactorily, without using what appeared at times to be a very simple method. In fact several of the trainees considered that the method was so simple as to be of no practical use. Those members of this group who did follow the method of fault finding implicitly showed a much more satisfactory improvement in performance.

However, the final result of this examination for all the four groups was very encouraging, and showed a definite improvement in fault finding performance after the trainees had worked through the programme. Thus the actual method of fault finding taught, and the programme used to do this, had both proved to increase performance in fault finding.

<u>Paramter - The number of steps necessary to clear the fault.</u>

In this test, the straight forward number of steps taken to clear the fault was taken as the criterion, no regard being paid to the relative complexity of the steps. Again the results are grouped by each of the four different types of classes who took part in the experiement, and are separated into results for the pre-test and for the post-test.

A further measurement was also taken during this test. For each group of faults used in either the pre-test or the post-test, the total "bogey" score was calculated. This was the number of steps which would be taken in finding the ideal solution to the three faults. For each trainee, a deviation from this bogey score could then be determined, this being the difference between the actual number of steps taken and the ideal, or bogey, number of steps. This gives a measurement of the amount of excess work, effort and time being wasted by the trainee in correcting the fault due to not following the correct fault finding method implicitly. This deviation score gives a more useful result than the straight number of steps taken to cure the fault.

As the deviation from bogey score gives a more accurate picture of the fault finding performance of the trainees, the results of this test are tabulated by deviation rather than by the straight number of steps.

The results of this test are shown in the table overleaf, (Fig. 5.2), tabulated by the four different groups involved in the test, and also showing the results of the control group.

Fig. 5.2

DEVIATION OF TOTAL STEPS TAKEN FROM TOTAL BOGEY NUMBER OF STEPS

GROUP	NUMBER IN GROUP	TOTAL POSSIBLE FAULTS PER TEST	PRE-TEST			POST-TEST			ACTUAL SAVING	AVERAGE SAVING	PERCENTAGE SAVING
			TOTAL FAULTS COMPLETED	TOTAL DEVIATION	AVERAGE DEVIATION	TOTAL FAULTS COMPLETED	TOTAL DEVIATION	AVERAGE DEVIATION			
REM	42	126	101	-785	-18.7	123	-511	-12.2	+274	+6.5	35
RMA	23	69	49	-600	-26.1	64	-355	-15.4	+245	+10.7	41
LREM	17	51	46	-131	-7.7	51	+91	+5.4	+222	+13.1	-
REAA	11	66	51	-221	-10.0	59	-103	-4.6	+118	+5.4	54
CONTROL	21	63	63	-315	-15.0	63	-320	-15.2	-5	-0.2	-1.3

All of the four groups in the test population achieved a saving in this parameter. Only one group, that of the Leading Radio Electrical Mechanics, achieved a post-test result which was better than the bogey score. The other three groups were still worse than bogey on completion of the programme. However, in each case, the improvement was satisfactory. The faults used for this test were comparatively simple compared to the faults which could occur in actual situations at sea. These more difficult faults could not be tested within the time and facilities available, but from the results of the criterion test, a more substantial and useful saving should be apparent by using this fault finding method on the more complicated faults.

Considering individual class results, the largest improvement was made by the class of L.R.E.M.s. This class improved their average deviation from the bogey score by 13.1 steps, and as has been discussed above, had a post-test score which was an average of 5.4 steps better than the bogey score. This shows a substantial increase in fault finding performance.

The group with the largest deviation from the bogey score was the class of R.M.A.s. Although the post-test result was still well over the bogey score, there was an average improvement in deviation from the bogey score of 10.7 steps. This again shows a substantial improvement in fault finding performance, if each trainee could cut out an average of almost eleven steps in fault finding on simple problems. It follows again that the improvement on more complicated problems would be more substantial.

The class of A.E.M.s and the class of R.E.A.A.s showed smaller amounts of improvement. They actually improved by 6.5 steps and 5.4 steps respectively. Although this result is smaller, it is still a significant improvement in fault finding performance. The results for the class of R.E.A.A.s are reduced to a pre-test and post-test of three faults each, in order to make them comparable to the other three groups. The post-test result for this class of R.E.A.A.s then closely approaches the bogey score.

The performance of the control group proved that there was little or no spurious influence accrued from experience in the pre-test producing a gain in performance in the post-test. In fact, the control group were slightly worse in performance on the post-test than they had been on the pre-test. The difference in performance on the two tests is so small as to be negligible, and there can be no justification at this stage for applying a correction factor to the experimental groups.

However, before these results can be finally considered, the level of significance must be determined. The system of pre-test and post-test marking lends itself very easily to a statistical analysis to determine the level of significance of the improvement in performance. As each individual in the groups has a pre-test and a post-test mark, the obvious test is the Wilcoxon Matched -Pairs Signed-Ranks test. This enables relative magnitude of marks to be compared, as well as the direction of the difference.

As was discussed earlier, the pre-test and post-test given to each trainee consisted of three specific faults. Although these could not be made the same faults, the two tests were balanced for bogey scores and for type of fault. The combination of faults in each test was also varied, still maintaining the balance between bogey scores and type of fault. Thus no extraneous factor could affect any change in performance other than experience gained in the pre-test. This experience factor could be discounted on the evidence of the control group results.

Only those trainees who fully completed three faults in both of the tests could be used for this analysis. The total number of trainees in each group which could be used was therefore as follows :

REM	18
RMA	14
LREM	14
REAA	11
Control	21

Taking the parameter of the deviation from the "bogey" number of steps necessary to clear the faults, The level of significance was determined.

Group	N	T	α
REM	18	41.5	$< .05$
RMA	14	5	$< .005$
LREM	14	12.5	$< .005$
REAA	10	0	-
Control	20	95	N sig

N is the total number of independantly drawn cases
T is the smaller of the sum of like-signed ranks
α is the level of significance

Thus all experiemental groups showed a significant increase in performance on the post test at the .05 level. Again the control group showed that the result of this test was not masked by extraneous factors.

The overall results of this test on the parameter of deviation from bogey steps needed to clear the faults, do not show outstanding improvements, but in each case a very satisfactory improvement is shown This improvement is again sufficient to justify the statement that, up to this stage of the evaluation, the programme had proved to be successful.

Parameter - Weighting of steps necessary to clear the faults.

It has already been described how a weighting scheme was devised for each step in the fault finding method. This was to allow for steps of differing complexity. This weighting scheme gave each step in the method used a mark of between one and five.

As for the straight number of steps taken to clear the fault, it is more meaningful to discuss these results in terms of the deviation in score from the bogey score for the ideal solution to the fault. The results given here are therefore the deviations from the bogey weighted score, and not the actual weighted score. They are divided into the four experimental groups, and results are given for the pre-test and the post-test separately. The results of the control group are also included. These results are shown in the table overleaf (Fig. 5.3)

All the four groups of the experimental section of the test population achieved a saving in this parameter. However, in this test there were no groups which achieved an average performance in the post-test which was better than bogey. The class of L.R.E.M.s, who had achieved a score better than than bogey in the post-test of the previous parameter, came closest to the bogey score for this parameter. Their average weighted deviation from bogey in the post-test was only 2.1 excess.

The L.R.E.M. group also achieved the highest improvement in fault finding performance when measuring this improvement on a percentage basis. However, the class of R.M.A.s achieved the highest actual average improvement as a straight count.

In general, all groups except the R.E.M. classes

Fig. 5.3

DEVIATION OF WEIGHTING OF TOTAL STEPS TAKEN FROM BOGEY WEIGHTED SCORE

GROUP	NUMBER IN GROUP	PRE-TEST		POST-TEST		TOTAL SAVING	AVERAGE SAVING	PERCENTAGE SAVING
		TOTAL DEVIATION	AVERAGE DEVIATION	TOTAL DEVIATION	AVERAGE DEVIATION			
REM	42	-2212	-52.7	-1620	-38.6	+592	+14.1	28
RMA	23	-1561	-67.9	-924	-40.2	+637	+27.7	41
LREM	17	-404	-23.8	-36	-2.1	+368	+21.7	91
REAA	11	-573	-26.0	-297	-13.5	+276	+12.5	48
CONTROL	21	-925	-44.0	-951	-45.3	-26	-1.3	-2.5

showed a very satisfactory improvement in fault finding performance as measured by this parameter. The R.E.M. group, although not showing such a large increase in performance, did still improve their standard.

In order to check the validity of these results, a Wilcoxon Matched-Pairs Signed-Ranks test was again carried out to determine the level of significance. The results are shown below :

Group	N	T	α
REM	18	26.5	<.005
RMA	14	10.5	<.005
LREM	13	5.5	<.005
REAA	11	0	-
Control	19	83	N.sig

N is the total number of independantly drawn cases
T is the smaller of the sum of like-signed ranks
α is the level of significance

The level of significance of all the experimental groups is very low, and thus the improvements in the parameter of deviation from weighted score of steps in clearing the fault are significant at the .05 level.

The control group again showed no significant improvement in performance on the post-test as measured against the pre-test.

This control group result was again very satisfactory as it showed that experience accrued during the pre-test was not affecting the performance of trainees in the post-test to any significant degree. In fact, the control group were again slightly worse in performance on the post-test than they had been on the pre-test for this parameter. However, the variation in results is not significant, and it can be stated quite definitely that the results of the experimental groups represent a true measure of the increase in fault finding performance accrued as a result of working through the programme on fault finding.

The overall results for this parameter are therefore very encouraging. All experimental groups showed a significant increase in fault finding performance, as measured by this parameter, and the results of the control group again proved that these results were not affected by experience gained in the pre-test affecting the post-test results , producing false values. All improvements are in fact true improvements.

Parameter - Number of components replaced.

In this test the number of components replaced during the attempts to correct the faults in the pre-test and the post-test were noted. This could quite easily be done by inspecting the completed simulator sheets. On these sheets there is a separate column for occasions where a trainee wishes to make a component replacement, and therefore the total for each fault is very easily found.

It had already been decided that the optimum case in fault finding would be to replace only one component. Correct application of the fault finding method should result in the faulty component being isolated, and thus only one component would require replacement. This is, of course, considering only simple faults where only one component is at fault in each case. There are a large number of faults which can occur in electronic equipments where the fault is cumulative, and the failure of one component induces failures in other components. For the purpose of this test, each fault given was due to a single failure to simplify the solution.

The results of this test are summarised in the table overleaf (Fig. 5.4)

[redacted]

Fig. 5.4

NUMBER OF COMPONENTS REPLACED

GROUP	NUMBER IN GROUP	PRE-TEST		POST-TEST		TOTAL SAVING	AVERAGE SAVING	PERCENTAGE SAVING
		TOTAL SCORE	AVERAGE SCORE	TOTAL SCORE	AVERAGE SCORE			
REM	42	553	4.4	343	2.7	210	1.7	38
RMA	23	204	3.0	112	1.6	92	1.4	45
LREM	17	136	2.7	102	2.0	34	0.7	25
REAA	11	132	2.0	99	1.5	33	0.5	25
CONTROL	21	200	3.17	202	3.2	-2	-0.03	-1

Each of the four experimental groups showed an improvement in fault finding performance as measured by this test. However, none of the groups produced consistent results showing only one component replacement in each of the faults in the post-test. This is only to be expected, as none of the groups had sufficient fault finding experience to enable them to use the fault finding method to its fullest advantage. In these circumstances, the post-test performances are thought to be satisfactory.

The group of R.E.M.s, those with the least training and no experience, had the highest post-test result. On average, this group made 2.7 replacements in each fault before the fault was cured. However, they did achieve the highest actual saving as a result of working through the programme.

Taking into account the level of training, and the lack of experience of the other groups, the results were all satisfactory. It must be emphasised that although the improvements shown by this test appear to be fairly small in absolute terms, they represent a very real improvement in fault finding performance. Any component which is replaced and is then found to leave the fault in the original condition is a complete waste of time, effort and a financial waste of a component. Thus the fact that each group in the test replaced less numbers of components in the post-test than they did in the pre-test represents a very real saving in all of these factors.

Once again, the results for the control group show remarkably little difference between the pre-test scores and the post- test scores. There was thus no improvement in this parameter as a result of experience gained in the pre-test affecting the results of the post-test. Therefore the results of the experimental groups represent an actual gain in performance which is due to the fault finding method as taught in the programme.

As pre-test and post-test results were avaiable for each trainee, the level of significance of the results could be easily determined by means of a Wilcoxon Matched-Pairs Signed-Ranks test.

The results of this test are shown below :

Group	N	T	α
REM	17	21.5	$< .005$
RMA	14	14	$< .01$
LREM	13	17	$< .025$
REAA	11	0	-
Control	16	73.5	N. sig

N is the total number of independantly drawn cases

T is the smaller of the sum of like-signed ranks

α is the level of significance

All the experimental groups have a level of significance below the .025 level. Although in general the levels are higher than in the previous test, they are such that all experimental groups again have a significant improvement in performance at the .05 level.

The control group again show no significant improvement in performance in the post-test as measured against the pre-test, and the chances of experience in the pre-test affecting the post-test results can thus be discounted.

Parameter - Weighted score of component replacement.

Taking the results of this parameter measurement as an individual result does not give a meaningful answer. Each fault in the tests has a different faulty component, and thus the weighted score for the replacement of this component could vary from fault to fault. In this case no general bogey score can be given to the pre-test and the post-test which would give consistent results.

However, these results were meaningful when taken in the context of the total weighted score to repair the fault, and these results have already been discussed. However, for the sake of completeness, the results for the weighted score of components replaced are included, and are shown in the table overleaf (Fig 5.5).

In fact each experimental group achieved a saving in this parameter, but this is only to be expected as each experimental group achieved a saving in the number of actual components replaced after working through the programme, as measured by the pre-test and the post-test.

The control group again showed very little difference

Fig. 5.5

WEIGHTED SCORE OF COMPONENT REPLACEMENT

GROUP	NUMBER IN GROUP	PRE-TEST		POST-TEST		TOTAL SAVING	AVERAGE SAVING	PERCENTAGE SAVING
		TOTAL WEIGHTED SCORE	AVERAGE WEIGHTED SCORE	TOTAL WEIGHTED SCORE	AVERAGE WEIGHTED SCORE			
REM	42	3192	25.3	2394	19.0	798	6.3	25
RMA	23	712	10.3	413	6.0	299	4.3	42
LREM	17	386	7.6	301	5.9	85	1.7	22
REAA	11	423	6.4	313	4.7	110	1.7	26
CONTROL	21	640	10.2	657	10.4	-17	-0.2	-2.7

between the results for the pre-test and the post-test. This again gives evidence that the test procedures were well controlled.

A Wilcoxon test was once more carried out on these results, and the figures are given below :

Group	N	T	α
REM	18	13	< .005
RMA	14	2	< .005
LREM	14	25.5	< .05
REAA	11	1	< .005
Control	21	106	N sig

All experimental groups show an improvement in performance significant at the .05 level. The control group show no significant improvement.

Parameter - Time taken for the pre-test and the post-test.

In this test the total times for the trainees to complete the pre-test and the post-test were measured. This was only recorded where a trainee complted the whole of the pre-test and the whole of the post-test, ignoring the cases of results of those trainees who completed only a part of the test by applying a correction factor to their times to give the total apparent time for the tests.

The results were divided into the four groups of the experimental classes, and results were also taken for the control group. The results are shown in the table overleaf (Fig. 5.6).

All of the four experimental groups showed substantial improvements in the time taken to clear a fault after working through the programme. The class of Leading Radio Electrical Mechanics again showed a very large improvement. It must be repeated that this is the only group with any practical experience of actual fault finding, and thus this improvement gives a very real gain in fault finding performance for electrical ratings at sea. In fact the class of L.R.E.M.s had a very low average time per fault in the post-test, actually 15.4 minutes per fault, and this shows a very satisfactory standard of fault finding. As the average time per fault in the pre-test for this calss was over 45 minutes, they saved on average 30 minutes on each fault which they repaired.

Fig. 5.6

TIME TAKEN IN MINUTES FOR PRE-TEST AND POST-TEST

GROUP	NUMBER IN GROUP	TOTAL POSSIBLE FAULTS PER TEST	PRE-TEST			POST-TEST			ACTUAL TIME SAVED	AVERAGE TIME SAVED	PERCENTAGE SAVING
			TOTAL FAULTS COMPLETED	TOTAL TIME	AVERAGE TIME	TOTAL FAULTS COMPLETED	TOTAL TIME	AVERAGE TIME			
REM	42	126	101	4252	42.1	123	3745	30.5	507	11.6	28
RMA	23	69	49	2744	56.0	64	1466	22.9	1278	33.1	59
LREM	17	51	46	1910	45.5	51	784	15.4	1126	30.1	66
REAA	11	66	51	1910	37.4	59	1564	26.5	346	10.9	29
CONTROL	21	63	63	2923	46.4	63	2980	47.3	-57	-0.9	-2

The class of Radio Mechanician Apprentices also showed a very large improvement in this test. The average time saved per fault was 33.1 minutes, although their post-test performance was not quite so good as the class of L.R.E.M.s.

The Radio Electrical Mechanics and the Radio Electrical Artificer Apprentices both showed a lower rate of improvement. However, this improvement is still satisfactory. The results for these two classes are both approximately 30% improvement in the time taken to clear a fault after working through the programme.

The results of the control group are again conclusive. The average time taken for the pre-test is well within the bracket of time taken by the other four groups, and they did not in fact improve in the post-test. The pre-test average time was 46.4 minutes, and the post-test time was 47.3 minutes, which is a slight fall in performance. This works out to be an average of -2% discrepancy between the time for the two tests. This is a very small factor, and would make very little difference to the results of the other groups if applied as a correction factor. However, the most important aspect of the results of the control group is that there was no spurious effect in the measurement of post-test performance due to experience gained by trainees in carrying out the pre-test. The improvement shown for this parameter is solely due to the influence of the programme.

A Wilcoxon Matched-Pairs Signed-Ranks test was once more carried out to determine the level of significance of the improvements in performance already calculated. The results are shown below :

Group	N	T	∝
REM	18	3	< .005
RMA	14	3	< .005
LREM	14	0	-
REAA	11	8	< .025
Control	21	63	~ sig

N is the total number of independantly drawn cases

T is the smaller of the sum of like-signed ranks

∝ is the level of significance

All experimental groups therefore show an improvement in performance which is significant at the .05 level, and in fact at the .025 level.

The control group shows no significant increase in performance on the post-test.

In fact, the percentage of time saved on these relatively simple faults would show to much more effect when the trainees were actually called on to carry out fault finding at sea when the faults would be more complicated. A saving in time taken to cure the fault of the order of the results shown here, would show a very large saving in actual time taken to cure a more complicated fault.

This completed the survey of results for the five parameters chosen. However, a final investigation was carried out. This was concerned with the number of trainees in each group who did not achieve a better performance in the post-test than they did in the pre-test. Although the average and total figures quoted so far have all shown an improvement in the post-test for the experimental groups, there were some members of these groups who did not in fact improve in the post-test.

The results of this investigation are summarised in the table overleaf (Fig 5.7)

Fig. 5.7

NUMBER OF TRAINEES NOT IMPROVING IN POST-TEST

GROUP	PARAMETER					
	NUMBER IN GROUP	TOTAL STEPS	TOTAL OF WEIGHTED STEPS	NUMBER OF COMPONENT REPLACEMENTS	WEIGHTING OF COMPONENT REPLACEMENTS	TIME TAKEN
REM	42	7	4	4	5	2
RMA	23	2	2	2	2	2
LREM	17	2	2	3	4	0
REAA	11	0	0	0	1	1
CONTROL	21	12	12	13	11	12

As would be expected, the group with the largest number of trainees contained the largest number who did not improve. This was the group of Radio Electrical Mechanics. In a total of 42 trainees in this group, seven did not improve their performance in the post-test when the parameter was the number of steps taken to cure the fault. This was the highest number not improving in any of the tests carried out with the experimental groups.

The group of Radio Mechanician Apprentices appear to have very consistent results, but in fact it was not the same individual trainees who did not improve in the different tests. However, the results for this group are quite satisfactory.

The results for the class of Leading Radio Electrical Mechanics are slightly worse than those for the Radio Mechanician Apprentices. However, considering the fact that this group overall produced some of the highest improvements in the parameters measured, the total result must be considered to be satisfactory.

The results for the class of Radio Electrical Artificer Apprentices are the best of the four experimental groups, but of course this group contains the smallest number of trainees so a slightly false picture is given. However, for three of the parameters all of the group improved their performance, and for the other two parameters only one of the group did not improve. In this case it was the same individual trainee who did not improve each time. He did, however, improve his performance on the first three parameters.

The results of the control group are very interesting. In each case approximately 50% of the group were better in the post-test, and approximately 50% of the group were worse in the post-test. This result, coupled with the small actual differences in their pre-test and post-test results, shows that the experiment was well controlled, and that the spurious influence which could have been introduced by using the same type of simulator sheets for the pre-test and the post-test was kept to a minimum. In fact it could be said that there was no correction factor which could be applied to the post-test, and the improvements shown by the experimental groups were all measurements of actual direct improvement due to the programme.

This concluded the evaluation tests on the programme.

It is considered that these results show a very real improvement in fault finding performance which can be attributed to the programme, and that this improvement was general over the entire range of the test population. However, before drawing final conclusions concerning the test results, it was neccessary to consider all the results collectively. The conclusions which were reached are discussed in the next chapter.

CHAPTER 6.

CONCLUSIONS.

The original requirements laid down for this investigation can now be examined to determine the extent to which they have been satisfied. It is therefore convenient at this stage to reiterate the original requirements, which were as follows :

1. To instigate an investigation into the possibility of discovering a general method of fault finding in electronic equipment, which would be generalised in content and which could be applied to any type of equipment.

2. To formalise such a method, if found, and discover the degree to which it would assist in fault finding techniques.

3. To discover if this method could be taught to the normal entry level of electrical trainee, and to what higher levels it would also be of use.

4. To initiate a pilot scheme if the above requirements were satisfied, and to carry out an investigation of the improvement, if any, in fault finding performance shown by trainees taking the course.

The first two requirements listed above need no further discussion here. It has already been described how a method of fault finding was developed which could be applied to any electronic equipment, and how this method was formalised. It was found that this fault finding method was very successful, and the use of the method produced a marked improvement in fault finding technique.

Thus the first two requirements of the original specification were completely satisfied.

It was also found possible to teach this method of fault finding to new entry electrical trainees, and that this could be done successfully. The method was also found useful for the highest level of electrical rating, and in fact could be used with success by electrical officers. Thus the method of fault finding which had been developed was suitable for the entire range of the electrical branch of the Royal Navy, from the lowest level of entry to the specialist officers in the branch.

The remaining requirement, that of initiating a pilot scheme of instruction and measuring the increase in performance due to this instruction, represented the major portion of the investigation.

Because of the conditions under which this pilot scheme would be organised, and other considerations already discussed, it was decided that the best vehicle for this course would be a branching programme of the multiple choice type. It was also decided that this would be best produced as a programmed text.

Great care was taken in the production and testing of this programme as it represented departures from normal practice in two major aspects. These were as follows :

1. Up to this time, although a great deal of work had been carried out in the Royal Navy on the use of programmed instruction, the emphasis had always been on the use of teaching machine presentation, as experiments on programmed text presentations had not proved as successful as the machine presentation.

2. The use of this generalised method of fault finding, applicable to all equipments, was also a new departure for the electrical branch of the Royal Navy.

Thus the programme and the method had to be decisively proved valid before they would be accepted for general use in the navy. To do this, the testing of the instructional course was split into two main divisions, the validation of the programme itself, and the evaluation of the training efficiency of the programme, taking into account the validity of the fault finding method used in the programme. To provide a significant result, each portion of the test procedures was carried out with a group of over one hundred trainees, and a further control group was used in the evaluation of the training efficiency of the programme.

During the validation of the programme, several frames were found which could usefully be revised. However, the revisions were not considered mandatory for the overall performance of the programme to be measured. Validation was carried out by detailed study of the responses made by the trainees when working through the programme, and it i.

considered that the programmed course in systematic logical fault finding has been validated successfully, and that the programme was in a suitable condition for immediate use.

The evaluation of the programme was carried out by means of a pre-test and a post-test, the tests being strictly matched, and the performance of the experimental groups being monitored by the use of a control group.

In the study of the results of the evaluation tests it is important to remember that there can be no such thing as a zero knowledge of fault finding for any person who has any electrical knowledge. Regardless of the extent of this knowledge, it must produce some standard of fault finding in electronic equipments. Conversely, there can be no question of attempting to teach fault finding procedures in electronic equipment to a trainee who has no electrical knowledge. Thus the evaluation results must necessarily be less spectacular than for a programme which assumes zero knowledge of the content before entry to the programme.

With this in mind, the results of the evaluation tests are very satisfactory. The results of the control group show that this improvement in performance in fault finding can only be attributed to the programme. ~~and that the measured increase in performance is absolute~~. The experimental groups showed an increase in fault finding performance in every parameter measured, and this improvement was significant.

It can therefore be said that the fault finding programme has provided a significant increase in fault finding performance, particularly in respect of the time and effort spent in the repair of the fault, due to instilling a logical standardised approach to the problem, and that this increase in performance should be more marked in the more complex faults and equipment.

As the programme does not teach fault finding on specific equipments, it is imperative that the programme be followed up by practice on actual equipments as soon as possible, using all of the basic steps taught in the programme. The simulator sheet as used for testing this programme is ideal for the transition stage between the programme and the actual equipment, enabling the basic method to be employed in an equipment circuit without the mechanical complications of the equipment.

The success of this approach to the problems of fault finding on electronic equipments was such that both the method of fault finding, and the programme, were adopted as standard for the electrical branch of the Royal Navy. A special teaching group was formed in H.M.S. Collingwood, the Royal Naval Weapons and Electrical School, to teach these principles. This group consists of five specialist officers, and is headed by a Lieutenant Commander. Amongst other problems, this group is working on the standardisation of specific fault finding procedures on all electronic equipment in the navy, based on this method of fault finding, and the use of simulator sheets as were used in the testing of the programme.

The group run courses which are attended by every member of the electrical branch of the Royal Navy, and the programme and method described in this report are standard to all courses.

There remains a great deal of work to be done on the topic of fault finding, and work is now proceeding on points raised during the testing of the programme. One particular question which could not be considered at the time was the question of which particular skills are required to make an electrical rating a good fault finder. Is a deep knowledge required of electronic theory, or could a rating fault find satisfactorily with a more detailed flow chart and only a small amount of theory.

Unfortunately the author was subject to routine transfer before being able to pursue this investigation any further, but work is still proceeding on the many and varied questions which were raised by the results of this investigation.

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