EDUCATION PAPERBACKS

This book is a study of the problems of functional and ideological adaptation of the curriculum in response to social change, based on a close investigation of a particular and very significant curriculum innovation, set up in 1962: the Nuffield Foundation Science Teaching Project. Within this scope the author focuses particularly on the development of the O level chemistry curriculum, which was one of the three founding projects.

In our loosely coordinated education system, in which power has become more and more diffuse and effective power increasingly difficult to identify, the process of effecting change is formidably complex and studies of such attempts understandably rare. And yet if sensible decisions are to be made about curriculum development, now and in the future, it is vitally important that we take account of the history of influential curriculum projects. Hence the great value of Mary Waring's book, which deals thoroughly with the various political, social and educational factors influencing the setting up of the Nuffield Foundation Science Teaching Project, the details of its execution (methods, the influence of pressure groups, and of particular individuals) and its outcomes (especially the effect of the post-publication failure to take proper account of teachers' perceptions and the constraints within which they operate).

At a time when there is considerable reappraisal of the value and effects of innovation in organization and content of the secondary curriculum, this book should be a stimulating aid to clear thinking. As history it makes fascinating reading.

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SOCIAL PRESSURES AND CURRICULUM INNOVATION
MARY WARING

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A Study of the Nuffield Foundation Science Teaching Project

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Mary Waring

1

Introduction: society and the functional curriculum

This book is about processes of change and of changing. In particular, it is about the problems of functional and ideological adaptation of the curriculum in response to social change, about individuals and groups who have sought to effect curriculum change and about the problems they have encountered and the strategies they have employed.

In an examination-orientated system in which power has become more and more diffuse and effective power increasingly difficult to identify, and in which there is no statutory, centralized control of the curriculum, the problem of effecting change is formidable. This is particularly so where teaching approach is involved and where it requires role change for teachers and pupils. Over time, various solutions have been proposed and two major innovatory responses made. The establishment of the Nuffield Foundation Science Teaching Project was one response; that of the Curriculum Study Group by the Ministry of Education the other. The final outcome of both was the Schools Council. Inherent in these approaches was a belief in the autonomy of the teacher, a belief manifested in various ways but most noticeably in the provision, by teachers, of 'resources, not courses' for intelligent selection, modification and adaptation in individual classrooms. Such resources are, then, merely on offer, though a number of pressures for at least partial adoption may influence teachers' decision making. Nevertheless, the freedom of choice that does exist means that widespread change requires widespread dissemination, persuasion, conviction and conversion — all of which may be extremely difficult. Although studies of diffusion, of summative evaluation and of the extent of change have been undertaken, there are still vast areas of ignorance, and considerably more research is necessary.

It was clearly completely beyond the scope of this study to examine all aspects of curriculum change, and attention has been focused upon the origins and antecedents, and the machinery-in-action of the Nuffield Foundation Science Teaching Project and, within it, Nuffield O level chemistry. In the last chapter, hindsight is used to try to extract some more general lessons for the future.

On 4 April 1962, in reply to a Parliamentary Question in the House of Commons about the steps being taken by the new Curriculum Study Group to improve the teaching of science and mathematics, the Minister of Education, Sir David Eccles, announced the setting up of the Nuffield Foundation Science Teaching Project.

> I am pleased to announce that the Nuffield Foundation has decided to make available £250,000 towards the cost of a long-term development programme to improve teaching in these subjects. The programme will be supervised by the Director of the Foundation, Dr Farrer-Brown, in association with the Curriculum Study Group, and with the help of advisory committees, but the detailed work will be carried out by practising teachers under the guidance of specially appointed full-time Nuffield Fellows. I am sure that the House will wish me to thank the Nuffield Foundation for the help they are so generously giving the schools.[1]

A simultaneous press release gave organizational details, as well as stressing the cooperative nature of the venture, for besides the Curriculum Study Group it would involve all branches of the educational service, professional scientific institutions, industry, the Science Masters' Association and Association of Women Science Teachers, Her Majesty's Inspectorate, the Scottish Education Department, the Gulbenkian Foundation and the American curriculum reform movement. The statement also gave some account of progress so far and of plans for the future.

The Science Teaching Project was to be designed 'for teachers by teachers', and it was to concentrate, in the first instance, on

five broad sections: physics, chemistry and biology for eleven to sixteen year olds in grammar schools and streams, secondary school mathematics, and primary and secondary school science for non-examination classes. Work on the latter two sections would, however, be deferred until further discussion and clarification had taken place.

In each section, the end product was envisaged as a 'coordinated set of materials ... to be used by individual teachers in any way they wish'. Such material was regarded as being most likely to be welcomed by experienced and inexperienced teachers alike. In the case of the former, it would form an efficient basis for putting across fundamental knowledge, while its usefulness to the latter was seen as being even greater, for the materials would, it was hoped, represent the best available knowledge and experience in school science.

O level projects were to offer to pupils entering for GCE O level (or Scottish O grade) examinations 'some insight into scientific thought and method'. Courses were to be equally suitable for future science specialists and for those who might later specialize in other subjects, or who would leave school early and take up non-academic careers. The programme was not a totally new venture, for it would be based upon and consolidate the work that had already been done in Britain and elsewhere to revise science curricula.

Each Organizer, selected because he was considered to be 'the man for the job', would be backed by a small consultative committee, chaired in each case by an eminent scientist, and detailed work on the programmes would be undertaken by teams of school teachers, chosen for their 'capacities for the task'[2].

The Science Teaching Project represents a major landmark in English[3] educational practice, namely, the development of an articulated and comprehensive set of tested teaching materials in an attempt to achieve coordinated and widespread reform in science and mathematics. In this, it reflected the intentions of the American curriculum development movement of the 1950s and 1960s. Fundamentally, however, its character was unique, for not only was it funded by a charitable trust, the Nuffield Foundation, and directed and controlled by Trust personnel, but it was based squarely upon a set of assumptions which, in part at least, reflected a history of science education peculiarly 'English'. It was thus essentially 'British' in spite of some similarity with corresponding ventures in America and elsewhere. Although some sixteen years have elapsed since its inception, a documented history is only now coming into being. There exists, however, an extensive and varied mythology, and this book is a first step towards placing on record something of the background to the Project and of the machinery of curriculum development.

The dynamics of change are very complex and impossible to grasp in anything like entirety. Any act can be explained only in relation to all the events of which it is a part, for changes and events are all linked in time *and* space with other changes and events. This two-dimensional web of interaction — sideways, as well as forwards in time — adds a further complicating factor, for it means that it is impossible to establish sequences of cause and effect except at the simplest level, and then only with caution and at the risk of error. For at every stage the many contingent factors make possible a variety of outcomes — even no outcome at all — and introduce the element of chance into change.

The Nuffield Project needs exploring, therefore, from a number of different perspectives: as a means to an end; as a response to social, economic, educational and ideological change; as a study in the history of ideas; as a study of decision making and action (including pressure group and individual initiative), and as a demonstration of a philanthropic institution, the Nuffield Foundation, becoming involved in education and, ultimately, curriculum change. To try to do so much is to run the risk of bastardizing history; yet to avoid it is to risk gross over-simplification, seen at its worst in the case of Nuffield in the 'Sputnik syndrome', the ascription of the curriculum development movement here and in America to this point source. While Sputnik certainly underlined the climate of concern about scientific and technological manpower in the West, it did not engender it nor did it prompt the curriculum development movement either here or in America. It is true that funding of curriculum projects on a massive scale came from the National Science Foundation in the United States only after October 1957, but mathematics projects had been on the go there since the early 1950s, and the Physical Sciences Study Committee's physics project was already established.

The changes that take place in any society are, inevitably, closely interconnected. There are many different areas of change — politics, the economy, population, culture (in its widest sense of beliefs, values and norms), scientific knowledge, education, military activities, transport and other forms of communication, technology; indeed, the whole way of life of the people. Since

all are interdependent, it is impossible, without distorting the picture, to isolate any one area in an attempt to show how it has led to, or resulted from changes in others. This distortion must be kept in mind when any attempt is made to trace the growing importance and ramifications of the effects of scientific and technological change in the development of our complex modern society, and to discuss the web of interaction with other aspects of society, and in particular with educational provision.

The curriculum of formal educational institutions is intended to be functional, fitting each individual for his place in society. As society has changed over time, so pressures for curriculum change have developed. Whatever their roots, cultural, ideological or economic, these pressures have generally been fairly specific in nature and the change largely remedial and piecemeal, so that, inevitably, the curriculum has always contained a fairly sizeable traditional element. Our own curriculum, with its roots in ancient Athens and Rome, has a very long tradition, and the result has been a curious and monumental accretion, the product of centuries of borrowing and modification, of gradual and partial adaptation to change and, however it may have been rationalized, of resistance to change by powerful vested interest. Nevertheless, as long as education remained the province of church and aristocracy, it was essentially functional until, with the gradual yet radical religious, political, economic and intellectual changes of the sixteenth and seventeenth centuries, the gap between social change and educational adaptation began to widen.

Towards the end of the eighteenth century social change became recognizably continuous and widespread. As with all social change, a complex of factors was involved. Many of them were economic, but change also encompassed not just the types of adult work available and the requisite social characteristics of workers, but the total way of life of the people. All changes reflected the growth of industrialization, in which, too, were the roots of the growth of democracy — significantly, a word whose meaning changed at this time. Industrialization greatly speeded up the rate of social change, increasing the division of labour, affecting social mobility, attenuating the boundaries between sub-groups in society and throwing new burdens upon education: burdens of mass literacy, of the promotion of scientific and technological advance, of occupational recruitment, of the provision of opportunities for social mobility, of social selection (by acting as a giant 'sieve') and of providing a common education for children in an increasingly stratified system, between whose sub-groups little consensus may be apparent in terms of norms, attitudes and values. Then, as now, the complexities of adaptation were made still more formidable because of large areas of ignorance about the processes of learning and teaching, because of conservatism and vested interest, because in a class-ridden society some kinds of knowledge are accorded greater value and status (hence desirability) than others due to their association with an elitist 'high culture' and with privilege, and because of the intricacy of relationships.

In the last hundred or so years, the image of the race-track engendered by the word 'curriculum' has reflected not only the race of the swift for academic success and, through it, social mobility, but also the vying for a place in the curriculum by protagonists for an ever-growing number of subjects, who plead on the grounds of 'utility', 'relevance', 'culture', 'academic excellence' or the 'development of mind, of rational autonomy'. It is hardly surprising that the last decade has seen growing concern — and not only among the radical fringe — that educational dysfunction may now have reached a stage at which, for the first time, really large-scale change may be necessary, change confined not simply to institutional structure or curriculum content, but change involving the restructuring in time as well as content of the whole of education.

Cardwell has drawn attention to a striking fact. Many societies in the past have made considerable achievements in music, sculpture, art, drama and literature, or have evolved complex legal and philosophical systems. Some have been technologically developed. Yet only one — our own Western society — has 'possessed those vital elements that made possible the systematic and widespread development of the advanced sciences and has succeeded, moreover, in utilizing science to solve problems in industry and the arts'[4]. Various suggestions have been put forward to account for the burgeoning of modern science in Western Europe during the sixteenth and seventeenth centuries, and for its continuing, exponential growth thereafter. Whatever the underlying causes, the growth of modern science has contributed, directly and indirectly, to a transformation of man's view of himself and of his world, and of the place of both in the universe; of attitudes, values and social relationships, of industry, of the rate of social change, and of his whole way of life. Clearly, the benefits have not been unalloyed. The power that modern science has given man has been matched by a corresponding growth in the size of the problems that have resulted, including some of the most critical that exist for our society today, problems that cannot be solved by science alone, problems that raise fundamental questions about issues of choice and responsibility, and about the role, the responsibilities and the capabilities of education in a democratically orientated technological society.

It took some three centuries to establish a place for science in the curriculum of all pupils, and during that period there were major changes in society, changes so considerable that Raymond Williams has described them as 'revolutions'. He has identified three such 'revolutions', all of them interrelated: in literacy, in attitudes to social justice, and in science and its place in society[5]. All produced pressures for change in schools, all produced pioneering ventures, all engendered and fostered (rarely attenuated) pressure group or individual activity and ideology, all influenced decision making, creating, in the process, a history of science education which can only be fully understood in a context which is still very largely unexplored.

In this book I am focusing strictly on those decisions that determined the trend of science education in secondary schools, and on the debate that has continued throughout this century and has informed the intellectual climate of the men and women who participated in the science teaching projects in the 1960s and 1970s. The book is about change and changing in relation to the curriculum, rather than about the history of science education *per se*. It allows current beliefs and assumptions and practices to 'exercise a censorship on the past'[6] which, as Webster has so cogently argued, provides the sort of distorted perspective that is so often found in histories of science, where historians have treated experimental investigations and conceptual advances very selectively, placing the greatest value on the history of 'subjects which are familiar in terms of contemporary priorities'[7].

Social changes and social pressures are not entities, but the products of the interaction of men and women, with distinct and differing attitudes and interests, who perceive and select from the milieu not only what is the case, but what they take to be the case[8]. The motive power of any pressure group lies in a shared belief in their perception of what is wrong or lacking in the current situation, and of what can be done about it, and in the ability of the leadership to canalize the dissatisfaction of the group, and of others, into line with these beliefs, by crystallizing, defining and focusing it in such a way as to create a widely shared frame of reference. But the ideas embodied in this frame of reference will be ineffective unless they reflect ideas already inchoate in society, and so have meaning and relevance for others, and unless they are legitimated by authority, personal and/or intellectual. And since men act as they do for a variety of reasons, the question of motives must be raised, for ideas can be used as political weapons as well as social or educational levers.

Pressures for curriculum change at any given time may be rooted in one or several areas as, for example, ideology, politics, economics, or professional knowledge and theory. Whatever the roots, such pressures generate expressions of growing concern that the curriculum, or part of it, is no longer serving its purpose, however that is viewed. Dissatisfaction is expressed more and more widely and diagnosis and prescription offered, at first by isolated individuals. This situation may obtain for many years, after which the need may disappear before the weight of new and different pressures. Alternatively, there may be an apparent crystallization of attitudes and ideas, frequently but not necessarily as a result of social and economic crisis.

The more general awareness and sense of urgency that is now occasioned creates an 'unfreezing' situation, in which assumptions and current practices are re-examined, and attitudes become open to change. But dissatisfaction tends to be impotent, because randomly orientated, and it is at this point that pressure groups can operate most effectively, first, because they are able to canalize the dissatisfaction to their own particular interests, and second, because they can bring more effective pressures to bear on decision makers, with a view to effecting change.

Arguments for promoting science, and to that end, science education, fall into two broad categories. First, there are those that stress the value of scientific knowledge as a part of man's intellectual heritage and, within it, the value of scientific activity, so-called 'scientific method', as a means to effective problem-solving and to the building up of *testable* knowledge and understanding, as well as to the development of its inherent intellectual and manipulative skills, values and attitudes. Arguments that stress the value of a subject *per se* form part of the armoury of group pressures for a place in the curriculum — or a bigger and more important place — for any subject. In the case of science, however, a second type of argument becomes possible: the importance of science and scientific activity to society, the contribution they can make to social welfare, to the economy, to defence and to national prestige. As science has

become increasingly important in society — and with the expansion of applied science especially in relation to defence, prestige and economic growth, this argument has grown more and more powerful in pressing for change — enthusiasts for science have not failed to recognize the fact, and to use it. Justificatory arguments are, of course, prescriptive in terms of both 'science-for-teaching' and teaching approach and, in a stratified society, in terms of client population. In the long term, the prescriptions advocating what 'science' should be taught to which groups of pupils, when, how and for how long, have had a considerable influence upon the path that science education has taken.

But who are the decision makers at whom these arguments are directed? Who controls the curriculum? A society with an ideal of freedom from central authoritarian control and in which freedom of speech is encouraged — paradoxically, perhaps, a constraint upon headlong change — will also provide freedom to experiment, usually within certain ideologically defined parameters. The spread of change, however, requires not only efficient communication channels, but action on the part of those in effective control of the curriculum. Custom and tradition are nowhere more comfortable than in the seats of power, and so the impetus for change has often to come from pressure groups and individuals who bring pressure to bear upon decision makers. In order to exert this influence they must identify and ensure the cooperation of all effective sources of control among such decision makers. This is, clearly, a considerable and extremely complex task.

For centuries, all three major forces for the control of education — finance, administration and professional considerations (such as curriculum and teaching approach) — were vested in ownership. As the educational system of England and Wales has moved towards the establishment of an articulated whole and as education has come to be seen as central to the nation's economy, control has become not centralized, but more widely distributed, often diffuse (because shared), more varied — and considerably more complex[9].

Unlike those countries which have centralized control of the curriculum, the only statutory requirement in England and Wales is the provision of religious instruction. While local authorities have the right to prescribe on any matter of the curriculum, final responsibility for what goes on in schools — curriculum and teaching methods — is officially vested in the head teacher, who is expected to act in consultation with his staff and governing body (managing body in the case of primary schools). This does not mean, however, that teachers have absolute freedom on curriculum matters. In the first place, the law requires that what goes on in schools be acceptable to parents and related to the ages and abilities of the pupils. In the second, many other individuals and institutions, such as HM Inspectors, head teachers, parents, governors, examining boards and, through entrance requirements, universities, have power which enables them to facilitate or to constrain attempts at change. In the third place, tradition, inertia, the piecemeal and *ad hoc* nature of most educational change, and the differential status accorded to different 'subjects' in the curriculum (often because of the association of certain subjects with the education of controlling elites) make the curriculum the product of historical as well as of contemporary decision making.

Yet, in the individual classroom, what each child takes away from each lesson is different. For the individual teacher, in any specific classroom, another complex of factors — personality, temperament and ideological stance, as well as the physical and situational constraints imposed by accommodation, finance and available help — affects the activities that produce learning. Further, each pupil brings to each lesson his own, partly unique, life experience and in these lessons accommodates and assimilates his experiences to his ever-growing and highly individual construction of reality. Wherever power and influence lie, however 'teacher-proof' the syllabus and resources a teacher draws upon or uses, becoming educated is a qualitative exercise and, in the long run, it is the quality of interaction between teacher and pupils that counts.

Though originally established in the mid-nineteenth century as a means of creating for the middle classes a uniform system of education in which maintenance of standards could be ensured, it is quite clear that examinations rapidly became powerful determinants of the secondary school curriculum. In the first place, examination requirements could exert a considerable influence upon the subjects offered and taken up by pupils in such schools. In the second place, their syllabuses and their question papers would determine not only content, but also, and to an ever more apparent extent, the method of teaching used. In spite of the examination boards' expressed intention that they should follow and not dictate the curriculum, the situation was such that, in 1962, two of the Nuffield O level Organizers could express their view of the situation in the following terms:

> Examinations — whatever else they do — control the success of any teaching plans[10].
> However acceptable a project may be on educational grounds, it will not be viable in the school environment unless the questions used in public Examinations are in keeping with the spirit.[11]

Examinations can, however, provide a very valuable means *to* change, and they have been used as such. Nowhere is this more clear than in the long battle to get science a recognized place in the curriculum of secondary schools, and in particular in independent schools. Again and again, when exhortation has failed, there has been recourse to pressing for change in the examination system.

Though many other factors operate to determine the curriculum, it is clear that teachers and examination boards provide a major focus for attention when change is wanted. Throughout the twentieth century there have been repeated moves by central authority to try to establish at least a measure of control over the university-dominated examination boards. The setting up of the Secondary School Examinations Council in 1917 and the changes in its constitution which altered the balance of power within it over the succeeding thirty years, were not just attempts to obtain coordination of the activities of the examination boards: they were also aimed at curriculum control. So was the Schools Council for the Curriculum and Examinations, established in 1964. In a decentralized system, however, such moves must not be seen to threaten the autonomy of local power groups and so, from 1917 on, central authority has (i) steadily increased the representation of sectional interests on, first, the Secondary School Examinations Council and then the Schools Council, and (ii) consistently backed teacher 'infiltration' of examination boards and their subcommittees[12].

At the same time the teachers themselves have sought greater control of the curriculum. They have used the opportunities afforded them of joining in the work of the boards. They have made representations to them about syllabus content, and they have formed associations whose central concern has been the improvement of (i) the status of the subject, by persuading boards to make their inclusion a requirement, and (ii) the teaching of the subject, by trying to ensure that the nature of the examination questions is in keeping with their objectives. Such associations have also brought normative pressures to bear upon their fellow teachers, through meetings, journals and books. In science education, by far the most significant association has been the Science Masters' Association and its forerunner, the Association of Public School Science Masters. There has been growing support from the Association of Women Science Teachers, with which the Science Masters' Association merged in 1963 to form the Association for Science Education. Yet, in spite of all their efforts, curricula in science became hopelessly outdated, partly because of the inertia of the examination boards, partly because of the rapid change and expansion in scientific knowledge.

The Nuffield Project was the evolutionary outcome of many years of work for the reform of secondary school science curricula, principally by small groups of science teachers who acted largely through these associations, but also by professional institutions and individuals, often working through more than one collective group. By the late 1950s and early 1960s there were considerable social, economic, national and intellectual pressures for educational change of many kinds. In the 'Two Cultures' climate around 1960, the position of the advocates of science was particularly strong. Yet government remained uninterested in secondary school science as such until it became an issue in the pre-1964 election debate and, subsequently, with the so-called 'swing from science'. Nevertheless, within the climate of that period, the Nuffield Foundation had been moving steadily in the direction of large-scale support for education and it was the partially fortuitous conjunction of time, place, circumstance and persons, that led to the establishment of the Science Teaching Project in 1961-2.

The Project aimed at achieving continuing, more efficient and rapid reform of school science curricula by providing resources for professional use by teachers; resources which encapsulated not only changes in the content of the curriculum but in approach, and hence in the roles of teachers and pupils. Organizers of individual Nuffield projects were given considerable autonomy with regard to the interpretation and carrying out of their brief, and to the selection and deployment of their teams. As a result, these aspects reflect very clearly the background and personality of the men and women chosen. In the end, the Organizer bore responsibility for all decisions. Yet he had, of necessity, to delegate work and thus some measure of responsibility. Inevitably, therefore, people, their personalities and their interaction are at the core of the projects and made them what

they are. The brief from the Foundation was, in fact, deliberately vague, stating only that the outcome was to be a coordinated set of materials, for use by teachers in any way they saw fit. From this brief, each Organizer had to identify, with or without the help of his team, as he chose, the framework on which development was to be based. His interpretation of this task, that is, his conception of the problems involved, and of what might constitute 'success' in solving them, then determined overall approach and content and, within them, relative emphases. Each project is therefore very different in a number of ways, and it is futile to seek for 'the Nuffield approach', for 'There is nothing more individual than an idea. No committee ever has or ever will form an idea. It can only adopt one. Ideas are formed by individuals from the depth of their personalities ... [13]'.

Nevertheless, it is important to recognize that ideas are seldom born in isolation, but are intimately tied up with the whole intellectual climate of the milieu. It is tempting — and easy — to attach credit to a point source in any field: but the dominant philosophies of any period are surely a product of time and place and culture. Similar philosophies are likely to be the product of similar causes and are not necessarily a matter of direct influence that can be 'validated' by chronology. There is no copyright on ideas that can prevent others from having them independently, producing them, not because of direct influence, but because the wider contemporary intellectual climate makes them all a product of one society. A cynic has said, 'You can find in Plato whatever you are looking for', and a continued preoccupation with the tracing of influences — or even a naive acceptance of an apparent causal relationship between ideas, except where directly acknowledged (and even here there may be dangers) — may well be, in part at least, a substitute activity or an act of intellectual evasion. No attempt has been made here to look for possible influences; all that is attempted is a sketching-in of some of the background of ideas and findings which formed part of the intellectual climate of the men and women who produced the science projects, and within this, the inclusion of specific influences, pin-pointed by them.

The Nuffield O level Chemistry Project is used to exemplify *one* approach to curriculum development in school science. Although, clearly, it shared many features with all other Nuffield, and many subsequent Schools Council, projects, it was also unique in a number of ways, for reasons already indicated.

Case studies present problems of validity and reliability. A case study is:

> ... an examination of an instance in action. The study of particular incidents and events, and the selective collection of information on biography, personality, intentions and values, allows the case study worker to capture and portray those elements of a situation that give it meaning.[14]

This is, surely, the essence — and the strength — of case study work. Recognition of the limitations it imposes on reliability and validity, and of possible sources of bias, confusion or conflict can be used to enhance that strength by recourse to as rigorous a process of cross-checking and negotiation as possible. Reference has already been made to the hazards of generalization from particular instances. The researcher must therefore tread carefully the narrow path between unwarranted generalizations and the identification of problems and issues that may well be common to other instances of the exercise in question and which may, therefore, have serious implications for curriculum development and curriculum change.

In any account of recent history, where much relevant information is available with regard to the context of events, as well as to the events which are themselves the focus of the study, an element of selectivity is inevitably present. In the case of recent events, where one interacts with participants in the event that one is recording, problems of involvement and of commitment to the individuals and to their conception of the task become formidable. It would be naive, then, to imagine that an objective account of 'what actually happened' is possible and that no interpretation of events has occurred.

At a macro level, an account of this nature is also biased by the ideological stance of the writer. This study could have been presented entirely in terms of, for example, the pursuit of power and control. Ideologies are mobilizing: they give direction and consistency to action. While the importance of the notion of ideology as a political weapon has been recognized in this study, the view adopted is that it has additional broader, less dramatic, gnomic functions, which are essentially therapeutic. For the author agrees that

> ... the battlefield image of a society as a clash of interests thinly disguised as a clash of principles, turns attention away from the role ideologies play in defining (or obscuring) social categories, stabilizing (or upsetting) social expectations, maintaining (or undermining) social norms, strengthening (or weakening) social consensus, relieving (or exacerbating) social tension.[15]

In pre-project days and in the early projects, there was little promise of personal return on involvement, other than that of achieving the cause for which many of the organizers had worked unremittingly for many years. The evidence in this study supports the view that, while differences of degree no doubt existed between individuals, the sincerity, the commitment and the dedicated work over a long period of time, on the part of the principal characters at least, and probably of many others, dwarf and transcend whatever vested interests may have been operating.

2

More and better science, better taught

In modern industrial Britain it might seem irrelevant to question the right of science to a place in the curriculum, and it is pertinent to ask why there has been so long and uphill a struggle simply to establish it in the timetable of secondary schools, a struggle which lasted well into the scientific and technological twentieth century. It is pertinent, too, to ask questions about what 'science' has been considered appropriate and why. Behind both sets of questions and answers lie issues of, first, social and intellectual change, second, pressure group arguments and justifications and, third, power relationships. These issues have a long history, which extends right back to Francis Bacon and the Puritan reformers. Most relevant to this study, however, is the period since the mid-nineteenth century, and it is necessary to look back to ways in which events, actions and ideologies of that era influenced the path that science education has taken subsequently.

Setting the path for secondary school science

Much public, as well as more specifically educational, debate in the mid-nineteenth century centred round three interrelated conceptions: (i) the nature and scope of a truly liberal education, (ii) faculty psychology and the 'development of mind', and

(iii) the nature of science and of so-called 'scientific method'. Because the arguments were taken up and used to promote the cause of science in the secondary school curriculum, in the long term the debate was to be of considerable prescriptive importance for school science.

A liberal education: '...some kinds of knowledge are more so than others'

From the very beginning, Western philosophy has been preoccupied with the problem of rationality (in the sense of keeping the mind open to reason) and so with the problem of finding an impartial, rational standpoint for discussion, comparison and judgement, and of developing in men impartial methods and procedures. From an early stage, all the philosophical theories produced to solve the problem have shown the same orientation. The search has focused on a 'single unchanging and uniquely authoritative system of ideas and beliefs', of timeless truths, external to the human mind, and so with a validity independent of individual opinion[1]. Toulmin suggests that the identification of *objectivity*, in the sense of impartiality, with 'timeless truths' derives from the association of the sought-for authoritative and universal system with the newly developed and abstract network of geometry and logic[2]. The orientation is not, therefore, a necessary one, but it had a very important outcome. Since man's rationality was now defined as his ability to recognize the logical structure on which the authoritative system depended, rationality became associated with the attainment of knowledge, and the rational merits of an intellectual position were identified with logical coherence[3]. Through the right use of reason, the mind would come to know the essential nature of things — the 'truth' — which would then shape man's whole life and thought and experience. For as reality was apprehended in its different manifestations a hierarchically organized pattern of understanding would be developed, from knowledge of particulars to ultimate ideas of pure being. The pursuit of knowledge was thus the pursuit of the good mind and the good life. A liberal education was not simply the education of a free man, but an education that frees mind to function according to its true nature, that frees reason from illusion and error, and man's conduct from wrong. It was a process, therefore, simply and directly concerned with the pursuit of knowledge of well-defined scope and content; that is, 'objectively-determined in range, structure and content by the forms of knowledge itself and their harmonious hierarchical inter-relations'[4].

Though modified and extended in matters of detail to accommodate new forms of knowledge (not without opposition), though sometimes strongly opposed in essence (for instance, by Dewey and the pragmatists), the idea has been a hardy perennial in education. The debate has continued to the present day, although in the first half of the twentieth century it became blurred, as participants safeguarded their interests, or reacted to the plethora of new ideas and findings in psychology, philosophy, pedagogy and, later, sociology. From the publication of the Report of the Harvard Committee[5] in 1946, however, the debate about the relation of a liberal education to the forms of knowledge once again gathered momentum. Educational philosophers in Britain and elsewhere continued to define the relationship between knowledge and mind on the basis of an assumed logical relationship and to emphasize that the 'achievement of knowledge is necessarily the development of mind — that is, the self-conscious, rational mind of man — in its most fundamental aspect'[6]. For them, a liberal education is achieved through the structuring of experience by 'initiation' into the distinct disciplines of knowledge, or 'realms of meaning'[7]. This belief achieved considerable currency in the late 1950s and 1960s, becoming almost a *credo* in curriculum planning. In the 1970s, however, there has been growing criticism by those who see it as no more than a rationalization of elitist tradition, and an 'elaborate academic defence of the *status quo*'[8].

In mid-nineteenth-century England the idea of a liberal education as exemplified by the classical-literary curriculum gradually gave way to an interpretation in terms of a broad, general education. The reasons were, no doubt, complex, but there was probably some connection with faculty psychology (a pre-experimental psychology that viewed the mind as composed of a number of separate powers, or 'faculties', such as intellect, will, reasoning, observation, etc.), since the change occurred during the period in which this was most influential. Certainly, faculty psychology has often been used to justify a general education as, for example, in Dean Farrar's celebrated collection of essays published in 1867. All the contributors accepted faculty psychology, mental discipline and transfer of training[9]. Many of those who supported the idea of a broad, general education also exhibited the Kantian belief, which was held with

varying degrees of sophistication, that within the whole complex of knowledge each discipline is a clear-cut system based upon a 'regulative idea' and, especially, marked by a mode of inquiry essentially its own[10]. By mid-century there was pressure for a broad education based upon a harmonious balance of both science and arts subjects, a balance in which the earlier antithesis in educational debate between utility and culture began to disappear. Examinations, now proliferating, specified just this spread of subjects. The University of London Matriculation, for instance, had, from its inception in 1839, required passes in nine subjects, covering a broad range which included science.

The idea gained further support from Herbartian psychology, which was becoming increasingly influential by the end of the century. Herbart had advocated a wide and balanced curriculum, for this alone could give scope for the many-sided development of interests essential to true 'education'. To limit the field of study, his supporters argued, would be to cut out and deny aspects of human development. Since then much of the debate among the advocates of science in education has focused upon the place of science in a broad, humanizing, general/liberal education. That this debate was later reduced to an arts/science dichotomy by more blinkered and limited perspectives has been a 'dehumanizing' force in science education in the second half of the twentieth century.

Science: 'A true and lawful marriage between the empirical and the rational faculty'

Much discussion in the nineteenth century centred on the nature of science and its relation to mathematics, and on the interrelation of the separate sciences. Two areas of debate were of special significance for science education: first, attempts by scientists to raise the status of science, linked with a growing distinction between science and its applications, and, second, attempts to clarify and formulate the nature of scientific activity or 'scientific method'.

Bacon had believed that God had demonstrated that understanding should precede control of Nature, and hence power, for He had created 'Light' alone on the first day and had only then turned to 'materiate work'[11]. For Bacon, this distinction was, however, merely temporal: each was a fundamental part of the other. This attitude was true, too, of the Royal Society in its early days, where some stress was laid on the practical value of scientific research — but it did not last. By the mid-nineteenth century scientific publicists were beginning to try to change the emphasis and to stress the importance of research for its own sake, without regard to its applications which might, in fact, interfere with attempts to ascend to 'laws of a more exalted generality and higher speculative beauty'[12]. In his Presidential address to the British Association in 1885, for instance, Playfair claimed,

> Abstract discovery in science is then the true foundation upon which the superstructure of modern civilization is built, and the man who would take part in it should study science and, if he can, advance it for its own sake and not for its applications.[13]

The motivation behind these arguments was clearly the advancement of science as such and, since there is *some* basis in fact, the claim has been used in various ways during the twentieth century to argue against constraint or control of scientific research, whether in the interests of social benefit (as in the 1930s and again in the 1960s and 1970s), or in the interests of those who hold the purse strings, and whose interest is therefore productivity- and profit-orientated. But the distinction had important implications for education and could be used as a political weapon from that time on, for it put the stress on 'pure' science as a secondary school subject.

Much attention focused on the nature of science and of scientific activity or method. For centuries, Western philosophers had believed that, through the right use of reason, the mind would come to know the essential nature of things, the 'truth'. On this common-sense view, man's belief in certain regularities (called 'laws of nature' and 'theories') is justified by the repeated observations which are responsible for the genesis of that belief, a method called 'induction' by philosophers from the time of Aristotle and Cicero. Through its use, experience (that is, information received through the senses) and reason provide a secure basis for all knowledge that is certain and infallible. Knowledge, on this view, consists either of accumulated perceptions (naïve empiricism) or of assimilated, sorted and classified perceptions.

During the Renaissance the word 'method' had come into quite wide use to denote modes of thinking, and by 1632 it was in sufficiently general use to form the subject of a conference held by the members of a small private academy in Paris. One of the

methods still prominent in the seventeenth century was the 'art of memory', which afforded a means of memorizing matters by relating them to images which could then be located, in sequence, on real or recollected places or things, and which had been much practised and developed over the course of many centuries. In seventeenth-century Europe, Bacon, Descartes and Leibnitz all practised it. All three devised from it an improved method for exploring the 'book of knowledge', and, by using it to explore the world, for discovering new knowledge. Descartes' advance depended upon the establishment of causal sequences, whilst Leibnitz hoped to achieve a 'universal calculus' based on numbers. From his use of the art of memory Bacon saw that if particulars drawn from the mass of natural history were sorted and classified, reason could be more easily brought to bear upon them[14]. He speaks of 'grapes', 'ripe and fully seasoned', which must be gathered, pressed and clarified in the vat in order to produce the pure wine of inductive science[15]. This idea contributed to his 'new method of science', which was set out in considerable detail in his *Novum Organum*. Although it remains unclear in some respects, the method was, according to Bacon, a 'true and lawful marriage between the empirical and the rational faculty'[16].

As scientific work grew during the eighteenth century, many scientists posited an imaginative element, impossible to describe in logical terms. In 1772, for instance, John Gregory suggested that the formulation of an hypothesis actually initiates inquiry, giving it direction and setting the parameters for observation. 'In every useful experiment, there must be some point of view, some anticipation of a principle to be established or rejected'[17]. Earlier, the philosopher Hume had noted that no number of verifications of an hypothesis, however large, could establish the certainty of any scientific law or fact, and inductive conclusions could, therefore, only be probable, never certain; whilst another scientist, Boscovitch, suggested in 1760 that falsifiability rather than verifiability was the important characteristic of a good hypothesis[18].

In the mid-nineteenth century the writings of Whewell and J.S. Mill led the field. They took essentially opposed views, to the extent that John Venn wrote of them in 1907 that anyone reading both would find it hard to believe that they were discussing the same subject[19]. For Whewell, induction started from *a priori* conceptions, under which facts discovered were subsumed. For Mill, no such *a priori* conceptions were involved, scientific activity being a logical process of observation and reasoning. The debate continued in public meetings and through successive editions of published works by the two chief protagonists and others, and so great was the interest and contention aroused that Herschel made a plea for clarification in his 1845 address to the British Association. Not only should terminology be clearly defined, he proposed, but scientists should offer accounts of their own activities[20].

Mill's view made much of the running for some time, but, as the century passed, scientists themselves grew increasingly dissatisfied with it, for it contradicted the evidence afforded by scientific discovery. Nowhere was this more apparent than during the fifty or so years about the turn of the century, a period marked by revolutionary change in all the sciences. Many logicians, however, remained committed to induction as the criterion for demarcating science from non-science. Seeing in a clearly formulated and understood 'scientific method' a means of effecting all things possible, they tried to get round the problem, for instance by postulating a Principle of Uniformity of Nature: which, together with premisses known to be true, serves to guarantee the truth of a conclusion; or by bringing in the notion of probability. Such attempts were not satisfactory, however, and the problem of induction remained the 'skeleton in the cupboard of science', and a 'scandal'[21]. The difficulty of defining the nature of scientific activity and the persistence of the 'myth of induction', especially in its more naïve forms, were to create many problems for science education in succeeding years as the emphasis in science teaching and learning moved towards some sort of simulation exercise.

Scientific and technological advances were also intimately associated with the rise of bureaucracy, not only as matters of interrelated social change, but in terms of a shared belief in an objective world 'out there' whose elements are related by laws, both elements and laws being identifiable and open to exploitation in the interests of more efficient progress. The spectacular success of science — at no time viewed as more spectacular than in late nineteenth-century Britain, gave support to this belief and to the growing faith in scientific method, which steadily became more and more of an orthodoxy in bureaucratic organizations, including government, industrial and educational institutions[22]. At the same time, equating a scientific approach with rationality provided further justification for the orthodoxy. From that time on the literature is filled with calls for a 'more

scientific approach', and with arguments claiming that it is in no way confined to science. For many educated men of the period, in fact, scientific activity came to be seen as superior in applicability to all other forms of intellectual activity. The implications for science education were quickly recognized, for it was only a small step to link Mill's rationally consistent and orderly 'scientific approach' with training the mind, and so with faculty psychology. It followed that a science education which reflected the 'science of the scientist' would contribute to the development of mind. Since justificatory arguments are prescriptive, acceptance of these ideas by many of the most influential enthusiasts for science was to have lasting repercussions. In the first place, stress on scientific method led to a major reorientation of school science, for it has kept as an ideal, ever since, a simulation of the activity of the scientist, although there has been an increasing awareness of the constraints placed on such experiences by immaturity. Moreover, although some nineteenth-century enthusiasts preferred Whewell's conception of scientific activity, in which the imaginative element of scientific exploration was emphasized along with its disciplining by rigorous testing and its body of concepts and theories, the cold and strictly logical Millsian view has tended to predominate[23].

In the second place, as Layton[24] has argued, school science became overburdened with educational responsibilities, while the contribution of other subjects to the development of problem-solving skills and critical thought as well as of values and attitudes claimed to be particularly associated with science was ignored. At the same time, it has had its horizons limited by the presentation of an image of science as an intellectual exercise largely separate from everyday life and experience. Third, emphasis on method and on the development of faculties gave rise to Armstrong's heurism and later to its re-emergence, under the influence of 'activity methods', in the modified forms of 'discovery' and 'inquiry' (often quite unjustifiably confused), in spite of the welter of untested assumptions underlying them.

Developing the faculties through science

Stress on the method of acquiring knowledge was especially significant for science education, for it contributed very considerably to support for an heuristic approach to science teaching. Armstrong claimed that this approach developed mental faculties of observing and reasoning from observation and experiment that are not aroused and are, in fact, frequently deadened, by the exclusive study of other subjects, and that faculty development was more important than knowledge[25]. He did not, however, believe that pupils should discover *everything* for themselves[26]. The idea that the pupils should learn by doing if work is to be understood was not new, but Armstrong's belief that 'doing science' provided not only scientific understanding, but the development of the mind in a unique way, was new. He also believed that it could help to build 'character' by virtue of its difficulty, since self-discipline was necessary for mastery. Countering accusations that some heuristic work was nothing but drudgery, Armstrong argued that drudgery was inseparable from all formative work, but that he had never advocated it for its own sake[27].

Armstrong's influence on science teaching was considerable. Within seven years several examination boards introduced examinations based on his scheme, and forty London school boards were using his methods, the boards making special arrangements for training teachers[28]. Around the turn of the century heurism became widespread, although its frequent distortion produced some reaction against it[29].

In 1929 HMI Westaway deplored Armstrong's revival of the word 'heurism', from the Greek 'to discover'. Had the word adopted been 'search' instead of 'discover', he argued, the problems that derived from the many and varied distortions of heurism seen in schools might have been avoided. He maintained that it was intellectually dishonest, and therefore unscientific, to let pupils believe that they were 'discovering' principles. 'A beginner may "discover" a test tube hidden in a drawer, but he will rarely or never discover a principle lurking in a group of facts'[30].

No system of science teaching was likely to be effective, Westaway claimed, unless animated by a spirit of 'search'. The pupil ought to see that the work that he was engaged upon was a problem worth solving, not merely a laboratory exercise. The teacher should keep the pupil's mind in a state of tension: he should compel the pupil to follow up the detail of an experiment and piece the details together; but the pupil's own inference, if correct, would never contain more than was included in the experiment. The attempt to teach science merely for the sake of the training it might afford had produced much ineffective work. Nevertheless, he believed, the 'spirit of inquiry' should most certainly be encouraged, and should run through any course of science teaching[31].

The impact of technological development: science, 'open and available to all'

As science became increasingly important in society during the nineteenth century, a number of enthusiasts worked both individually and collectively to promote its cause in England. All recognized that a national system of education was an essential first step; all argued that a secure place for science in this education was the only means of ensuring the provision of scientists in the future, the development of a scientifically literate population and, even more important for decision making, a scientifically literate ruling class. Yet the secondary schools — so crucial to the provision of this scientific elite — remained largely untouched by science. The attitude of headmasters and parents was either characteristic of the attitude of society at large towards science — that, for gentlemen, it was a leisure occupation, harmless, if eccentric — or it was antagonistic, especially when the Department of Science and Art started up its science classes and, later, when Organized Science Schools gave science the taint of association with manual labour and the industrial classes.

Later in the century, growing competition from international trade led, gradually, to a wider acceptance of the view that physics and chemistry had a place in education, especially for the sons of the burgeoning wealthy middle class who, in fact, began to demand it because they could see it as directly relevant for their sons. For the sons of gentlemen, however, utility had to be of a different sort altogether. Boys embarking upon professions like medicine and civil engineering clearly needed some basic science, and this was an important factor in getting it into the curriculum of public schools. Elsewhere, however, and in spite of the recommendations of successive commissions, it made little progress. There was some response as a result of the efforts of pioneers whose concern lay in sharing their enthusiasm and, too, under the influence of faculty psychology and a growing faith in the efficacy of so-called 'scientific method' in training the mind. Science could now be introduced to this end, especially for less able, upper-class boys. Lord James reminds us that within living memory the prospectus of one of our major public schools carried the comforting statement that for boys with little aptitude in classics or modern languages a science course was provided. This statement reflects both the acceptability of science as a harmless, leisure pursuit and the possible benefits that might accrue from training the faculties. Here, then, was one argument that might be influential in persuading schools in the fee-paying sector to introduce science more widely into the curriculum. The other was to show how science education could and should become a part of a liberal education.

In spite of considerable activity on the part of many of the 'cultivators of science', who worked indefatigably and who remained highly vocal over the whole period, relatively little was achieved in secondary schools during the nineteenth century. Why was there so little response? Brock believes that the reasons lie in the indecision of those pressing for a place for science in secondary education, in their lack of policy and of agreement as to which sciences should be taught, and where[32]. All such arguments, however, reflect the fact that the activity was really at an individual, rather than a corporate level, even when it took on the superficial aspects of pressure group activity in the interests of school science.

The third quarter of the century was especially favourable to the cause of science and reformers of many kinds flourished, with various targets that were, in themselves, a good deal more specific. At one extreme were those whose common bond was their faith in, and support for, science and so for science education at every level. At the other were those whose cause was educational reform as such, especially the reform of popular education and of existing institutions for the social elite. Lubbock, for instance, was very concerned with the state of the educational system as a whole — he was a founder member of the Central Society for Education in 1857, a society whose major aim was a remedying of the 'want of national organization in education'[33]. It seems likely, then, that there is danger in overlooking differences in motivation and in assuming that all were immediately and deeply concerned for the promotion of science or of science education, or both.

Again, when major figures are considered separately, it is clear that none of them embraced all the specific ideas and theories associated with the movement for science in the public mind at that time, although it may be that a composite of their views would produce something very like it. It is hardly surprising, then, that among the recognizable groups, such as the X-Club, and the various British Association committees who pressed for change in the interests of science, it is difficult to establish any coherent overall policy.

Other factors probably operated as well. Apart from the problems and prejudices of a class-ridden society and the rationalization by vested interests of their opposition to change, there was also the simple problem of a lack of science teaching posts in public schools. Another factor might have been the growth of imperialism, which kept public school boys in careers in the Empire. (It is interesting to note that a continuing justification for the introduction of biology into secondary schools during the twentieth century, and one that was used as recently as the 1950s, was the needs of colonies and dominions that were heavily agricultural and pastoral.)

Although society was undergoing extensive changes, although scientific and technological advance was becoming increasingly and obviously important to the economy, although the position and status of science in society was considerably improved and although society was reconstructing its institutions as education, too, became more and more central to the economy, educational adaptation remained extremely slow. The lag between social need and educational provision had, by late nineteenth century, become enormous, and education was patently dysfunctional. The whole purpose of education became a subject of continuing and heated debate, and there were growing pressures for the expansion and coordination of secondary education to meet changing social needs. The Bryce Commission[34], which reported in 1895, represented an attempt to meet these pressures, and led to the 1902 Act. Although the Act placed much of the initiative for the curriculum in the hands of the newly created Local Education Authorities, overall consistency was needed, and this came from the Board of Education's 1904 *Regulations for Secondary Schools*. Framed by Morant, McKail and Headlam, the *Regulations* were concerned to provide a balanced curriculum, to discourage early specialization and to develop the faculties. The blueprint was, quite explicitly, the curriculum of the public and older grammar schools, as exemplified in the regulations of examination boards. They required that every school provide a four-year course in three primary groups of subjects, one of which contained mathematics and science. These were to occupy not more than one third of the timetable and not less than seven hours' instruction a week. In contradistinction, however, to the examining boards' regulations, which allowed mathematics and science to be alternatives, the 1904 *Regulations* required that three hours of the time allocated were to be given to at least two distinct branches of science, for each of which adequate laboratory accommodation must be provided. For the protagonists of science in schools this, at least, represented a victory in that it ensured a place for science in the curriculum of all maintained grammar schools, something that the examination boards had so far failed to do. At the same time, however, it ensured that the type of science being taught in secondary schools was without technical or vocational bias and was very different in character from that which had been developed in various types of post-elementary school in the past three decades[35].

It is not possible to assess the extent to which this inclusion of science in the secondary school curriculum resulted from concern to provide a broad general education or from contemporary feeling about the state of science and the nation. The third quarter of the nineteenth century was a period of national self-confidence and of tremendous faith in science. But the accumulated economic problems of the last quarter led to a recession of this optimism. British industry was now all too clearly being seriously challenged by Germany and by the United States of America, two relative late-comers in the race for industrial superiority. By 1900 the evidence of the vast German chemical industry alone vindicated all that the prophets of doom had been forecasting for more than half a century, and made clear the fact that the rate of technological advance, and so economic growth, was directly related to the possession of qualified scientific manpower, equipment and money for research and development in established industrial research laboratories. Although scientific knowledge had continued to grow and to increase in sophistication and applicability, scientific development still lagged behind because of lack of support. There was concern about energy supplies in the future because of the demands upon accessible coal that had resulted from industrialization[36], and even the theories of science, once seeming to promise the millennium, now indicated alternative possibilities which, in the state of general depression and continuing economic crisis that characterized the last quarter of the century, seemed more imminent. 'If you believe in improvement', wrote Joseph Conrad to a friend, 'you must weep, for the attained perfection [of mankind] must end in cold darkness and silence'[37].

In the ten years around the turn of the century there appeared a number of best-selling books and sporadic press campaigns, all highly emotive, all serving to arouse alarm. *British Industries and Foreign Competition* (1894) and *Made in Germany* (1896) both aroused much press and public comment. The *Daily Express* ran a series entitled 'Wake Up, England' and in 1901

The Times produced 'The crisis of British industry' and 'American engineering competition and progress'[38]. Seizing the moment, an editorial in *Nature* on 3 January 1901 drew attention to the fact that within one week *The Times*, the *Daily Mail* and *Pall Mall Gazette* had all produced reasons for the 'new and alarming state of things', and then argued the case for using 'scientific method' to get at the real origins of the anxiety and to end the specious excuses being offered. It was clear from the success of her competitors, the author claimed, that Britain's great failure lay in her neglect of practical scientific work and research in general higher education. In Germany and America the scientific spirit had been a dominant factor between science and industry, and it was the scientific spirit that was needed by decision makers here in Britain. The editorial went on to quote a letter from Sir Henry Roscoe, which had recently appeared in *The Times*, in which he called for

> ... a straining of every nerve to place the country educationally on a level with its neighbours. No effort, no expenditure, was too great, to secure this result, and unless our leaders, both in statecraft and in industry are quickly aroused to the critical condition of our national affairs, in this respect, and determine at once to set our house in order, our children and grandchildren may see England sink to the level of a third-rate Power: for upon education, that basis of industry and commerce, the greatness of our country depends.[39]

All these fears, opinions and palliatives were reiterated by speakers from all parties in the parliamentary debates on the 1902 Education Bill.

Even after 1904, however, science could remain an optional subject in schools in the independent sector until those responsible for their curriculum could be persuaded that it was an essential part of a liberal education, or until it became a required subject for university entrance, or in army, civil service or other professional examinations. Thus, even in 1918 the Thomson Committee was to complain that 'no general recognition of the principle that science should form an essential part of secondary education yet existed', and that it was still missing from the education of many boys below the age of sixteen in public schools[40]. For much of the first half of the twentieth century the status of science remained low in most schools in the independent sector, due to a variety of reasons which it is beyond the scope of this volume to explore. At the same time, it must be noted that laboratories and apparatus cost money and that there was a considerable growth in science teaching in this sector when money for buildings and equipment became available from the Industrial Fund after 1955 (see Chapter 3), and that independent schools played a significant role in the development of curriculum materials in science in the 1960s.

More and better science in schools

Pressure groups in science education

It was the situation within the public schools that produced the first real pressure group for science education, and it is worth noting that its inception coincided with the crisis period of 1901-2. The Association of Public School Science Masters was established for the express purpose of improving the status of science in public schools and of providing a meeting place for the exchange of ideas[41]. Cordial relations were rapidly established with appropriate examination boards[42] and a network of very useful contacts with the world of science was developed in the early years, a link consolidated by the appointment, each year, of an eminent scientist as the Association President[43].

1912 saw the establishment of a complementary group, the Association of Women Science Teachers, which was formed as an offshoot of the Association of Assistant Mistresses. Though much smaller, less powerful and less active, this Association worked alongside the Science Masters' Association for the next forty years, sharing its journal, the *School Science Review*, and gradually becoming more and more involved in joint work, until the two finally merged in 1963 to form the Association for Science Education[44]. Working for and alongside these two Associations was the increasingly powerful 'science lobby' (the word is not here intended to have pejorative overtones), again involving groups and individuals.

The first major opportunity for pressure group activity came with world war, in 1914-18. The Association of Public School Science Masters then initiated what were to become widely publicized negotiations between the advocates of science (represented, first, by the Neglect of Science Committee and later by the Conjoint Board of Scientific Societies) and the educational Establishment (represented by the Council for Humanistic Studies)[45], and they produced their first policy statement, *Science for All*[46], as evidence for submission to the J.J. Thomson Committee.

Wartime typically generates discontent with education, partly because of the way in which some of its deficiencies are highlighted, partly because of a concern with reconstruction. The period 1915-19 was no exception. There was long-standing discontent with education and, by the middle of the war, some concern to establish a governmental committee to review the system as a whole, under the aegis of Asquith's Reconstruction Committee, fore-runner of Lloyd George's Ministry of Reconstruction. This scheme ran into difficulties because of the threat it posed to the jurisdiction of the Board of Education, whose members instituted delaying tactics, so that the reviewing committee did not, apparently, ever meet. Two of its subcommittees did, however, get off the ground, and produced reports. These were the Prime Minister's Committee on Natural Science (the J.J. Thomson Committee) and that on Modern Languages[47].

Whatever its effect on the climate of opinion, the Thomson Committee's Report could have few outcomes in real terms. Recommendations for maintained schools required reform of the national system of education as a necessary first step. In the case of public and preparatory schools, response depended upon the extent to which they, and the examining bodies concerned, could be influenced by the (perceived) authority of the committee. The Report had, indeed, pointed out that 'to make a subject compulsory in an examination in order to guard against its neglect is not the ideal method of obtaining the best education', but they also recognized that it appeared to be the only way to get what they wanted[48]. They had come up against the same stumbling block as the Council for Humanistic Studies and the Conjoint Board of Scientific Societies in their deliberations:

> The one and effective way of changing this attitude and of giving us both better educated Civil Servants and a true and reasonable appreciation of science in all classes is in the hands of the Legislature and of it alone. If a Bill were passed directing the Civil Service Commissioner and Army Examination Boards to give a preponderating — or at least an equal — share of marks in the competitive examination to natural science subjects, with safeguards so as to make them tests of genuine scientific education and not an incentive to mere 'cram', the object we have in view could be obtained.[49]

The Secondary School Examinations Council, established in 1917, initiated negotiations with universities over entrance requirements in 1920. Meetings were also held with representatives of professional bodies, the Civil Service Commission and teachers' organizations to try to persuade them to accept the new School and Higher School Certificates as alternatives to their private qualifications. Eventually the curriculum of all grammar schools, both maintained and independent, came largely under the control of the Secondary School Examinations Council and its recognized examination boards, and into line with their requirements. Even so, science could be avoided by taking mathematics, or by by-passing the first (School Certificate) examination altogether[50], and pressures for making science a compulsory subject in the examination therefore continued. In spite of these efforts, compulsory science has never become a reality in the independent sector. Nevertheless, science teachers in them, as well as in maintained schools, have worked throughout the century for more and better science, better taught, and for its corollary, more and better science teachers.

'Science for all' and the general science movement

The central concern of the Association of Public School Science Masters was to try to ensure a place for science in the curriculum of public schools, and to enhance its status. They also believed that the content of science courses should cover a far wider field than had been customary. Science, they argued, had been introduced into the curriculum because of its usefulness in an age of inventions which were mainly the outcomes of applying physics and chemistry. Heurism, too, had favoured these two sciences. The result was a school 'science' which demanded a detailed knowledge of one, perhaps two, isolated branches of science. This was a limited view which had been perpetuated chiefly by examination requirements and by a self-perpetuating tendency in schools. Subsequent addition of physical measurement to courses had merely added 'dull and unattractive routine work', whilst heurism had too often degenerated into a skilfully articulated skeleton. Self-conscious attempts to inculcate the spirit of science by method alone was, in the committee's opinion, foredoomed to failure, for in reality it could come 'only from the enthusiasm of a teacher who is teaching a subject that he likes and developing it according to his own inclination'[51].

'Science for all', the Association's first policy statement, was the product of this thinking, and it was written initially for the information of the J.J. Thomson Committee. When reprinted

in the *School Science Review* in December 1920[52], a preface was added to 'direct attention to the general characteristics of a science course worthy to be accepted as part of essential education', and as an antidote to the very limited, closely defined and 'stagnant' courses then current. What was needed, the preface added, was a course that would appeal strongly to the imagination, having a lasting effect (so that enthusiasm could not simply be ascribable to novelty), arouse serious interest, provide a corrective to preserve the humanity of future specialists (who needed to know the relations of their subject to others) and, by these means, provide a 'prophylactic to pedantry'.

A truly educational course in science could be achieved by providing a broad range of science subjects, there being no justification, except expedience, for specialization before School Certificate. Broadness, however, must not be equated with shallowness or a debased 'popular science', nor with 'mere index-learning', and it was up to the teacher to ensure this[53].

The preface was more concerned with the shortcomings of the current situation which, the authors claimed, kept science on the 'lower level' of the school curriculum, than with justifying its statements, and it simply implied that the new broad course being advocated would overcome the defects identified. This failure to justify the claims made probably reflects the general consensus of the period; that a broad, general education was most desirable, and that science should have a place in it[54].

In urging a pre-School Certificate course in General Science for all secondary school pupils, 'Science for all' was also pressing for more widespread teaching of science; and in advocating the coverage of at least the three main sciences, it was asking for what was, in effect, more science. For it argued that time allocations should be stepped up; the three subjects were not simply to be condensed into the time hitherto allocated to one or two. Not less than five hours per week in school plus one hour's preparation was the figure suggested. The Thomson Committee proposed not less than three periods per week in the first year, and not less than six for the remainder[55]. The British Association's committee on science in secondary schools suggested that at least one sixth of the total teaching time for boys and one seventh for girls should be given to science. But General Science won neither time nor status in the inter-war years[56]. Although the number of pupils taking it grew steadily, relatively few wrote the examination, either because it was being taught mainly to younger pupils, or to older pupils not considered to be examination material, or because teachers did not regard it as a suitable basis for pupils entering for matriculation and scholarship examinations, or because some examination boards dragged their feet over introducing it. A study carried out by the Science Masters' Association in 1932 showed that the average time allocated to General Science as a whole was less than the total time allotted to physics and chemistry when studied as separate subjects[57]. There were continuing complaints that non-scientific headmasters saw General Science as one subject, not two or three, when timetables were being arranged and, too, that a subject that counted as a single 'credit' in the School Certificate examination would tend to be given only the amount of time considered appropriate to this. Certainly, this was the attitude of the Spens Committee, who stated quite clearly that General Science did not need the same time as physics, chemistry and biology, taught separately, and suggested that seven periods a week for science *and* mathematics be allocated in the first three years, and ten periods a week in the fourth and fifth years for those specializing in science and mathematics[58]. This, the Science Masters' Association protested, would entail serious sacrifice, and a correspondent to the *School Science Review* described it as a 'clean sweep of something like half the time' normally allowed to these two subjects[59].

In the changed climate of the 1950s, with science in the ascendant politically, economically and academically, it seemed that extended pressure for more school science might at last be likely to succeed. There had been a steady rise in the number of candidates taking science for O level between 1954 and 1957, and a steady decline in General Science entries. The Science Masters' *Policy Statement* of 1957 recommended a course in Natural Science in the introductory period from eleven to thirteen years. This should preferably be taught by one teacher, and it should consist of physics, chemistry, biology with, probably, astronomy. Geology should be included in geography lessons. All three separate sciences — physics, chemistry and biology — should now, it claimed, be taught for the rest of the O level course, that is, from thirteen to sixteen years[60]. The statement in the revised version of 1961: 'We realize that we are asking schools to give more time to science below the sixth form than most of them do at present and that other subjects will therefore have to give way ... '[61] reflects the changed situation. The three sciences should, they argued, be taken by *all* pre-O level pupils, no matter what their future interests[62]. Clear pressures for more time, more science, more pupils! (Something rather similar was happening at sixth form level. There had been pressures for sixth form science classes for arts specialists since the time of the Thomson Report. Now science teachers were urging that the time used for making arts pupils scientifically literate should be shared with sixth form scientists. In this way, the latter would be getting a rounding-off of their specialist studies through the addition of a course providing a 'wider view' of science — and another slice of the timetable![63])

For more than forty years the Science Masters' Association had advocated General Science for all pupils up to the age of sixteen. Now they were — or appeared to be — advocating separate sciences after the first two years, and only a measure of initial integration. Early in 1958 the General Committee of the Association received a letter from two members asking for clarification of its policy on General Science. The minutes of the committee meeting emphasize 'that the Science Masters' Association never advocated a single-subject General Science approach as being the only way of teaching science'[64]. This was both a justification of the new moves to have unreservedly specialist teaching instead of General Science in the last three years of the O level course, and an indication of the new climate, which enabled them to press in this way for more time and more science. The revised *Teaching of Science in Secondary Schools*, published in the same year, carried a comment from the drafting committee to the effect that they no longer had the 'confidence in the value of General Science which characterized the earlier Report'[65]. Association members, too, had shown 'very little positive enthusiasm for it for any but the less able', and the General Committee spoke of 'some signs of a desire to revert to specialist sciences'.

In January 1959 a resolution expressing 'disapproval' of the teaching of General Science as a 'substitute for the separate sciences' was put before members at the Annual Business meeting. The debate is recorded in the *School Science Review*, and makes very interesting reading. An amendment was finally passed which stated that 'the meeting disapproves of the continued teaching of General Science on an inadequate time allowance'[67]. The change reflects the contemporary current of opinion, and it supports the contention that the General Science movement was in fact a means to more science, taught for more periods a week, to more children.

These proposals, and many others like them[68], were all based on an apparently genuine belief, held at various levels of sophistication, that the problem of a liberal education is essentially a problem of curriculum content, a problem of providing a balanced array of subjects. This might seem to imply an underlying assumption that certain subjects 'contain intrinsic values irrespective of how they are taught and learned, and of who teaches them'[69], and the argument has often appeared to remain at that level. Nevertheless there had been, amongst those generally concerned with education, a continuing preoccupation with attempts to clarify the concept of liberal education in a democratic society. Whatever vested interests science teachers may have had, the debate on the place of science in a liberal education — and on what 'science' — reflects a concern for the kind of education that should be provided.

As far as the Science Masters' Association was concerned, the General Science movement was not an attempt to promote integrated science as we now understand the term. In its publications and in specific statements, official policy was consistent and clear:

> There has been some misunderstanding and ambiguity in the use of the term 'General Science'. Some people have thought that we advocated only a unified course of science, taught by one General Science teacher and that we wish the separate science subjects of the pre-School Certificate course to be replaced by 'General Science'. We would maintain, however, that a school is, in fact, teaching 'General Science' if its pupils study physics, chemistry and biology separately under different teachers, and do some geology and astronomy as part of their Geography. It is an *increased breadth* [author's italics] of the science course that we advocate under the name 'General Science', and we are content to leave the details of the teaching of such a course to individual schools.[70]

The focus was on information, upon the 'facts' essential to an understanding of everyday things, which are distributed throughout the special sciences. Much of the General Science debate was therefore focused upon content and upon time allocation. Nevertheless, a great deal was being written at this time about teaching approach in science classes, under the leadership of men like Dewey, Nunn, Gregory and Westaway. The Science Masters' Association's two handbooks, *The Teaching of General Science, Parts I* and *II* (1936 and 1938), mark the beginnings of the Association's advocacy of inquiry/discovery approaches, although such conceptions were seldom spelled out in detail. Nevertheless, there was now an official view that every lesson should be a 'voyage of discovery', and that this depended far more upon presentation than on the arrangement of topics[71].

'More of the spirit, less of the valley of dry bones' in school science

In 1918 the Thomson Committee had welcomed the moves made since the turn of the century towards a more practically orientated school science, which had given pupils experience of the experimental method of the sciences. At the same time, however, the committee believed that many teachers had become so dominated by their faith in experimental work that they had come to see it as an end in itself. There was, too, another unfortunate outcome: teachers had tended to restrict their teaching to subjects like physics and chemistry, in which experimental work was most easily organized, instead of trying to cover a broader field of scientific knowledge. A general course in science should not only train the mind to interpret evidence and to reason, it should also acquaint the pupil with the broad outlines of great scientific principles as exemplified in familiar phenomena, and in their applications for the benefit of mankind. In the past, the first had been overemphasized, the second 'unduly neglected'[72].

The British Association's Committee Report, of 1917, *Science for Secondary Schools*, argued that the object of science education should not be to impart facts or data prescribed by an examination syllabus, or even to systematize their rediscovery. Rather, it was to impart a steadily growing understanding of the nature of science, in which the 'broader aspects of scientific discovery and investigation as human achievements' and the 'applications by which mankind is benefiting' should play their part[73].

An education in science could only come through a welding together of scientific method and scientific matter (in effect, though not expressed as such, of scientific 'process' and 'product'). 'Scientific method is an abstraction which does not exist apart from its concrete embodiments', the committee claimed, and the 'methods of science are nothing other than the way it grows ...'. Education in science should consist neither in imparting facts, nor in the provision of mental training. It should be a genuine pursuit of knowledge, an activity guided by the teacher, and motivated by the 'historic activities of scientific minds working at their best', and it should be carried out in accordance with the varying capabilities of pupils at different ages. This was a very much more sophisticated view than that evidenced by either the Thomson Committee or the subcommittee that had drafted 'Science for all', although both had some members in common, and both reported at about the same time. The influence of both Gregory and of Nunn is clear in the way the British Association Report reflects their other writings.

Elsewhere Nunn had argued that if science was merely useful it had no place, or only an inferior one, in education. But, if it was 'one of the grand historic expressions of the human spirit', it was entitled to an honourable and spacious place, and a science education worthy of the name would reflect its nature[74]. Under the influence of faculty psychology, he continued, teachers had been too ready to think that the educational virtue of a subject lay in 'some essence that can be distilled from it and administered in regular doses as a mental tonic'. In the case of science teachers, the elixir had been 'cultivating observation' and 'inculcating scientific method'. But this was a blinkered view of reality, for it was only part of the greater whole. Whilst scientific method was 'as necessary to the scientific life as breathing to the bodily life', cultivated as an end in itself it was as akin to the method of the real scientist as artificial respiration was to breathing. The prime contribution of great scientists to the world's cultural wealth was not the scientific method, but the *scientific life*—and the business of the science teacher was to teach the realization of that life, not the mastery of the method. The proper aim of science education, then, was

> ... to make our pupils feel, so far as they may, what it is to be, so to speak, inside the skin of the man of science, looking out through his eyes, as well as using his tools, experiencing not only something of his labours, but also something of his sense of joyous intellectual adventure.[75]

This is a most interesting conception and one which was far in advance of its time. It was to find fertile ground more than forty years later, for H.F. Halliwell, Organizer of the Nuffield O level Chemistry Project, believes that Nunn, who taught him at the then London Day Training College in the mid-1920s, was the major influence upon his teaching.

Nunn's view derived directly from his earlier work in the philosophy of science, and in particular from his interest in epistemology. In an article published in 1906 he had described science as a 'conative process' which 'aims at rendering objective facts intelligible to an individual consciousness, and reaches that end by building up these primary facts into secondary constructions or apperception systems, by means of ideas drawn from the contexts of experience'. To understand the genesis of theory, then, it seemed to him that the psychology as well as the logic of the investigator must be taken into account. In a paper published in the following year Nunn suggested that the recent growth of psychology was most beneficial for philosophy since it helped to transform the logician into an epistemologist. Earlier adherence to faculty psychology, which regarded knowledge as the special product of an independently functioning 'intellectual faculty', had resulted in a view of the subject matter of logic as no more than the determination of the general relation between one piece of knowledge and others. But recent psychology had shown that, while distinguishable, knowledge and feelings were not separable features of any continuous individual experience, and that, therefore, to explain the genesis of understanding in terms of cognitive elements alone was inadequate. Conative and emotional factors were equally important elements: any conative act involved both cognitive and affective elements and both altered as conation proceeded[76]. Hence Nunn's belief in the importance to the child of *feeling* what it is to be a scientist. He saw the aim of science education as giving, not an exhaustive knowledge of detail, but 'a realization of the scientific life and an appreciation of its more important contributions to the world of ideas and the welfare of man'[77].

Nunn proposed a theory of epistemological levels which, he believed, were also reflected in the stages of child development. These he identified as 'wonder', 'utility' and 'scientific thinking', and at each level, he argued, attempts to reach knowledge exhibit a rhythm of alternating induction and deduction. In the growing child, the first level manifests itself in the child's interest in the strange and wonderful; but it is not long before the practical value of studies appeal. In later adolescence there is a quest for a comprehensive formula that will provide an explanation of all the varied phenomena that he has studied. Nunn warned, however, that premature use of systematic theory in science might account for grammar school 'boredom'—for schoolchildren, often a term synonymous with 'difficult' or 'incomprehensible'. Nunn was, clearly, trying to link his epistemological theory to the observed behaviour of children in exploring their world, and to his belief in the value of a 'realization of the scientific life' at an appropriate level at every stage of education.

The idea of stages in mental development had, of course, been around for some time. Rousseau, for example, based his categorization on the faculties of 'sensation' (infancy), 'sense judgement' (childhood), 'practical thought' (adolescence), and 'abstraction' (late adolescence), and he stressed that teaching should be related to the child's stage of development. There was a time for every kind of teaching and every stage should be fully exploited before moving on to the next. From the turn of the twentieth century, there was considerable attention to the stages of mental growth in children, descriptions being remarkably similar, though the stages that were identified were called by different and somewhat arbitrary names. For instance, Whitehead distinguished three stages, which he called 'romance', 'precision' and 'generalization'[78]. Attempts were even made to explain the regular occurrence of such predictable stages. A correspondent to the *School World*, for example, ascribed them to the 'natural development of the brain and the blood pressure characteristic of different ages ... I suspect a physiological factor in growth which all methods, logical, historical, heuristic, etc. are powerless to contest against and with which all methods are capable of cooperating'[79].

The first systematic study of child language, conceptual development and understanding, by Piaget, was published in English in 1926[80], and this was followed by numerous works which defined, clarified and extended his theory of genetic epistemology. Piaget's ideas did not, however, become widely known in England until considerably later, and it is only relatively recently (that is, since the last war), that attention has turned to empirically based findings, especially those related to Piagetian thought, and to their relevance for schooling, especially secondary schooling.

In the nineteenth century Hegel had taught that reality was a process of 'becoming' and he stressed that education should not be regarded as the 'fortuitous furnishing of many little finite personalities'. Pestalozzi and Froebel, too, had regarded development as coming from within, and drew attention to the 'unfolding' nature of children's minds. Spencer had argued that the education of a child should accord in both mode and

arrangement with the education of mankind, considered historically, as did G. Stanley Hall, who taught John Dewey. Gradually, the development of mind was coming to be seen as a process of growth towards self-realization, and the sequencing of knowledge was seen as being concerned with this, as well as with its logical characteristics. This view, clearly, regarded the teacher's role as that of an organizer of learning, and suggested that it was the skilful selection of ideas and the weaving of these into the texture of pupils' minds that moulded growing children. With the return to ideas of transfer of general principles in the 1930s, attention focused once more on the importance of teaching method in promoting conative and affective aspects of learning as well as cognitive, and of making pupils conscious of this training. Thorndike had written in 1926, 'the intellectual value of studies should be determined largely by the specific information, habits, interests, attitudes and ideals which they demonstrably produce'[81]. From about this time there is evidence of growing concern, especially in American literature, that values and attitudes be inculcated along with training in 'scientific method' in school science. Just how the two are related was seldom made explicit. More often, there has been an implicit assumption that appropriate training in 'scientific method' will automatically be accompanied by the development of specific values and attitudes, though there has been little systematic attempt to test for their achievement[82].

In the early stages of the science versus humanities debate during the First World War, the Association of Public School Science Masters had suggested that science education could be valuable in two ways: first, as the search for truth, based on evidence rather than authority, and fostered via the interplay of imagination and observation and experiment; and second, as something of immediate use, through the development of understanding of its potential for human welfare and of causal relationships in the world of nature, as well as its demand for intellectual honesty[83].

In 1942 a speaker at the first Annual Meeting of the Science Masters' Association after the outbreak of war reminded his audience of Sir Richard Livingstone's very influential little book, *The Future of Education,* which advocated that Hellenism and Christianity should be the twin pillars of education, and so of all postwar reconstruction plans in this area. However, the speaker continued, since science is the search for truth, it represents a 'fundamental principle in the development of high ethical standards'. Education required a third pillar (which would, in any case, as every scientist knew, give it a more stable structure!). To 'beauty' (Hellenism) and 'goodness' (Christianity) should be added 'truth' (Science). This idea was incorporated into the preamble to the draft policy statement of the Science Masters' Association, prepared in 1943, but it was later decided that to support a particular religion was to go beyond the province of a science teachers' association and so, although the amendment retained the reference to 'beauty', 'truth' and 'goodness', these were not allocated to specific parts of the curriculum[84]. From then on, however, the association of science with truth features in all official statements by the Science Masters' Association.

Truth is woven into the fabric of science, both in its major aim — approximation to the truth — and in its process, the disinterested search for truth. This, in turn, requires that certain values and attitudes underlie the search, giving intellectual commitment and an acceptance that no question of fact or theory is, in principle, ever closed. These are values of objectivity, of integrity and intellectual honesty, of open-mindedness and anti-authoritarianism. Even the decision to become a scientist involves at least implicit commitment to these values, nor can the scientist escape value judgements, for any action of any kind involves at one and the same time judgements of knowledge and judgements of value[85].

From these values arise attitudes — curiosity, respect for truth, objectivity (so far as that is possible), willingness to experiment wherever experiment is possible in the solving of a problem, clarity of reasoning, conscious effort to overcome prejudice and personal bias, cooperation, sharing, and recognition of the subjective element in *all* perception[86]. (Some of these attitudes are in conflict with human motivation and self-interest, and it is a moot point whether they are indeed inculcated during the long process of socialization that constitutes research training, or whether they are, rather, necessary forms of social control imposed by the community of science in the interests of survival as much as the growth of scientific knowledge.)

If these are, indeed, values and attitudes that can be transmitted in science lessons, it must be remembered that the inculcation of values and attitudes and, too, of the aesthetic elements of any subject, is deeply dependent upon how it is taught. That they are, in fact, more likely to be caught than

taught has not always been kept in mind, partly because it is a good deal easier to exhort than to demonstrate, partly because of a faith in the 'professional' capacity of any teacher to translate aims and objectives into practice — a faith, therefore, in teacher training as well. Pupils get out of their science education, or any education, only as much as they and their teachers put into it. The literature is full of claims that such qualities as, say, critical thought, a questioning open mind, a spirit of inquiry, an exploratory approach to problem solving, or an ability to codify and systematize observations into generalizations and to make creative hypotheses, can be developed by science. But the matter is inextricably bound up with methods, and here there is a good deal less certainty. Critical thought, so often claimed to be a product of inquiry science, is not an innate tendency, nor is it easy to acquire or to develop. It will certainly not be acquired by exposure to science *per se*. One must keep critical company in order to elicit the critic within, and one must also have some facts about which, and with which, to be critical[87]. The questioning of assumptions, which is the basis of all critical thought, does not arise spontaneously, nor does recognition of the fact that the perception of 'evidence' is dependent upon many factors, even in a single individual, and that it is important, always, to look for other possible interpretations and evidence before coming to conclusions or making decisions. Practical work in science can be valuable, or it can be a meaningless form of time-structuring, and recognition of the fact calls into question, once again, the calibre and the intellectual grasp of the teacher, and the quality of his classroom interaction, both of which are, in turn, heavily dependent upon the quality of pre- and continuing inservice education.

School science as simulation

Whatever the realities of the classroom, it is clear that the idea of science in schools as a sort of simulation exercise in which content and process as well as appropriate values and attitudes will be inculcated has underlain much of the debate. (The argument that overladen syllabuses, inadequate time allowances and laboratories have prevented its realization has also been a powerful source of complaint.) However adequate or inadequate the theoretical conception of school science as 'teaching the pursuit of science' may have been at different times, in practice the suggested simulation has really been only partial. This is hardly surprising. As both Nunn and Gregory's British Association Committee had recognized, misconceptions about the nature of scientific activity can put too great an emphasis on the value of practical work as such. Neglecting, for the moment, the difficulties of successful realization with children in classrooms, this emphasis implies a very restricted view of 'what scientists do'. Medawar has pointed out that scientists are individuals of very different kinds of temperament, doing very different tasks in different ways, and at very different intellectual levels[88]. Their procedures are flexible, being adapted to the nature of the problem in hand, and, for a great deal of their work, the parameters are set by the prevailing paradigmatic conceptual framework.

Much of the literature of school science displays a concern to approximate the process of science in the classroom to a commonsense model of induction. Compare the following, produced over an interval of fifty years:

> Scientific method ... consists of obtaining facts and ideas by experiment and observation, classifying them and comparing them and discovering a formula or principle to express them.[89]

> ... the scientific method of observation and of experiment, of the grouping of significant fact, and of deduction from all this.[90]

> ... to lead pupils to observe, and to solve problems by controlled experiments, to draw conclusions from observations, and to appreciate the systematic laws and principles of science.[91]

Dewey's influence in maintaining this step-wise view of scientific method among teachers, as well as his central assumption that scientists are engaged in what he calls the 'quest for certainty', has probably been highly significant. Yet it must not be forgotten that many scientists subscribed to this model, too, until long after the major scientific discoveries of the early twentieth century had demonstrated the inadequacy of the analysis. Some of the confusion undoubtedly derives from the fact that 'induction' can mean all things to all men, and that philosophers themselves have not been able to agree upon its nature.

Although others had suggested essentially hypothetico-deductive views of scientific activity, the first rigorously argued account was that of Karl Popper, which appeared in 1934

(English translation 1959)[92]. Rejecting induction altogether, Popper used the logical assymetry of proof to argue that, though not verifiable, empirical generalizations are falsifiable — and so testable. They can be tested rigorously and systematically in attempts, not to verify or confirm, but to refute them. On Popper's view, the growth of knowledge derives from man's efforts to solve problems, which usually arise because of a clash between expectations (which are based on previous knowledge and assumptions) and actual events (observations). To solve such problems man propounds falsifiable theories which go beyond existing knowledge and which require, therefore, a leap of the imagination. The bolder the theory and the greater the imaginative leap, the more it tells us, and the greater the possibility of refutation by still more rigorous testing of its predictions and implications. Even if it is corroborated, the possibility of refutation always remains, as does the possibility of its replacement by a better, more comprehensive, hypothesis. The role of empirical 'facts' is thus quite different here: they serve as *tests* for theories, not as their originators.

Scientific knowledge, then, is the product of bold conjectures and indefatigable, ingenious and severely critical attempts to refute them, and 'theories are nets to catch what we call "the world", to rationalize, to explain and to master it. We endeavour to make the mesh ever finer and finer'[93]. In doing so, scientific knowledge gets ever closer to the truth. But, although we may know that we have made an advance, there is no way of knowing if the goal is reached. So it must be accepted that scientific knowledge — all knowledge — remains provisional always, 'for all is but a woven web of guesses'[94].

Lakatos has pointed out that, since research needs theoretical parameters to give it direction, rejection of a refuted theory requires the existence of another, more comprehensive, more fruitful and more powerful theory to replace it. Until that is available, the old theory will have to do[95].

The idea of science as a 'magnificent human achievement', motivated by a distinterested search for truth and requiring bold use of the imagination and, subsequently, of severely critical testing, has given science a strong claim to be recognized as a humane study. If, however, the claim is to be used as a *justification* for science education, then science teaching must reflect it in some way.

Science in its social context

Any simulation exercise is bound to be incomplete in its reflection of the 'scientific life', and this raises the question: If the aim is to teach science as a humane study, at what point does it become necessary to put aside the simulation and teach *about* science? For most questioners this has led to discussion of the place and handling of the history and philosophy of science in schools. For some, it has also raised the question of the inclusion of science as social process.

The British Association committee on secondary science had, in 1917, advocated a treatment of the 'broader aspects of scientific discovery and invention as human achievements'. Every child should be given an opportunity to learn something about the lives and work of such men as Galileo and Newton, Faraday and Kelvin, Pasteur and Lister, Darwin and Mendel, through lessons in the history of science, biographies of discoverers, with studies of their successes and failures and outlines of the main road along which natural knowledge had advanced. This would direct attention and stimulate interest in scientific greatness, instead of concentrating only on the dehumanized material of physics and chemistry, which, seen in disconnection, may tend to be dull and spiritless[96]. That this approach could become as dull and spiritless as the dry bones of fact when reduced to 'potted biographies and pictures of old men with beards', was made abundantly clear over the years.

The history of science must be alive, something more than the bare bones, urged HMI Westaway in 1929. Accounts of great scientists must bring their personalities alive, illustrate their devotion to work and their self-sacrifice and tell of the satisfactions, disappointments, failures, successes and rewards of discovery. These studies should be supplemented by readings from their works — Newton's *Opticks*, Faraday's *Researches* and Darwin's *Earthworms*, for example — so as to give insight into the spirit of research. Westaway wanted pupils to be kept in touch with contemporary research, too, by hearing accounts of, and visiting research stations[97].

Nearly forty years later J.K. Brierley, HMI, was still finding it necessary to urge that it was important to stress the controversies, struggles, mistakes, flukes and achievements of scientific discovery and to avoid teaching science as a series of end-products, because the 'process by which men come to their conclusions is often more fascinating than the conclusion itself'[98].

Older pupils, wrote Westaway, should also have lessons on 'Earlier Science', on the history of particular subjects, such as the history of textiles, and on particular ideas such as evolution and gravitation. These pupils should start, too, to examine the nature of scientific evidence, laws, hypotheses and induction, as well as the various assumptions that they had been making in their own science studies[99]. But overburdened Higher School Certificate syllabuses, with their too narrow view of the nature and functions of science and their neglect of its social implications, and the pressures that they put on the use of time, combined to keep the subject out of most school courses. So did the fact that the philosophy of science makes difficult examination material at this stage, when pupils' knowledge and understanding is likely to be fragmentary[100].

Writing in 1942, Humby and James complained that science was still only very imperfectly incorporated in education, for its social context was generally totally neglected. In particular, they complained, schools had failed to demonstrate to future citizens of a scientific and technological society that the discovery of scientific truth is a social activity that has meaning only in relation to mankind; that scientific discoveries have social results, and that such discoveries are embedded in the socio-historical background.

The facts of science, they urged, needed to be related to the facts of history. This did not mean pre-digested lives of great scientists and brief records of great discoveries, though. These were lifeless facts. 'The history of science only becomes significant when it is interpreted in terms of the needs and conditions of real men and real women', they argued. Hogben's book, *Science for the Citizen*[101], had shown scientific discovery in its dual capacity as man's answer to certain social problems and creator of new ones. Whilst Hogben's approach, as such, was, they believed, too difficult for children, Humby and James thought that it could be ideal if suitably adapted[102].

None of these ideas was particularly new. Erasmus Darwin had advocated teaching the practical applications of science in 1797 (along with educational visits to local factories)[103]. The British Association's committee under Gregory, in 1917, the Thomson Committee, Westaway and many others, had urged that the social consequences of scientific discoveries should be included in courses for all pupils. Most of the advocates had been concerned to stress the benefits of science to man, but Westaway emphasized that pupils should not be taught to believe that science could bring in the millennium. Science could provide the tools for material progress, but could not direct their use. This was a question for its leaders to determine, and so teaching this extended view of science raised issues of choice and responsibility as well as of material satisfaction with the achievements of science. Pupils must be helped to recognize that, not only had science transformed man's view of himself and of his world and affected every branch of human thought, but that it had itself been affected by changing social and intellectual climates[104].

Humby and James went further in providing a number of concrete suggestions. They pointed out, for instance, that the history of metallurgy could be taught either as a series of chemical reactions or as a connected story of man's progress in the use of new materials, and they outlined how actual developments in metallurgical techniques might be treated as chapters in social history. Nor should the prospect of the future be forgotten. Even if it were not possible to do a great deal of this work at pre-School Certificate level, they urged that no opportunity should be missed 'of dropping hints, even to quite elementary pupils, that there is a close relationship between science and history (especially *why* a particular problem is investigated at a particular time) and between science and the future ... '[105].

By the sixth form, pupils should be old enough and intelligent enough to see historical and social relationships. At this stage, therefore, a broad course, 'infused with the ideal of scientific humanism' should be given to both arts and science specialists, it should include some consideration of the history of scientific discovery and its social repercussions, and some account of the relation of science to the general thought of mankind, especially in philosophy. It should also include more biology, but biological topics with social implications, such as the facts and theories of heredity, the measurement of intelligence and problems of population. There should be a brief survey of modern physics, including atomic structure and radioactivity, but probably not relativity. Science and agriculture, science and building, and similar topics should also have a place. Finally, scientific method should be dealt with as a special subject; so should the idea of 'social purpose'. Pupils must be aware of the problems and responsibilities of citizenship for the scientist, as well as viewing science in the light that history throws on it[106].

Humby and James and their predecessors had anticipated the need for a wider view of the role of science in education in an advanced industrial society, a view that was both liberal and liberalizing. Their ideas were echoed, though not so comprehensively, by a number of other writers during the Second World War[107]. But such ideas became submerged after the war by pressures for specialist courses of far more limited scope. What factors combined to keep them in the background (at least with regard to their possible inclusion in examination syllabuses where they were more likely to be a focus for dissension and debate) during the science-promoting, scientific manpower-orientated 1950s? Clearly, the reasons are complex, but some factors, at least, can be pinpointed. Manpower pressures put stress on specialist studies and on still earlier specialization. Examination syllabuses were already overloaded, and their general coverage remained virtually unchanged, although many changes in syllabus were under consideration. University expansion and the growing competition for places led to ever-rising standards of entrance to university, where the situation was exacerbated in the case of science departments by the swing to science. All of these factors encouraged an emphasis on scientific information and on O and A level specialist studies. There was, too, a belief in the need for every citizen in a technological society to have some knowledge and understanding of science, a need which seemed so self-evident that the question of what constitutes 'relevance' in such an education tended to be ignored. Future scientists were wanted, and future scientists needed 'more science', generally interpreted in very limited terms. Technology retained its low status in the eyes of those responsible for syllabuses, and there was probably a shortage of science teachers willing and able to cope with courses of this 'wider', more 'socially relevant', kind. Science teachers were under considerable pressure — they were in short supply, as were technicians; there was the 'bulge' and the 'trend', there were the beginnings of secondary reorganization[108], and they had little time to consider and prepare new and comprehensive courses — especially General Studies courses, which was the one area where there was sufficient freedom to innovate. There was also very little guidance available for those teachers who wished to run such courses, but who lacked the security and assurance to go it alone. Finally, there had been a growing tendency to regard the place for such science studies as sixth form General Studies lessons — for both arts and science pupils. It was in this context that the debate was continued, but even here there was frequently a contraction of the conception of 'science' that was being advocated[109], so that it was brought more closely into line with current, discipline-orientated perspectives, with a focus on process and product.

Advocating change is one thing; getting it implemented quite another, especially in an examination-orientated, decentralized system in which examining bodies hold the key to the content of the curriculum, and individual teachers that to classroom interaction and knowledge structuring. Again and again, the advocates of change have been forced to recognize that until examinations can somehow be made to follow and not to lead in the determination of content and approach, and until syllabus decision making is taken out of the hands of those whose primary interest is individual specialisms, little change is likely. Further, it must be recognized that the conditions obtaining in each classroom, the resources available to the teacher in the form of space, accommodation, technical help, finance (and the intelligent use of these), the quality of teacher-pupil interaction and the quality of content-choice and structuring, are crucially important factors in determining outcomes. More and better teachers are absolutely essential to 'science better taught', and it is not surprising that pressure group activity has turned again and again to the problems of teacher supply, teacher education and teacher help in the form of adequate laboratories, equipment and technical assistance.

3

More and better science teachers

Growing concern about the supply of science teachers

Until relatively recently, the twentieth century has been characterized by a steady growth in the number of secondary school pupils and the general question of teacher supply has been a constant preoccupation. In spite of continual gloomy prognostications by the advocates of science, the situation in boys' schools presented few problems (in numerical terms) until after the Second World War, largely because of the combined effect of industry's preference for non-graduate scientists trained on the job, and of economic recession. In the competitive situation that existed before the last war the academic qualifications of science teachers were relatively high. In 1938, for example, all posts in maintained grammar schools for boys were filled, and 60 per cent of students going from university departments of education into such schools held first or second class honours degrees. 15 per cent had first class honours. Public schools rarely employed any candidates without either first or second class honours degrees[1]. (In girls' schools, and despite the lack of alternative job opportunities in science, the position has remained one of chronic shortage to the present day, especially in the physical sciences.)

The early post-war years brought a dramatic change. The lost war years had inevitably meant a general shortage of teachers, and the situation was exacerbated by the expansion of secondary schooling and by the post-war increase in the birthrate (the 'bulge'). The National Advisory Council for the Training and Supply of Teachers was set up in 1949 to try to monitor differential needs and so to coordinate the supply of teachers, and it issued its first report in 1951[2]. While the prospect of recruitment among arts graduates was good, the report warned, this was certainly not the case for science and mathematics, for teaching now faced severe and rapidly growing competition from industry and from other employers of scientists and mathematicians, such as the Scientific Civil Service, set up in 1945. As far as women were concerned, the figures could not even offset normal wastage, let alone meet the new additional demands[3].

By the time the third report appeared in 1953 (the second was not concerned with teacher supply) there were too many arts and far too few science and mathematics graduates, the demand from industry had not declined as the Ministry of Labour had anticipated, and very few women were coming forward to read science and mathematics at university. Numerically, the situation was disquieting. Much worse, however, was a widespread concern about the quality of these teachers. (In mathematics, this was thought to be the main problem.) Anxiety over quality, the report continued, related in part to teaching ability, on which 'no objective, statistical checks' were possible, and in part to academic standard, where such checks were possible in terms of degree class. Although there had been no lowering of degree class level since 1951, a situation of demand balanced by supply must mean that some schools were being 'seriously disappointed' with the quality of their applicants[4]. Widespread complaints about falling quality did seem to have some substance, however, for figures showed that the percentage of men leaving university departments of education who had first class degrees had fallen from 14.7 per cent in 1938 to 4 per cent in 1953, and there had been a similar fall-off in those with second class honours. Although the report added a warning that such figures should be viewed with some caution because they were based on comparisons for two single years, because they ignored the degree class of untrained graduates entering the teaching profession, and because more graduates were now receiving training than before the war, the feeling that there was cause for concern appeared to them to be substantiated[5]. The figures quoted in the report were derived from studies of teacher

shortage made by other organizations, most of whom had vested interest in the promotion of science. This is not to suggest that there was necessarily distortion or overemphasis of figures, or 'lobbying' in any pejorative sense — but the facts of the matter are that such groups had been actively collecting data to support their contention about needs, and included some groups with growing political power — the Advisory Council on Scientific Policy, the Parliamentary and Scientific Committee, the Council of Professional Scientists, and University Appointments Boards, as well as the British Association, the National Union of Teachers and the Science Masters' Association[6]. The science teachers had carried out a pilot study in 1953, which indicated:

1 That the growth in science sixth forms as a result of the 'trend' (staying on in the sixth form) and the swing to science since the war put particularly heavy demands upon teacher time, just when the proportion of teachers in schools had decreased.
2 That class sizes were generally well above the figure of twenty, the maximum for efficiency and safety in practical classes.
3 That a significant number of science posts in grammar schools (115) were unfilled, resulting in curtailment of science programmes in these schools.
4 That in the preceding ten years about 1,000 science teachers had left teaching posts for posts in industry or administration, presumably because pay and/or promotion prospects were better.
5 That a high proportion of grammar schools had no satisfactory laboratory assistance, in spite of the extra burden and heavy demands upon teacher time resulting from the shortages and from increased pupil numbers[7].

These findings were published in the *School Science Review* in March 1954, but they had already been given to the National Advisory Council, and had been discussed with them and with the Advisory Council on Scientific Policy, at a meeting at the Ministry of Education. They were also leaked to the journal *Discovery* before publication and, not wanting to be forestalled on their own findings, the Science Masters' Association held a press conference. The ensuing coverage added to the publicity[8].

Widespread attention was now focused on this apparently well-documented problem, and the promoters of science began to describe it as a matter for national concern, because it threatened the supply of science students to the universities, hence the supply of scientists to industry and to research and so, ultimately, the 'standard of life of the whole community'. The shortage was clearly not going to be short-term, as government officials had promised. An editorial in *Nature* demanded prompt measures for alleviation, analysis of the fundamental cause of the shortage and of the 'reluctance so far shown' to take steps to end it, and the application of long-term as well as short-term remedies. This was essential, it claimed, before the greatly increased supply of scientists needed by the community could be forthcoming. 'To get more good science teachers', the editorial pointed out, 'needs more science graduates.' But more graduates could not be hoped for without more science teachers — hence the 'present deflationary spiral of science teachers'[9].

As anxiety about manpower grew, industry, too, began to show signs of concern. In January 1954 the Federation of British Industries held a conference on the shortage of science teachers and a committee was set up to look into the situation. It later published a report[10].

A variety of panaceas were suggested: higher salaries, enhanced status, better career opportunities, extra time for preparation of practical work, laboratory help, the provision of facilities for independent research, more money for laboratories and equipment, short courses and conferences, part-time teaching by university and industrial scientists, keeping science teachers on beyond retirement age (with pension benefits — this actually operated temporarily from 1955), persuading married women to return to teaching, the deferment of National Service (which operated from January 1956 to the summer of 1958), and the rationing of scientists between the major markets — industry, the Scientific Civil Service, universities and schools. Most of these were recognized as no more than palliative measures[11]. Those remedies actually tried were equally short-term, small-scale and *ad hoc*. For instance, a scheme tried out at Manchester had five physics graduates doing research part-time; the other half of their time was spent teaching in grammar schools. Local Authorities paid them for this, and the rest of the support for the scheme came from a grant from the Nuffield Foundation[12].

Nevertheless, the debate served to focus the attention of a far wider and more influential circle upon the shortage of science teachers and on their quality, and so to heighten concern to make teaching more attractive as a career and also to provide hard-worked and often less capable teachers with every possible

resource that might improve the general level of science teaching in grammar schools. This climate of concern led to activity in a number of quarters which had previously shown relatively little interest in school science.

The quality of science teachers: intellectual calibre

The intellectual capabilities and 'grasp' of the teacher are frequently indicated by the quality of his university degree — but only up to a point. In the first place, while a good honours degree may indicate true cognitive perspective, it may also represent little more than the possession of factual information. In the second, degree class may afford very little indication of the breadth of this knowledge, or of the perspective with which that breadth is viewed.

As far back as 1918 the Thomson Report had raised the question of relevance in academic courses for intending teachers. Such courses, they argued, should ideally have been taken under the influence of inspiring lecturers, who would, presumably, transmit the overall grasp of the subject so essential to good teaching, an awareness of the aesthetic elements of the subject and a sense of commitment to its values, beliefs and attitudes. The committee had also suggested that, on the matter of content, university courses should aim at producing a wider outlook so that future teachers could 'deal with the relation of science to the progress of civilization, its influence on human thought, and the history of scientific discovery'. In a climate favouring General Science for all up to the age of sixteen, the committee had also advocated a spread of subjects for undergraduates who intended to teach[13]. The Spens Report had reiterated this demand twenty years later, suggesting that at least three sciences should be studied in a degree course[14]. Yet, after the war, a Professor of Education was still complaining that students — even honours graduates — lacked relevant knowledge. Their degree courses, he wrote, provided no training in laboratory maintenance and laboratory skills. Moreover,

> What everybody says we need in schools are science graduates who have been trained in scientific ways of thinking, who have a good knowledge of the social applications of science, and who are interested in its history and philosophy. What we get are persons who have been forced to purchase a superficial acquaintance with recent researches at the cost of basic

> training, and who have studied the advanced parts of their subject in an elementary way, instead of the elementary parts in an advanced way. They should have a broad and cultural education, fitting them to become guides for the young. They get, instead, a narrow and specialized training which equips them (more or less) for an industrial or research laboratory.[15]

The issue was, no doubt, bedevilled by the differing status of 'pure', research-orientated degree courses and general or pass degrees, and by the fact that most of the influential members of the science 'lobby' were themselves specialist, 'pure' scientists, whether researchers or teachers. But efforts to get more broadly educated science teachers have never made much mark on the educational system, and jobs in those schools with the best career prospects — the independent and grammar schools — have tended to go to the Ph.D. with esoteric research experience. It is too early, as yet, to see at all clearly the effects of comprehensive reorganization.

The quality of science teachers: teaching calibre

Teaching calibre is, of course, far more difficult to assess, for it depends not only upon the possession and discriminating use of wide-ranging pedagogical skills, knowledge and understanding, but also upon personal characteristics, attitudes and values. Intellectual ability is, clearly, only part of the story, although it has often been assumed, implicitly if not explicitly, that, given intellectual quality, teaching quality will follow, if not immediately, at least with experience. The situation is, clearly, infinitely more complex.

A decentralized system is heavily dependent upon professional expertise in its teachers. In spite of this fact, and in contrast to almost all developed countries, England and Wales have waived, until very recently, any requirement of professional training and qualification in secondary school teachers in maintained schools. Independent schools have been equally slow to demand it. Even today science and mathematics teachers remain exempt, because of continuing shortages[16]. Official policy since 1908 has regarded a course of professional training as desirable for university graduates entering secondary schools but, while considerable financial encouragement has been given to individual students and to university departments, such training has tended

to be seen as additional rather than as an indispensable part of the secondary school teacher's preparation. This is because of a strong belief that, given initial intellectual capability, skill in the classroom comes from experience rather than from organized training; that, given a good degree and the will to learn from experience, all else will follow. It is hardly surprising, then, that so much emphasis has been placed on degree class and so little on the possession of professional qualifications and skills. Whatever the inadequacies of teacher training courses, the considerable growth of knowledge and understanding — and of perspective — in educational theory and practice and the opportunities afforded to student teachers to watch competent and experienced teachers in action in the classroom and to benefit from their advice and criticism, does call into question such an attitude.

Underlying all this is the expression of the ethos of the practical man on the job as the real expert. Yet questions of what makes a first-rate teacher are not easy to answer, and the term can be applied equally well to a competent but didactic authoritarian, who gains spectacular examination successes and little else, as to the practitioner who demonstrates his superior capabilities in every aspect of his work, including examinations, and who imparts to his pupils an understanding of, and feeling for, the subject which lasts, whether or not they go on to further study in this field.

There is little consensus — and even less evidence — as to what constitutes sound pre-service training. Yet even the 'best' pre-service course cannot provide the young teacher with everything he will need to know. For one thing, there is simply not the time; for another, more practical experience is required before the real benefits of the interaction of practice and theory can be felt. In addition, there is always a need to up-date content as well as method, and to develop monitoring skills. Consequently, the provision of short inservice courses has long been seen as essential to teachers' continuing development. The Board of Education started short courses in 1918[17] and over the years these have gradually become more numerous. But the scale of provision has never been fully adequate, and there has been little official incentive in the form of financial reward or recompense. Without compulsion, inertia has, as always, resided where action was most needed[18]. HM Inspectors and, more recently, Local Authority Inspectors and Advisors, have acted to *advise* teachers, informally in the classroom and formally in their reports, their pamphlets, such as *Science in Secondary Schools* [19], their journal, *Trends in Education*, and their courses. Advice can be as powerful as prescription when it comes from high status persons, but the potential is considerably reduced here by the strong belief in teacher autonomy: 'It has never been the policy of the Minister of Education in any way to impose rules in these matters, but rather to help those responsible for the work to reach decisions for themselves'[20]; and by other factors which interact to constrain the secondary school teacher, such as examinations and examination success.

As a result, many teachers have had to rely on their own experience, on pre-service courses of variable quality or on advice in teachers' journals, such as the *School Science Review*. That a felt need was not being met seems likely and, certainly, a correspondent to the *School Science Review* in 1942 suggested that young teachers of some six to eight years' experience might be given an opportunity to spend one or two weeks observing 'first-rate teachers' in action in classroom and laboratory. (One might note wryly that in the heyday of the 1960s, most young teachers with this amount of experience would already be Heads of Department, giving advice to less experienced colleagues!) He asked, too, that more space in the *School Science Review* be devoted to articles on methods of teaching and of introducing specific topics, to laboratory planning and organization and, perhaps, to articles by 'leading teachers, of acknowledged experience', who might contribute their own solution to specific problems such as timing and approach used in teaching, say, valency or potential difference[21]. In 1949 another correspondent asked if time could be given at the next Annual Meeting to discussing the 'actual teaching of science, as apart from the study of science itself'[22].

Although other institutions and organizations extended short course opportunities after the Second World War, they remained somewhat inadequate as a communication channel, for the scale of provision remained such that relatively few teachers could benefit.

In 1918 the Thomson Committee had suggested two other means of facilitating communication between science teachers: first, by encouraging teachers to visit other schools for periods of a week at a time; and second, by producing a journal or a series of leaflets in which teachers who had 'devised new lecture or laboratory experiments or new methods of dealing with particular problems in their work' might bring them to the notice of their colleagues[23]. Whether or not this recommendation was directly responsible, the *School Science Review* appeared in 1919, soon after the Association of Public School Science Masters had extended membership to graduate teachers in secondary schools, becoming, in the process, the Science Masters' Association. A subcommittee of the new Association, set up under G.H.J. Adlam of the City of London School, planned to publish three issues a year, through John Murray. These would include articles covering a wide range of topics, both scientific and educational, and would provide a forum for the discussion of new ideas. The first issue appeared in June 1919, and more than 300 copies were sold, over and above those going automatically to members of the Association. In 1922 publishing became a joint venture with the Association of Women Science Teachers. The much-enlarged and widely read journal still flourishes.

The Association of Public School Science Masters had produced a pamphlet in 1913 which listed books suitable for a school science library. The list was revised and reissued from time to time, and the service still operates. The original pamphlet was the starting point for a wide-ranging and still growing series of occasional publications on every aspect of science teaching at every level[24].

In the first forty years of activity the Science Masters' Association produced a great deal of material help for teachers, increasingly in collaboration with the Association of Women Science Teachers, sometimes with other bodies. They had also established an extensive communication network, which was supplemented by regular branch meetings and by the Annual Meeting, which has always been attended by a very large number of members. In the 1950s these activities took a new turn as communication and cooperation with other institutions and organizations increased, and as these bodies, too, became interested and involved in the field of secondary science education.

The impact of increased technological demands

Between 1939 and 1945 the mobilization of science and its effectiveness highlighted once again the importance of scientific and technological advance for national security and power, besides demonstrating how rapid progress could be if efficiently coordinated. Besides, science had caught the imagination of the general public and this helped to create something of a mystique about the potential of peace-time science and technology for economic growth, national welfare and prestige. (The atom bomb had the reverse effect, and many scientists withdrew from political activity, so that their influence tended to decline, though some, like Bernal, remained active.) There was, therefore, considerable concern for the expansion of science and technology. Formidable problems faced post-war governments. In the first place, reconstruction had to be given priority in the immediate post-war years. In the second, there was no machinery for planning, administering and furthering the expansion of state support for scientific research in civilian as well as military sectors. The Scientific Civil Service was established in 1945, but most senior civil servants were non-scientists and there was very little scientific expertise in the higher echelons of government[25]. The Barlow Committee's Report in 1946[26] predicted an escalating manpower shortage unless the annual output of scientists could be doubled, and the Advisory Council on Scientific Policy was created in 1947 to match, for civil science, the Defence Research Policy Committee, and to advise on such questions as the supply and training of manpower. They, too, faced formidable problems. In the first place, their advisory character proved to be a considerable handicap, for it precluded access to information held by senior, non-scientific, civil servants, and even when their advice was sought it was often ignored[27]. In the second place, manpower forecasting proved to be far more complex and intractable than anyone had anticipated, partly because of an assumption that 'need' is synonymous with 'demand', partly because their emphasis remained on the production of high-level, university-trained scientists, with little apparent recognition of the differing needs of individual sciences, and of 'pure' and applied science[28]. By the mid-1950s it was becoming painfully clear that this emphasis had led to a failure to explore at all adequately the kind of scientific manpower needed, the relative proportions of each type needed, the requisite balance between scientists and technologists, and the proportion to be trained at university level as compared with those trained in technical institutions. Interest in technology was certainly not fostered or encouraged to any extent in grammar schools, for the effect of the emphasis on university training put the stress on specialist studies for university entrance. At the same time there had been almost no government attention to the development of technical and technological education. Further, there was plenty of

evidence that there were still large segments of British industry that felt no acute need for greatly expanding their technical force. Although voices were raised to ask questions about this state of affairs there was little response in government circles or in schools[29].

In mid-1955, however, Austen Albu, MP, initiated a debate in the House of Commons in which he related the manpower situation in Britain (for which he gave figures) to educational policy as a whole, and he urged the Minister of Education to provide a statement of policy, giving specific regard to technical education. This was promised 'before Christmas', but it appears that the Minister took evasive action, for he stressed that alleviation of what he called a 'critical shortage' of scientists and technicians was largely a matter, not of administration, but of public education, of 'firing the imagination of school children, their parents, teachers and employers, with the adventure of the scientific revolution'. He emphasized the importance of a general education: teaching men and women to enjoy wealth was as important as teaching them to produce it. In spite of the unsatisfactoriness of this reply, an editorial in *Nature* expressed satisfaction at the level of awareness that appeared to exist of the seriousness of the situation and of the problems of trained scientific manpower as a *whole*. At last, it commented, there was a realization that the expansion of university and technological education was related to the whole of education and to the shortage of science teachers — and the 'right' questions were being asked, 'even to the extent of ... whether the right departmental organization exists for linking the educational needs of the nation with the actual policy being pursued in universities and technical colleges and by local authorities'[30]. Whether or not this climate alone could have produced action is a moot point, but events were precipitated by the publication, in late 1955, of a report on Soviet scientific and technological training and manpower, by Nicholas de Witt[31]. In the context of manpower anxiety, continuing economic crisis and the Cold War, the report aroused considerable press and public comment, and no little criticism of government priorities, ineffectual deployment of resources and inadequate government machinery for policy-making[32]. The White Paper on technical education, which appeared in February 1956, admitted that 'it is clear enough that all these countries [the Soviet Union, America and Western Europe] are making an immense effort to train more scientific and technological manpower, and that we are in danger of being left behind'[33]. Now, at last, official attention turned to technical and higher technological education, although it took a long time for the new attitudes to filter down to grammar schools. Now, too, British science policy began to develop into a political issue, and both parties promised, and the victorious Tories created, a Ministry of Science after the 1959 election[34]. Vig gives interesting figures which corroborate Cotgrove's pinpointing of de Witt's study as the precipitating factor. In the first five years after the war the average number of parliamentary questions and debate on science and science-related policy and progress was eleven per session. In the next five years it rose to sixteen per session and then, from 1955-6, rose very rapidly to 111 per session[35].

Government remained uninterested in school science, however, until the start of the next election campaign, after 'Labour and the Scientific Revolution' formed the topic of Harold Wilson's speech at the Labour Party Conference at Scarborough in 1963, and soon afterwards, with the first intimations of the so-called 'swing from science'[36]. The Advisory Council on Scientific Policy had given official expression to concern in its thirteenth report in 1960, but with little apparent effect. It is, however, a body of scientists, and might be expected to take a lead in this connection. 'We have no doubt', the report stated, 'that school science curricula are in need of a thorough re-examination. They tend at present to be unimaginative, and to be overloaded with factual material'[37].

A clear indication of lack of government interest comes in an article by Lord Hailsham, the then (and first) Minister for Science, which appeared in the *Sunday Times* in May 1963, a year after projects had got under way. An extract from his book *Science and Politics*[38], the article is, for the educationist, notable chiefly for its ignorance of what had been going on in science education in Britain for well over a year, and for its out-of-date information on American developments in the same field. Although Hailsham had been to a dinner at Nuffield Lodge in June 1961, at which school science had been the focus of the discussion, and had been sent a copy of the press release that announced the establishment of the Science Teaching Project, he made no reference to it whatever in an article advocating change in school science, writing, instead, of British conservatism and of forging links with the work going on in America. Many others, however, were very much more concerned by this time about the implications for school science of the new position of science and technology in society — and vice versa.

In October 1957 *Sputnik* appeared in Western skies. It is often claimed that the curriculum development movement in America — and here — arose as a result of this event. Whilst national and international prestige and defence considerations were, no doubt, important in helping to create a climate of opinion that supported changes in science education at every level, mere reference to dates shows that curriculum reform of this kind had earlier roots, for the first new experimental curricula in mathematics were underway in the very early 1950s, and although Sputnik-induced traumas expedited and increased the size of the grant, federal funding for the work of the Physical Sciences Study Committee's work was in fact made some weeks before that event. In Britain, partly because of the very different location of power in curriculum decision making and of a commitment to the ethos of teacher autonomy, partly because government was not prepared to be similarly involved, the initiative had to come from teachers, and from a philanthropic organization. For the teachers, it was the evolutionary outcome of many years of work to help other teachers, and at the outset it was not even a new departure from what was already long-established practice.

Awareness develops into action

The climate of change

Within the matrix of general social and educational change in mid-twentieth century — secondary education for all, selection and the tripartite system with its grammar, secondary modern and technical high schools, growing pressures for common schooling and for a broad general education for all, with 'balance' and less specialization — a number of pressures put the groups working for 'more and better science' into a particularly strong position. Growth in the bulk and sophistication of scientific knowledge, in understanding of the nature of science and of epistemology, and in the sociology of science, was creating serious problems at all educational levels: problems of keeping up to date, of overloaded syllabuses and of social relevance. Universities were dissatisfied with the quality of students, especially science and mathematics students, whom they regarded not only as illiterate but as lacking relevant scientific knowledge. School-teachers were dissatisfied with the nature of the 'science' they were having to teach on the prescription of examination syllabuses — the weight of dead wood, the lack of modern material and the emphasis on rote memory and didactic methods; and with neglect of the growth of knowledge of how children learn. In America, exciting new curriculum development projects, directed by very eminent scientists and mathematicians, and involving teachers from all levels, were under way. These incorporated a new discipline-orientated, 'inquiry'-based conception of science-for-teaching, a conception supported and elaborated by educational philosophers in the United States and Britain, which was becoming highly influential. Rethinking of curricula was also going on nearer home, in Scotland.

The linking of national and international prestige with scientific achievement and technological progress had been an important source of pressure since the mid-nineteenth century, although government, industrial and public interest had tended to be sporadic and to occur chiefly in times of crisis. There is little doubt, however, that anxiety about Russia's technological progress and our own manpower shortages and industrial backwardness did much to foster pressures for change in school science. It also quite considerably affected the nature of those changes, and it encouraged support for what appeared at the time to be priority areas, for example, the provision of specialist-orientated courses for abler children — even for all children.

The significance attached to C.P. Snow's Rede Lectures in 1959[39] almost certainly reflects the heightened awareness of the period, although, clearly, the vituperative personal attacks that followed them gave considerable additional publicity to the subject. Snow himself later pointed out that the ideas were not really new, that he and others had been saying the same sort of thing for some time without arousing much comment[40]. And it is not necessary to look far for corroboration of this claim. At a British Association conference on school science in 1958 Jacob Bronowski had demanded, and with a far greater show of arrogance, that the nation should 'saturate the schools with science'. For, he warned: 'The scientists are inheriting, they are conquering the earth, and if you do not speak their uncouth language, then you will sink to the status of the native yokels when the Normans overran England[41].'

Snow had spelled out the implications of his thesis in more

detail, with proposals for educational reform which say little for his view of the nature of the whole enterprise. With their preoccupation with scientific content and literary studies as the key to 'numeracy' and 'literacy' — a very narrow view of balance and breadth in education — they reflect little of the wider humanistic goals of educational thought during this century. It seems likely that the general anxiety about the progress of science, hostility from vested interest and widely voiced contemporary concern over premature specialization in schools, gave what was really a very slight handling of an important subject an influence in society that was out of all proportion to its worth, for the controversy was widely debated and the original lecture much quoted — and it remained so.

International organizations and professional institutions

The concern for science, and the focus upon school science in particular, was not confined to Britain, but was common to all the nations of Europe. At an international level UNESCO and the Organization for European Economic Cooperation (which in 1961 became incorporated in the Organization for Economic Cooperation and Development, OECD) were concerned with the broader problems of science education. UNESCO held a conference in 1956 to discuss school science teaching which was an important take-off point in the history of the Science Masters' Association (which will be discussed later). UNESCO also conducted international surveys, held conferences and published general recommendations. At the height of the manpower and economic anxieties of the late 1950s, the Organization for European Economic Cooperation set up an Office for Scientific and Technical Personnel to promote international action, to increase the supply and to improve the quality of scientists and engineers in member countries. With the establishment of the OECD in 1961 this function was taken over by a Directorate of Scientific Affairs. International courses were held at Keele (with the cooperation of HM Inspectorate) in 1958, in Dublin in 1961, and in Norway in 1962[42]. An international meeting of science teachers from Germany, France, Sweden and the United Kingdom was arranged in 1959, to discuss ways in which the organization could help science teachers. Again, in 1959, 1961 and 1963, chemistry seminars were held in Ireland, Italy and London, with the object of producing a handbook for chemistry teachers (published in 1963 as *Chemistry Today — a Guide for*

Teachers) and, subsequently, a manual of experiments. Similar ventures were undertaken in physics[43].

Professional bodies, too, had concerned themselves with school education from time to time, and had school-teachers on their education subcommittees. But their concern was chiefly related to the education of specialists and therefore to higher education[44]. Nevertheless, there had been desultory efforts at arousing interest, and during the 1950s interest and activity began to grow as one by one these bodies appointed full-time education officers. Soon they, too, were organizing courses for teachers, principally up-dating and extension courses[45]. This was particularly true of the Royal Institute of Chemistry, which during the 1960s built up a nationwide network of symposia and conferences. Special committees on education in chemistry, physics and biology were established in 1961-2, in conjunction with the Royal Society, and these will be mentioned again later. Journals concerned with education in their individual specialisms soon followed.

In the mid-1950s Sir Lawrence Bragg, the newly appointed director of the Royal Institution, which is best known for its Friday evening discourses and its Christmas Lectures for young people, launched two new schemes. The first involved twice-weekly experimental demonstrations illustrating sixth form course work, and some 20,000 tickets were soon being issued every year. The second enabled teachers to meet leaders of research and their teams and to hear about their work. It also included a library membership scheme, which enabled teachers to use the library facilities at the Institution. Initial financial support for these schemes came from the Nuffield Foundation; subsequently it came from industry[46].

University science departments had offered occasional courses for teachers since the First World War, and these began to take on a more regular pattern in the late 1950s. As early as 1957 there were Easter courses in chemistry at the recently established University College of North Staffordshire (later the University of Keele). These courses were specifically advertised as 'Some Modern Aspects of Chemistry and *their Application to pre-University Teaching*' (Professor Halliwell's italics). In the four years that these courses were held, they were attended by some three hundred teachers of chemistry in fifth and sixth forms in grammar schools — a high percentage of those so involved, which indicates a considerable interest in developments in school chemistry teaching[47]. Shortly afterwards University College, London, started an annual conference for chemistry teachers, and other university departments soon followed suit. In most cases these university courses depended upon the individual initiative of senior staff. In the 1960s, when the first Nuffield Projects began to appear on the market, universities, polytechnics and technical colleges took increasing initiative in organizing courses. Through the activities of the Institute of Physics and the Physical Society, Science Teachers' Centres were created in university departments to complement inservice courses, and in the winter of 1968-9 the British Committee for Chemical Education initiated the setting up of a number of parallel centres for chemistry teachers.

Industry and the industrial fund

Business concerns are not charitable trusts and their philanthropy is, in general, either promotional or in the interests of recruiting better employees (though the two are not entirely separable). In the case of support for education the major purpose is the production of better and more useful recruits to industry, and so the relevance to the company's needs will be an important consideration in determining whether or not help will be given to any educational scheme. In short, motivation is clearly and unashamedly self-interest.

> We have never had the temerity to tell professors or schoolmasters how or what to teach; what we have had to do, however, is to assess our future manpower requirements, and, when it has been within our ability, to remove difficulties in the way of university departments attracting and training the necessary specialists in sufficient numbers.[48]

Industrial companies can help education in two ways: first, by giving money for bricks and mortar development in the form of buildings and equipment; second, by providing grants, fellowships or other forms of financial support for education.

It was the changed climate of the 1950s that turned the attention of industry to school science and mathematics education on an appreciable scale. From a situation in which a few informational booklets, pamphlets and visual aids were available on application to individual teachers who displayed the necessary initiative, an increasingly cooperative enterprise has developed over twenty or so years, encompassing a considerably expanded visual aids and other resources service, a substantial investment in school bricks and mortar, the sponsorship and organization of courses and conferences for teachers, and involvement in curriculum development work. As these activities have evolved there has also been more and more cooperative work between industries themselves.

Only big firms can support any large-scale production and distribution of educational aids, though many others are prepared to supply, to individual teachers requesting them, copies of promotional literature intended for commercial customers and/or informational material prepared for internal consumption, and to welcome school parties on factory or works visits. In some cases this service has been available for many years on a small scale. Imperial Chemical Industries, for instance, was lending films free of charge in the 1920s[49]. A measure of coordination and organization was achieved as a result of the initiative of a small group of industrial scientists and members of the Science Masters' Association in 1949, and this eventually led to the establishment of joint teaching aid subcommittees in each of the sciences and the continuing preparation of published lists of available aids[50].

By far the most important venture, however, and one of the first major essays by industry into the provision of help for school science, was the establishment and deployment of the Industrial Fund[51]. This was set up in the mid-1950s, when concern for school science and its relation to manpower began to show a sharp rise in all quarters. The Fund was the brainchild of Jack Oriel, of Shell International, who was involved with measures for improving the manpower situation. With the help of Lt Gen. Lord Weekes, then chairman of Vickers Ltd, Sir Alan Wilson, FRS, then a director of Courtaulds, and George Courtauld, a Trust Fund was set up by, eventually, 141 industrial companies, including a number of giant firms as Founder Members (among these latter were Associated Electrical Industries, British Petroleum, Courtaulds, Esso, Imperial Chemical Industries, Shell International and the Wellcome Foundation). The Fund was to be used for giving grants to independent and direct grant schools for building, modernizing, expanding and equipping school chemistry and physics laboratories (there was no appreciable support for biology teaching[52].) At its inception the Minister of Education had undertaken to give special attention to maintained schools, although in the event other pressures on the educational purse, as always, took precedence. By the time it wound up in 1963, building grants of varying size had

been given to 210 schools, along with an appropriate apparatus and equipment grant. Further grants, for equipment only, went to another 129 schools and twelve more received £400 each to help to pay for newly designed apparatus for physics teaching. The bases on which grants were calculated and allocated is described in the Final Report.

When the Advisory Council on Scientific Policy complained in its 1963 report that there was still a shortfall of high calibre applicants for technology courses, in spite of an increasing output of scientists (the 'swing from science' had not yet been detected), some of the remainder of the Fund was used to help set up an engine test-bed at each of seven schools. The sum of £3,000 went to the Association for Science Education to help establish a permanent headquarters at Cambridge, and Malvern College received £2,000 to extend the laboratories because of the considerable amount of Nuffield Foundation Science Teaching Project work being undertaken there.

The Chief Assessor's Report to the Executive Committee claimed that the effect of the Fund was to make it possible, for the first time, for every pupil in these schools to take at least one science subject at O level. Moreover, in the schools helped, the number of science and mathematics specialists had increased from 12,937 to 18,000 (these figures may, however, have been considerably influenced by the swing to science in the late 1950s, and early 1960s, and by the 'bulge' and the 'trend'). The investment of £2½m. in buildings and of nearly £400,000 in apparatus is a quite staggering figure, and the total of £3¼m. far exceeds the entire cost of the Nuffield Projects. It must have made an enormous difference to many schools in the private sector, not all of it so easily visible. Even so, the Assessor sounded a less cheerful note in his comment that 'there is still room for doubt whether the Science Sixth yet attracts enough of the ablest boys who enter the largest and best-known schools'. Nevertheless, the Fund represents nuts and bolts provision on a very grand scale, and it did much to alleviate the frustration of those in the independent sector whose wish for change had been hampered by lack of facilities, while at the same time it removed the excuse for inertia. A full history of this most significant pressure group would provide a valuable addition to the history of science education.

To help teachers to incorporate industrial applications in science courses, a number of industrial firms and organizations, such as the Federation of British Industries, Shell International, BP and the Salters Company, began to organize courses for teachers at about the same time. It is interesting to note that in 1959-60 at least two major companies, Shell and BP, turned their attention quite independently to the running of conferences on teaching methods in place of the more usual focus on their specific industrial undertakings. Other firms took a direct interest in the science education of young people. Esso, for example, offered to give lectures in London schools, and they also financed a 'Senior Loan' and 'Junior Loan' service, which made equipment available to schools, free of charge, Esso funding the cost of running the service as well as the purchase of equipment. This was wound up only in 1968[53].

In 1956-7 a member of the staff of Shell International carried out a wide-ranging inquiry which led to a series of recommendations for activities that would 'bring science effectively within the horizons of young people, especially in their extra-curricular lives'. Shortly after it was completed the British Association, anxious to concern itself more with young people, asked to see the report, which had been recommended to them by the Royal Society. After studying it, they and Shell International agreed that the Association should use the report as the basis for their own work, Shell retaining only that part specifically concerned with petroleum and, in addition, providing the Association with staff help and finance. By 1961 the money was being used to fund a variety of activities, including meetings, Science Fairs, and film shows held in conjunction with a number of industrial firms[54].

This account has been selective and brief to the point of failing to do justice to the rapidly growing interest and involvement in school science of industry and others in the 1950s and 1960s, and in ignoring altogether the continuing growth and diversification of activity after 1965, but it is intended only to sketch in the early development of what has now become a powerful pressure group with considerable financial resources. It shows, too, the way in which general opinion became so favourable to school science that when the science teachers' associations began to look to outside sources of help on a large scale there were a number of organizations and institutions ready and eager to provide it. Figure 3.1 is included simply to sustain a sense of chronological order in events, especially in relation to the section that follows. It is not intended to be exhaustive.

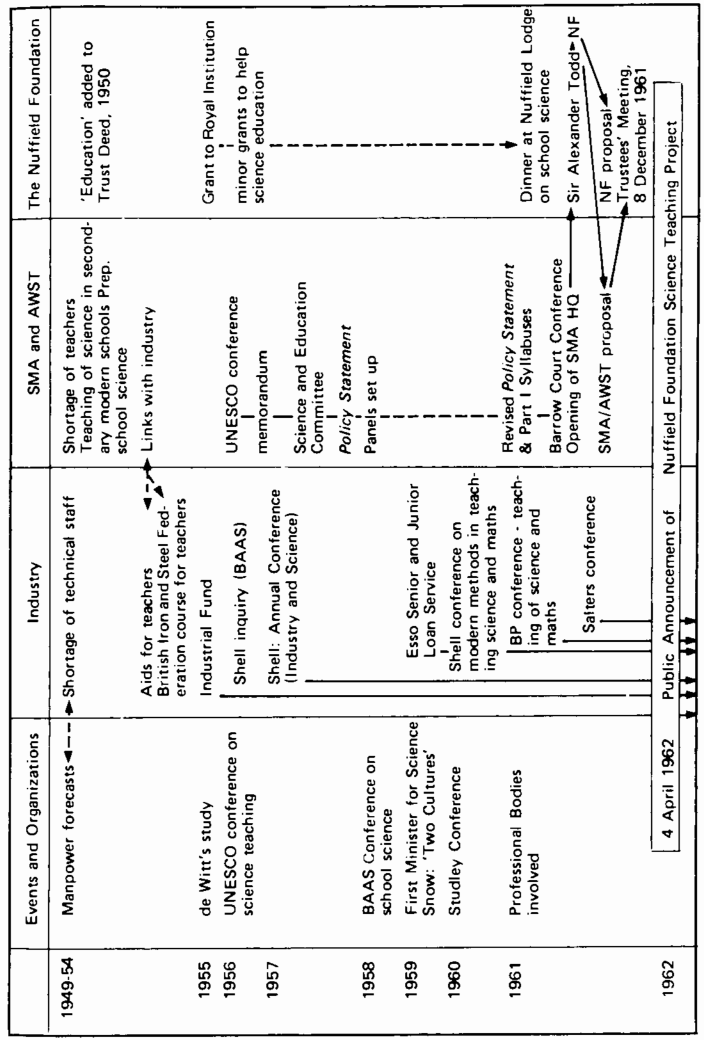

Fig. 3.1 Growing involvement in school science 1945-62

The science teachers' associations

From the inception of the Association of Public School Science Masters, many science teachers had worked indefatigably to promote their cause of 'more science, better taught', first, by bringing pressures to bear upon their fellow members and, second, by collaborating with more widely prestigious scientific pressure groups and individuals to improve the status of science in education, especially in those educational organizations with which they were immediately and professionally concerned, secondary schools and universities. As teachers, their representation on examination board subcommittees had grown with the years, giving the active core of membership considerable insight into the working and relative power of these bodies, the Secondary School Examinations Council, and university entrance requirements.

The 1944 Education Act brought a new aim — the extension of secondary education — and for some years the attention of this active core was focused largely on the needs of the new sector, especially the needs of secondary modern schools[55]. In the meantime, growing dissatisfaction centred on the shortage of science teachers and its implications in terms of 'lower standards', and on examination syllabuses, by now hopelessly outdated and overloaded. Revision of syllabuses in Scotland and the increased momentum of the curriculum development movement in America heightened discontent still further. But dissatisfaction, however widespread, does not alone provoke action. The motive power of any pressure group lies in a shared perception of what is wrong and of what can be done about it, but it is also heavily dependent upon the ability of the leadership to canalize the dissatisfaction of others by crystallizing, defining and focusing it into a clear statement of policy. Only then does action become possible.

The idea of producing a policy statement had, in the case of the Science Masters' Association, been latent since the early years of the Second World War. It was brought up quite specifically again in 1949, when a subcommittee was formed to 'try to define what is meant by an educational policy and to explore ways and means of formulating an educational policy' for the Association[56]. Although the subcommittee was to report back to the General Committee later in the year, the Minutes contain no further reference to policy until the autumn of 1956, when action was precipitated by Dr Henry Boulind's attendance at the UNESCO conference held in Hamburg[57]. At the next meeting of the General Committee in March 1957 Boulind presented a memorandum, and another member told of a meeting at the Institute of Physics at which very similar views had been expressed. After some discussion, the Committee agreed that the aims and content of science teaching in grammar schools needed to be 'thought out afresh from first principles', and so they set up a subcommittee to 'inquire into the aims, scope and content of science teaching in grammar schools with special reference to the part that science can play in general education'. This was the Science and Education Subcommittee[58]. In recent years some critics have made much of the fact that the policy statement that they produced, and the work that derived from it, was centred on grammar school syllabuses[59]. Motives are seldom unmixed, but it is clear that, whatever covert motivation may have existed, the primary motivation was undoubtedly the urgent need to prune, modernize and improve science teaching in those schools in which most teachers were working, in a still predominantly selective educational system. Records from the late 1940s and 1950s afford evidence of a great deal of time and energy given to attempts to provide appropriate, relevant and meaningful science for 'less able' pupils. Nor were these children forgotten when the scope of the Nuffield Project was being discussed.

Over succeeding months members of the new Science and Education Subcommittee pooled their ideas and produced a draft policy statement for the October meeting of the General Committee. This discussed, very briefly, the aims of science teaching in grammar schools and it made recommendations about the courses in the first five years of secondary schooling and in the sixth form. It took its point of departure from the prevailing situation and from norms of the ideal educational situation, as then conceived. These were then used as a base for criticizing existing defects, for drawing attention to deficiencies and dysfunctions, for identifying them as the source of individual discontent, and for making recommendations whose implementation would, they argued, help school science to move nearer to realization of the then ideal of a discipline-centred, inquiry model. Like all statements of policy, these were expressed in very general terms, a recourse essential for obtaining broad consensus (typically, it is in the execution of policy, when detailed interpretation becomes necessary, that problems of difference arise — as they did here). What was being sought was, in effect, a change in the conception of science education, within the stable context of the educational *status quo* — and it is unrealistic to criticize them for not attempting more.

After considerable discussion, the draft was passed by eighteen votes to two. 11,000 copies[60] (with subsequent reprints) were printed and circulated to members of the associations in the November *School Science Review* and, together with a covering letter, to the Ministry of Education, university science departments, the Royal Society, the British Association, the 'Joint Four', the National Union of Teachers, the Headmasters' Conference, all Education Officers, the Incorporated Association of Assistant Masters, and head teachers of all schools except those in Scotland.

The policy statement received favourable comment in the press, and the committee had a number of letters asking for more information or expressing minor criticisms on matters of detail. They therefore agreed to revise and then republish the statement[61]. In the meantime, however, its tenets provided a basis for action by four 'panels', set up to prepare detailed syllabuses in biology, chemistry and physics and to make proposals for a non-specialist sixth form course. These 'subject panels' met at regular intervals over the next three years, in their own time and usually on a Saturday[62]. By the end of 1959 each had produced a draft syllabus, and these were circulated, in confidence, to those members of both associations who had expressed an interest in commenting upon them. The drafts were also discussed by members attending the Science Masters' Association Annual Meeting at Southampton in January 1960. Now they were all redrafted and then prepared for publication[63]. Long before publication, however, it had become clear that they could be only a beginning. New ideas, and the teaching of new ideas, would need specification and amplification, and they would have to be examinable and demonstrably so. A steady escalation of the scale and scope of the exercise, from syllabuses to teaching schemes with notes, to additional appendices, and finally to the idea of separate Teachers' Guides had developed. The need for so much detail was underlined at meetings held all over the country. Early in 1960, therefore, the General Committee decided that the proposals for each subject should be published in two parts: Part I would consist of the syllabus and teaching scheme, with notes; Part II would be a teachers' guide, containing a detailed exposition of the new approach that they were advocating.

Part I in each subject was published in February 1961, along with an injunction on the cover that it should be read along with the revised policy statement which was published simultaneously[64]. The syllabuses in chemistry and physics met with relatively little criticism, though there was concern about some of the theory that was being included for the first time at this level. Biologists were less united in welcoming the new suggestions, possibly because of the very uncertain position of biological science at this time, which meant that there was far less consensus as to what might constitute a desirable school course in the subject.

In December 1960, shortly before these documents were published, the Secondary School Examinations Council held a conference at Studley, at which members of the Council's Science Panel and of the science teachers' associations discussed with HMIs the question of examinations in relation to the new physics and chemistry syllabuses. In the case of the latter, participants agreed that the first twenty-three sections provided an acceptable and unexceptionable basis for the introduction of a new examination syllabus, but section 24 (atomic structure) contained a great deal of new material and should, therefore, be excluded from examinations for the time being. There was too little experience of teaching and examining at this level, and experimentation would be best handled without examination pressures.

In the case of physics, it was clear that considerable changes in current approaches to teaching and examining were needed and so it was decided to carry out a controlled experiment. The 'pilot scheme' (also known as the 'Studley experiment') was established as soon as possible. A letter was sent to heads of science departments in grammar schools and others with a 'grammar' stream asking for volunteers, and of these, thirty schools were selected, covering a wide range of types of school and including some 750 physics pupils. Teachers were given as much help as possible and were also offered a short course on unfamiliar apparatus at Malvern College and in London. In addition, parties consisting of one HMI and a member of the science associations' physics panel spent a day with the science staff of each school, discussing the syllabus and scheme, and any problems being experienced over apparatus. They also talked to pupils[65].

In April a five-day residential meeting was held at Battersea College of Technology under Dr L.R.B. Elton, head of the physics department and a member of the physics panel. The meeting was designed to provide an opportunity for thrashing out the difficulties arising from the new physics proposals. Interested teachers from a variety of schools put forward their views on method and presentation, and debated among themselves. No solution, even in embryo form, was reached; what emerged, rather, was a recognition once again that, while the need for change was widely appreciated, its implementation was going to require activity on a major scale[66]. Just how large-scale it would turn out to be was not at all clear either then, or at the time of the launching of the Nuffield Projects a year later.

The chemistry panel was coming to a similar conclusion, and in the middle of 1961 they agreed that a letter should be written to the chairman of the Science and Education Subcommittee — Boulind, a physicist — expressing their strong feeling that, because of the implications of the continuing escalation of the exercise, an approach should be made to the Minister for Science for a 'substantial sum of money to organize a programme of writing and experimentation involving schools, industrialists and university teachers'[67].

It is clear from the records that the scope of the operation widened with each step, and that it was becoming increasingly obvious that to carry out the exercise effectively would require much expenditure of both time and money. Certainly, it could no longer be viewed as being within the scope of people working on a voluntary and part-time basis, people who already carried heavy teaching loads and other full-time responsibilities in schools. There was also a growing conviction that if science curriculum revision was going to be undertaken on this sort of scale, the work should be extended to cover the needs of other types of school, primary, preparatory and secondary modern. There was no precedent for the sort of activity envisaged, nor was there any recognized central body to whom appeals for help might be directed. Committee members of both associations therefore began to look around and to consider appropriate sources of funding.

At the end of August 1961 a five-day conference was held at Barrow Court, near Bristol, supported by a generous grant from the Esso Petroleum Company. Thirty-three members of the chemistry and physics panels and the Science and Education Subcommittee met to consider what had still to be done to follow up the syllabuses. At the start of the week a 'very helpful' and 'frank' exchange of ideas with representatives from the Ministry of Education, the Royal Institute of Chemistry and the

Institute of Physics resulted in agreement that it was going to be necessary to prepare teachers' guides and laboratory manuals, to produce films and other aids, to develop a new conception of examinations and examination questions, and to organize courses for teachers — a giant step from the initial task of preparing a new syllabus!

Other discussions took place on examinations (considerable dissatisfaction with the current situation emerged), on the work of the new panels set up in the previous January in an attempt to spread the load of work a bit further and, in the case of the 'Teaching of Modern Physical Science' panel, on the urgent need for published material for the Studley scheme. In between meetings, panel members carried on with their work on the Part II manuscripts. Once again, however, everything served to underline the vast scale of the task upon which they had embarked and the fact that it was rapidly growing beyond whatever resources of time and money they could provide. In addition, a new sense of urgency was appearing, for the committee was warned that if the associations did not move quickly 'there was a danger that others would forestall them', and that their lead should be maintained at all costs. Representatives of learned societies and professional organizations had indicated informally that they supported the belief that these two associations should take responsibility for putting forward suggestions for methods of implementing the new syllabuses, since the venture had originated with them, and they had the necessary classroom experience. There was activity in several other quarters and there should be at least a measure of coordination if confusion and delay were to be avoided. The Science and Education Subcommittee now decided that the chairman should seek an interview with Sir Alexander (later Lord) Todd, chairman of the Advisory Council on Scientific Policy, to discuss the feasibility of making a formal approach to the Council with the aim of enlisting their help in order to secure:

1 As an urgent priority, the conditions (adequate finance, secondment of teachers, secretarial help, office and laboratory accommodation) necessary for the panels to complete their work and publish their conclusions.
2 The organization of a comprehensive and large-scale programme of inservice courses for teachers, to implement the work of the panels.
3 The establishment, as a long-term project, of a permanent

Institute, to guide future developments and to undertake research in areas relevant for science teaching[68].

Less than one month later, on 30 September 1961, the new headquarters at Bateman Street, Cambridge, were officially opened. One of the principal guests was Sir Alexander Todd, who had been President of the Science Masters' Association in 1956, and who was also present in his official capacity. After the ceremony he was talking to two members of the association, E.H. Coulson and D.G. Chisman, both of whom had been heavily involved in what was going on, and in the course of the conversation they asked, quite unofficially and informally, if there was any prospect that, if approached, the government would give a (substantial) sum to 'do the sort of thing that had been done in the United States'. Sir Alexander, however, thought it 'most unlikely' although any such work would receive a great deal of encouragement. However, he added, as he turned to talk to someone else, why not try the Nuffield Foundation[69]?

The Nuffield Foundation? This possibility had not even occurred to the committee. In the first place their belief that, because of the national importance of scientific and technological manpower, the government would be ready and willing to be involved, had so far prevented them from considering any alternative sources. In the second place, even if they had thought of the Foundation, it would not have appeared to be a likely prospect. Its philanthropy, though considerable, had so far been confined very largely to other social issues, its grants to education had been mainly for psychological and sociological research rather than for curriculum matters, and the sort of sum they were now contemplating was far in excess of any previous grant in the field. Science education had, indeed, benefited from a number of small grants during the past decade and it is possible that, given the contacts already established, an approach might have been mooted at some point. But at that time they had certainly not reached this point. It was purely fortuitous that the person whose advice they asked was also a Trustee of the Foundation, a fact of which they were unaware. What was doubly fortunate was that, unknown to the chemists, the interests of the Foundation's personnel had been moving in the general direction of curriculum reform, especially in French, science and mathematics, and that there was now both the interest and the money available to make possible the necessarily large-scale investment. To appreciate fully the Foundation's crucial role in succeeding events demands a separate discussion.

4

Background to the Nuffield Foundation Science Teaching Project

The Nuffield Foundation

The Foundation as a charitable trust

English education has a long history of philanthropic provision, extending back to the Middle Ages, when first churchmen and later other social groups, notably wealthy merchants, founded or endowed schools in their native towns (usually in connection with chantries, foundations designed to pray for them after death, or gilds, fraternities devoted to honouring particular saints or performing good works). Over succeeding centuries English philanthropy became 'something of a national tradition', so that the failure to settle a substantial charitable trust as a gift on, for instance, an almshouse or a grammar school was a source of shame to prosperous Englishmen. Such philanthropy, whatever its motivating source, was confined mainly to provision of the bricks and mortar of education — grammar or charity school endowments — and it enormously enlarged this country's educational resources, playing a part in changing the pattern of education in England. Later, money was given to the establishment of public libraries in large towns such as Norwich and Bristol. The twentieth century saw a new development, the large charitable trust, whose trust deed allowed it considerable freedom in its giving. These appeared first in America, in the early years of the century, with the Ford, Carnegie and Rockefeller Foundations, and it was wealthy Americans who established the first such trusts in Britain — the Carnegie United Kingdom Trust and the Pilgrim Trust. The first to be based upon individual British wealth was the Nuffield Foundation, set up in 1943, and this was followed after the war by a number of others, amongst which the Calouste Gulbenkian Foundation and the Wellcome Foundation have relevance for this study.

The Nuffield Foundation was the last of a series of public gifts made by Lord Nuffield, who believed that the use for social ends of fortunes made from private enterprise both validated private business activity and made for better human relationships. By 1943 he had already given some £15m. to public causes, £4m. of it to Oxford and other universities, but all such trust funds were allocated to specific beneficiaries, whereas the new Foundation, with its initial endowment of £10m., had very wide terms of reference and thus very considerable freedom[1]. The original aims set out in 1943 were:

1 The advancement of health and relief of sickness.
2 The promotion of social well-being (especially that likely to have its roots in scientific research).
3 Support for the aged and poor.
4 The support of charitable purposes.

The last, most open-ended aim has allowed for considerable flexibility in succeeding years and has also made possible a steady move in new directions as, in a welfare state, government has gradually taken over many of the responsibilities for medical and scientific research that Nuffield pioneered. In many cases the Foundation's launching of a project appears to have prodded public authorities into action, so that government or other takeover of a scheme can be regarded as vindication of their policy. Major changes of orientation are outlined in quinquennial reports, which describe needs now being met elsewhere and indicate new needs and proposals for meeting them for the consideration of the Trustees.

During his lifetime Trustees were chosen by Nuffield himself, and the Foundation has been fortunate in experiencing a considerable degree of continuity both here and in its senior official[2]. The first Secretary, and subsequently Director for twenty-one years, was Dr Leslie Farrer-Brown, CBE, who was to play a major role in the establishment of the Science Teaching

Project and in its operation during the crucial early years.

From the start, Nuffield policy has been consciously one of 'prudent pioneering' and 'considered risk-taking'[3]. If Trustees, aided by the opinions of their contacts in the wide and often very high-powered communication network that exists between government, intellectual and financial expertise and charitable trusts in and around London, judge a man or group 'competent' and his ideas 'good', they will be prepared to give him the money for getting his project off the ground. Further, they consider that they have a mission to 'seek out', if necessary, the 'unique project and try out the unique man' and to fund ventures 'about whose success there may be some measure of doubt'[4]. Once established, a project can expect to have to find long-term support elsewhere. So renewals are unlikely, and the Foundation's function is seen as pump-priming, both in relation to the fields supported and in relation to individual projects.

From the point of view of curriculum reform in schools — in other subjects as well as in the sciences — 1950 was an important date: it was the year in which education was added to the specified areas included in the Foundation's aims. At first, support was mainly in the form of 'spot grants' for 'sharpening the tools of education'. This included the support of a number of general surveys relating to university, technical and adult education (but not to schools) and some sociological and psychological studies during the 1950s. There was also support for a few teaching and curriculum studies, but on a very much smaller scale. For instance, the Leeds and East Ham experiments in teaching French to eleven year olds were set up in 1959. Small grants also went towards various attempts to improve the quality of science teachers and teaching[5].

The Foundation becomes involved in innovation in education

Over the years the contacts of Foundation personnel with scientists and science teachers had grown, and along with it there had been a quickening of interest in education, especially in the fields of primary school French and school science. At this time two ideas in particular were firing Farrer-Brown's imagination. He had long believed in the value of experiment as a method of advance, even in social and political matters, and during a lengthy and highly theoretical discussion about motivating eleven year olds during French lessons it had occurred to him that a telling experiment with real children and good teachers might be a more appropriate approach — and a more convincing one.

The second idea arose out of discussions with John Lewis, physics master at Malvern College and a key figure in the Science Masters' Association work on new physics syllabuses. Lewis had recently visited Germany and the Soviet Union to look at the teaching of physics, and Farrer-Brown had read his report on his impressions. Lewis told him that although he had gone into many Soviet schools unannounced he had never heard a bad lesson, even though he saw many teachers whom he would not rate as particularly expert. The key, to him, seemed to lie in the masses of centrally produced materials which Russian teachers were obliged to use. There was little doubt, he believed, that providing good materials for classroom use benefited pupils overall. Such central direction was clearly out of the question in Britain, but Farrer-Brown thought that if really good materials could be produced here, teachers, good and indifferent, might be persuaded to view and to use them as a set of valuable resources[6].

It is quite clear that the possibility of innovation based on these two ideas was germinating at Nuffield Lodge throughout 1961, well before any approach came from the Science Masters' Association. In accordance with a long tradition of consultation with appropriate Ministries about matters of major importance in which they might become interested, a private and informal discussion of the problems of science teaching was held over dinner at Nuffield Lodge in July 1961[7]. Beforehand, a note from the Ministry of Education stressed the importance of providing a course in science which would be a general education for both future scientists and non-scientists, as well as a base for further studies in science[8]. To personnel at Nuffield Lodge it now seemed that here was an opportunity to do something about an important issue with far-reaching implications, and in an area where the appropriate authorities seemed to be showing little, if any, concern. Such a venture would necessarily involve the cooperation and collaboration of a number of interested parties, some of them with vested interest in science education, and the Foundation's neutral position could be particularly useful here, bringing together on neutral ground varied and sometimes conflicting interests in an atmosphere likely to encourage the free exchange of ideas. This factor was actually pointed out in the Sixteenth Report, published in 1961[9]. That it was not mere rationalization of their wish to involve themselves with school

science is indicated by the fact that they had served as intermediaries in this way some years previously, between the Agricultural Advisory Service of the Ministry of Agriculture and other interested groups. In any case, they had a great deal of extra money available, they had a fair degree of confidence that they were on to something that mattered and they thought that they knew how to go about it[10]. It was at this point that contact was made with the Science Masters' Association.

After the Cambridge ceremony (p.78) the Science and Education Subcommittee's chairman had consulted Todd, and had then been to Nuffield Lodge to talk to Farrer-Brown, who asked him to provide a detailed statement of current needs and of the association's proposals for meeting them. These were accordingly drafted and discussed by the General Committees of the Science Masters' Association and the Association of Women Science Teachers. The revised draft was shown to Farrer-Brown, and the proposal finally went forward to the Nuffield Trustees' meeting on 8 December 1961. Although the science teachers' associations had envisaged that they would control and operate the work, it was already clear to them that they were unlikely to be asked to do so if the scheme went through. Nevertheless, they still hoped to be represented on the 'steering committee' which they had proposed, and to have at least some of their members involved in the development work[11].

In the meantime, officials at Nuffield Lodge were holding talks with Professor Nevill Mott of the Royal Society and Norman Clarke of the Institute of Physics, representatives of a newly formed national committee for physics education, set up by the two bodies and industry, primarily to consider sixth form physics and its integration with university work[12]. Soon afterwards, talks started with the Education Officer of the Royal Institute of Chemistry, D.G. Chisman, with a view to creating a similar national committee for chemistry, and this was followed in 1962 by a counterpart in biology.

It was becoming clear that the various efforts towards improving science education needed coordinating. A national institute of research had been mooted in various quarters (including the Science Masters' Association) and this possibility was considered, along with other ideas, but it was finally put aside as plans began to take shape. The ideas underlying these plans were outlined in two papers prepared by Farrer-Brown for the Trustees' meeting in December 1961, and put forward alongside the science teachers' association's proposal.

The first paper, outlining policy for the coming quinquennium, proposed that research and experiment in education should now become a major focus of attention. The figures showing current expenditure and output in educational research in Britain make interesting reading, for they were extremely meagre, and the paper stressed the great need for more work, more trained researchers and greater coordination of the very limited human and financial resources[13]. When Trustees discussed the proposals, one suggested that it might be politic to see, first, what had come out of educational projects already supported by the Foundation, whilst another proposed that a possible course might be the coordination and financing of the current 'ineffective and dispersed efforts towards educational reform', especially that relating to science teaching[14].

The second paper, entitled 'The Teaching of Science and Mathematics', quoted the Crowther Committee's view that the need to give the majority of children some insight into scientific thought was one of the most important tasks confronting the schools, and listed a number of 'assumptions' underlying the proposal that the Foundation should engage itself in the advancement of science teaching. These 'assumptions' represent, in effect, the first formulation of basic policy for the Nuffield Foundation Science Teaching Project, and they are very closely and clearly related to the science teachers' associations' proposals. The Foundation, it was proposed, should invest a large sum — 'up to £250,000 would not seem excessive for a project of such urgency and importance' — in the advancement of science teaching. Because of the scale of the investment the Foundation should be an 'equal partner' in the planning and operation of the exercise as a whole and not merely a grant-giving body. The strategy should be comprehensive and aimed, eventually, at every science subject at school level, but with a coherent overall pattern and coordinated objectives. Tactics, on the other hand, should be opportunist. Whilst reforms at all levels were equally pressing, work should concentrate in the first instance on certain key areas, namely, O level courses in physics, chemistry and biology, which should then form the core of the Project. Here the syllabuses already devised by the science teachers' associations — 'which are generally agreed to be satisfactory' — should form the basis of the attack, with the 'spearhead of the campaign' at O level physics, where most work had already been done, and where the national education committee had already been established. Chemistry and biology

should meanwhile be actively softened-up for attack'.

Since it might be regarded as important to inculcate a satisfactory attitude and approach in the earliest years, science in primary schools should also be given particular attention. Less pressing, but no less important needs included the provision of suitable science courses for arts sixth formers, better integration of A level with first year university work, a measure of inservice training for science teachers, a 'dramatic improvement in methods of teacher training' and a continuing review of curricula and of methods of presentation to avoid periodical recurrence of the current situation. (It is, perhaps, a reflection of the general climate that no mention of science for 'less able' secondary school pupils was made until April 1962, when it appears in the press release accompanying the public announcement of the project.) In a situation of 'acute shortage of suitably trained teachers and scant opportunities for refresher courses', proposals recommended very full documentation, and thus the provision of teachers' handbooks, laboratory manuals, textbooks, demonstration equipment and visual aids. This was essential, it was argued, if courses were to be widely adopted. Finally, the situation in mathematics was, perhaps, even more critical and, since 'successful teaching of the exact sciences is heavily dependent on an understanding of mathematics, the teaching of mathematics should be regarded as an integral part of the whole project'[15].

After discussing the papers before them the Trustees agreed that they themselves should go ahead with plans for a development project in science, after further consultations had been held with interested parties, especially the Ministry of Education [16]. Clearly, this decision meant turning down the proposal from the science teachers' associations, although the outcome was very largely an incorporation of their scheme into a far more wide-ranging, ambitious and costly venture. Nevertheless, it also meant that there was now no obligation to use all or, indeed, any members of the science teachers' associations in the project teams, or even to follow their syllabuses. There was, quite naturally, some disappointment over this and some science teachers saw it — and still do — as a sell-out by their associations or a ruthless take-over by the Foundation, or both. Others, however, recognized that the exercise now being planned made compromise inevitable, and some even came to appreciate that there was some merit at least in the associations' being able to maintain an independent, and so more objective, official position[17].

The establishment and rationale of the Nuffield Foundation Science Teaching Project

The following month was one of considerable activity, starting with a meeting with representatives of the Ministry of Education at which the Foundation's plans were discussed. Ministry officials wished to remain non-committal at this stage, pending consultation with their own advisers, but sufficient approval was expressed to make feasible more detailed planning of the organizational structure of the Project, and its discussion at the next Trustees' meeting in January 1962[18].

The original proposal had suggested that direction of each project team should be carried out, full-time, by an eminent scientist or, failing that, by a small consultative committee consisting of at least two school and two university teachers, the development work itself being in the hands of teams of seconded teacher-fellows. By January 1962, however, the desirability of appointing an Organizer with an interest in both science and science education had become clear, possibly because of the qualifications of the, by then, probable physics Organizer, Donald McGill, of the Scottish Education Department. The Consultative Committee was now seen as an advisory body composed of scientists, teachers from different types of institution (as appropriate), and representatives of relevant professional bodies. No attempt could be made to represent all possible interests on the committee, however, since this would make it impossibly large. It was crucially important to have a chairman who was a scientist of high standing, with a name that would carry wide respect. Expert help of other sorts, for example in psychology and in examination techniques, could be recruited individually as needs became clear. Subsequently, normal procedure was for Nuffield personnel to choose a chairman in consultation with the education committee in the subject concerned, the Ministry of Education and professional institutions. Then this chairman, in consultation with the Organizer, invited other members to join him, drawing them from tertiary educational establishments as well as from schools, from professional institutions and from the Ministry.

The roles of team and Consultative Committee were therefore quite distinct. The team was responsible for classroom proposals and teaching materials, the Consultative Committee for debating matters of policy and for supplying expert advice on the handling of modern scientific ideas or on children's learning, for

legitimation in the eyes of the professions, and for affording liaison with the universities. This last function was particularly important with O and A level courses, since university selection in the United Kingdom is heavily dependent upon success in public examinations. Again, the chairman was the key figure in ensuring cooperative interaction and in smoothing paths, for sharp differences of opinion are inevitable in so controversial an area as education, and clashes were bound to occur.

The Organizer was to be appointed to the Foundation staff for two to three years, and criteria for the choice were deliberately left open to ensure flexibility in the future. in accordance with the policy of the 'man for the job'. The Organizer was to direct and to bear responsibility for the project. The first task after appointment would be to draw up a timetable of operations and a provisional budget, and then names would have to be suggested for team membership. Once these had been approved, arrangements with their schools would be necessary on the matter of secondment. Close liaison between projects would be vitally important, and it would be the responsibility of the Organizers to ensure it.

Teams would be located in London, but, however desirable their location at Nuffield Lodge might be, there was simply not the space, and headquarters accommodation would have to be elsewhere. American projects had been organized on a centralized, if rather different basis, and the science teachers' proposals, too, had recommended it. Sound reasons lay behind this, such as the opportunity it would afford for the development and maintenance of group climate, for group debate and decision making, for the discussion of matters of common concern between projects to ensure that resources formed a coherent and unified whole, and to facilitate contact with experts of various sorts and examining bodies. In the event, however, there were considerable differences between projects in the degree of centralization and the degree of secondment, as well as in team size. It was frequently, but not always, a matter of deliberate policy on the part of the Organizer that his teacher-fellows should continue to teach, at least part-time, so as to remain in direct contact with the client population. Again, an Organizer who took direct editorial responsibility could impose unity on a heterogeneous assemblage of manuscripts at the end of the exercise, thus obviating the need for continued contact. Both approaches were used — centralized and decentralized teams, full-time and part-time team membership — choice reflecting the

Organizer's assessment of the relative value of each approach.

By the end of January 1962, officials at the Ministry were prepared to offer comment and criticism, and on 25 January Farrer-Brown met a group of them, along with the Deputy Secretary to the Minister of Education, T.R. Weaver, at the Ministry. There was a strong feeling among the HMIs that initial emphasis should be placed on A level courses, and so discussion was lively. In the end, however, it was agreed that a first move on O level courses was likely to be the most practicable and effective step[19].

Over the next few months the search for, and appointment of, Consultative Committee chairmen and Organizers continued. At the same time numerous discussions were being held with university scientists, with professional institutions, with industry and with the Ministry of Education and the science teachers' associations, while all were kept informed, informally, of the trend of thought at Nuffield Lodge. All were also notified officially before the public announcement on 4 April which took the form, as we have seen, of an answer to a parliamentary question in the House of Commons, and a simultaneous press release.

The statements contained in the press release (see Chapter 1) raise a number of questions which the preceding pages have sought to answer, and which fall into three main areas. In the first place, there are those that relate to the fact that it was a charitable trust, and not the government, which was prepared to fund the venture and that, because of the size of the sum involved, and because of personal interest at Nuffield Lodge, Trust personnel were in overall control of the work.

The second group of questions aroused relates to the choice of O level and of separate subjects for abler pupils in selective schools or streams. A great deal of work and thought had already gone into the framing of syllabuses in the three sciences by the science teachers' subject panels, and the work was now ripe for full-scale development. However, Dr Farrer-Brown insists that the main reason was that they wanted to 'sell' this method of going about reform, and that in using an experimental approach they were entitled to go in at the point at which most could be made of it. Then the rest could follow. Had they gone in at A level (as the Ministry wanted) they would not have tackled what seemed to them to be very important, namely, giving the intelligent child who was not going to be a science specialist an awareness of, and a familiarity with, the habits of thought of the scientist, which would help to bridge the 'two cultures' gap. The choice of O level as starting point was made on the basis of that value judgement. They accepted the division into the three sciences from the start because they were unsure whether a worthwhile general science course could be developed. Nevertheless, they knew that the work could not be done in isolation; that they would have to carry on with it, extending it forwards to A level and backwards into the primary school[20].

The third major group of questions centres round the 'for teachers, by teachers' ethos. In a system which favours the idea of teacher autonomy, centrally produced curriculum 'packages' are clearly out of the question. Any set of materials produced must be unambiguously intended as a set of resources (along with, at most, suggestions for their use) from which the teacher can draw as a matter of considered choice, and which can also provide a starting point for the teacher's own innovation. 'We never contemplated that these should be tablets from high heaven', Farrer-Brown insists. The materials were merely a starting point, and they believed that the various schemes and assemblages of materials would be changing all the time. Ready availability and high quality of materials would enable the indifferent teacher to work easily with them, while at the same time the good individualist could use them, adapt them and even effect improvements over time. If the resources were designed only for the inadequate teacher, they would, he believes, have lost their potential for future improvement, because good teachers would not have been interested in them. What they wanted was that they should be tempting to both[21].

The set of resource materials being offered by a curriculum development project embodies change in content and/or approach in the eyes of clients as well as developers — and the two views are not necessarily congruent. In a decentralized system teachers can, on the whole, exercise choice in the matter of resources such as textbooks, visual aids and laboratory guides. (The degree of expertise brought to this area of teacher decision making must vary enormously with background and experience and would repay detailed study[22], as would a study of the extent to which habit and/or authority and/or status figures function in influencing choice.) Whatever the bases of teacher decision making on the matter of uptake, it seems clear that they will include considerations of both the 'quality' of the resource materials (however that quality is judged), and the 'legitimacy' of the authors. Further, the development teams' main sources of 'legitimation' — expertise, practical experience, authority, prestige — as well as of influence, including charismatic influence, are very important in determining the extent to which change is possible. So, too, are those of the various satellite committees and of other bodies involved.

Clearly, the higher the calibre of the team and the greater their range of knowledge and expertise, the better the quality of the end product. But the range of requisite and relevant knowledge and experience is enormous, extending far beyond knowledge of, say, chemistry, and of educational theory and practice to include such areas as the psychology and sociology of communication and of change, and an understanding of the educational system and of the constraints and facilitators likely to influence the success of the programme. How can such a range of expertise be incorporated in a team of manageable and efficient size? Even if it were feasible to regard decision making in so complex an area as an intellectual problem in which possible ends can be identified and related to means in a coordinated scheme — and this is questionable — is it practicable in relation to the cost in terms of time, energy and human and other resources? Further, at this early stage in the development of educational theory, too single-minded a theoretical approach is, as Schwab has pointed out, probably dangerous[23]. To add to the complexity, development work of this kind was a relatively new type of activity in 1962, with many unknowns and, clearly, it demanded a range of personal and intellectual capabilities in those concerned. Inevitably, the approach would have to be eclectic and its pragmatic recourse to action research would, it was hoped, help to consolidate, to ameliorate and to justify the decisions taken. The solution adopted was to have the development work carried out 'for teachers by teachers', with expert help from the Consultative Committee and from individuals brought in for specific purposes. There seems little doubt that this helped to make the projects 'legitimate' and acceptable in the eyes of teachers. The statements of teachers who have had considerable experience in classroom and laboratory with pupils of the relevant age and ability range, who have worked with other teachers and whose standing among their colleagues is high, will carry considerably more credibility with other members of the teaching profession (and possibly also with other groups) than those emanating from those who, however knowledgeable and well-regarded, have not had such practical experience. An experienced teacher's argument that something *is* teachable, that pupils can understand more sophisticated concepts than has

previously been considered possible, and his account of the methods he has used, together with related problems and successes, is more likely to be accepted.

> What we were doing was giving them a chance to recall systematically how they went about teaching science ... and that was the best guide one could get. That was the basic idea, and it was deliberately chosen.[24]

Farrer-Brown believes that one of the most important features of the Nuffield Project was that it brought distinguished practitioners together, and helped them to think and to collaborate unhindered by other demands, and without inhibitions.

The model for development, then, was 'action research'. The new approach, defined and exemplified in draft materials by the central team, would be tested in schools, following careful briefing of teachers to ensure understanding of the underlying ethos. Feedback from trials could then be used to modify, replace and generally improve the materials before publication. Trials would also make possible the use of materials in a variety of classrooms with teachers of varying degrees of experience and expertise, and so provide information as to the overall feasibility of the materials as a set of resources 'on offer' to teachers. They would also mean that a large number of teachers other than team members would be involved from a very early stage. This would be likely to aid dissemination and diffusion.

Effective achievement of the Organizer's objectives depended very much upon his style of leadership and upon its congruence with the perceptions of the team. Since the choice of team was left to the Organizer the likelihood of such congruence was reasonably good. Though he bore the ultimate responsibility for all decisions, he had, of necessity, to delegate some work and thus some measure of responsibility. As Whyte has noted, the problem of allocation of authority and responsibility is 'not one of eliminating authority, it is a problem of weaving authority and participation effectively together'[25]. Again, differences between teams were clearly related to personality, some Organizers operating on a principle that involved a considerable devolution of authority, overall coherence being obtained by initial discussion of perspectives and intentions; others organized a sort of commando exercise, where the leader remained in clear command throughout, making all decisions and ensuring overall coherence at the end of the exercise by editing all materials.

Several American studies[26] have indicated a very close correlation between, on the one hand, the effective achievement of a desired end product, the maintenance of group 'climate', and the efficiency with which the group works and, on the other, two particular dimensions of leadership, which are described in terms of observed behaviour (what the leader *does*), rather than any posited personality traits (*why* he has done it). The first dimension concerns the extent to which he defines the relationship between himself and the rest of the group, establishes clear patterns of organization and of communication and methods of procedure. The second dimension involves the evidencing of friendly behaviour, intimations of personal worth and the creation of an atmosphere of mutual trust. An effective leader scores high on both dimensions. Clearly, this still leaves room for the existence of other dimensions such as authoritarian or non-authoritarian patterns of management, which do not appear to be significant for group maintenance, efficiency and effectiveness. It is very interesting to note that, in spite of considerable differences in 'style' between Organizers, their leadership was on the whole effective; this was helped, no doubt, by the fact that each probably chose team members who would fit in with his preferred style of leadership, and by the sense of involvement and commitment so characteristic of team membership[27]. The procedures that made this possible would therefore seem to have been justified. Allowing Organizers to choose their own teams ensured cooperation, individual satisfaction and efficiency, for it enabled each to go about things according to his own personality and philosophy, since the same assumptions were operating, however unconsciously, at both levels.

Mention has often been made of the value of complementarity of function of the Organizer and his immediate deputy although, clearly, there must have been an initial consensus on aims and procedures. Provided that a project's proposals are feasible, linking a man of ideas with a sensitive, but essentially practical, deputy may be crucial to success. The Nuffield teams, Farrer-Brown recalls, had both the right Organizers and the 'right number two people'[28].

Through their association as coordinated parts of the Nuffield Project, individual projects enjoyed a unity and an interrelatedness that derived from common aim, spirit and basic attitudes. Within this unity, however, each developed its own particular colouring. The brief from the Foundation was deliberately vague, stating only that the outcome was to be a coordinated set

of materials, to be used by individual teachers in any way they wished. These materials were to help teachers to offer O level candidates 'some insight into scientific thought and method', and they were to be designed to be equally suitable for future science specialists and for those who might later specialize in other subjects. From this brief, the Organizer had to identify, with or without the help of his team (as he chose), the framework upon which development was to be based. His interpretation of the task, that is, his conception of the problems involved and of what might constitute 'success' in their solution, would determine overall approach and content and, within them, relative emphases. In an area such as curriculum development the identification of every problem — let alone its solution — is impossible; so, in effect the Organizer had to select those aspects of the task that he identified as the problems to be solved and, among these, those that he believed *could* be solved. These became his basic decision points, or 'choice-points'[29] and they related to philosophical, psychological, sociological and pedagogical issues such as theories of learning or views of the nature of science and of scientific activity, whether these were implicitly or explicitly held. Each choice point might, moreover, contain a set of alternatives, each of which could have different curricular consequences. For example, adoption of a particular view of the nature of science would affect the role allotted to experiment in any course seeking to give pupils experience of the 'science of the scientist'[30]. Similarly, adherence to a particular theory of learning (such as Gagné's, for instance) would determine content structuring and affect teaching method[31]. Choices, whether conscious or not, reflected not only the Organizer's range of actual knowledge about educational research and theory (and to some extent, that of his team), but also his and their own experience, predilections and personal value systems, as well as the *Zeitgeist*.

It is not surprising, then, that the whole philosophy of each project, the way it developed and the kind of people who worked for it have reflected, to a quite remarkable degree, the personality of the Organizer. Nor is it surprising that, over and above a commitment to a discipline-orientated inquiry approach to school science, there is no such thing as 'the Nuffield approach', but that there are as many varieties of Nuffield approach as there are Nuffield projects. At the same time, while the Organizer has often been the key to success of a project, all those involved in and with a team — Consultative Committee and personnel from the funding organization as well as from other major bodies — have a considerable effect, for good or bad, on the outcome, because of the personal contribution that each brings to the exercise, because of their importance as a source of legitimation, credibility and influence, and by the quality of their interaction. On such personal and group qualities depended the maintenance of commitment and enthusiasm, the cooperation and the cut-and-thrust so vital to the whole undertaking.

Recruitment and team structure

By February 1962 negotiations between the Royal Society and the Royal Institute of Chemistry over the formation of the proposed national committee for education in chemistry (the British Committee on Chemical Education) were well in hand, and so Trustees at Nuffield Lodge agreed that as soon as it was established the chemistry section could be set going on roughly the same basis of collaboration with the Royal Institute of Chemistry and the science teachers' associations as had been possible in the case of physics[32]. On the recommendation of D.G. Chisman, Education Officer of the Royal Institute of Chemistry, Professor R.S. Nyholm, FRS, of University College, London met Dr Farrer-Brown and one of his deputy directors at the end of March. As an eminent chemist and academic, who also had school-teaching experience, Nyholm appeared admirably suited for a key position in the Project. He was, however, quite clear that his commitments made it impossible for him to direct the Project, although he would be very happy to provide help in the form of advice. During the following week he met H.F. Halliwell of the then University College of North Staffordshire at Keele. Immediately afterwards Nyholm wrote to the Foundation saying that a long talk with Halliwell had convinced him that he was 'eminently suitable' — and he gave a number of reasons for this opinion. Accordingly, a letter from the Foundation invited Halliwell to come for a discussion of his views on the proposals for chemistry, without commitment either way[33].

By May, Nyholm had agreed to chair the Consultative Committee, and steps were being taken to secure Halliwell's secondment from Keele as from the following September. This was finalized within a month, and shortly afterwards secondment of the first two members of the Chemistry Team was secured. When the Project started officially on 15 September,

the nucleus of both Consultative Committee (six members) and Headquarters Team (Organizer, two members and a third under negotiation) was established. Shell International had agreed to help with the production of visual material and the Royal Institution had offered laboratory space[34]. Halliwell had also attended a conference organized by the physics section at Caius College, Cambridge, and had visited America, where he had participated in a *Chemical Bond Approach* summer school.

Under the chairmanship of Professor R.S. Nyholm, FRS, the Consultative Committee nucleus included two schoolmasters (one of whom also represented the science teachers' associations), the Education Officer of the Royal Institute of Chemistry and two more university scientists: E.H. Coulson, E.S. Kreis, D.G. Chisman, Dr A.S. Sharpe and Professor A.D. Walsh, FRS, respectively. Subsequently, they were joined by A.C. Cavell (from an independent school), A.J. Mee (Scottish Education Department), Professor J. Lewis and Professor D.J. Millen.

Consultative Committee meetings were held some four or five times a year. At them, detailed proposals from the Headquarters Team were discussed and amended by mutual agreement. However, after nearly four years of working together on the Chemistry Panel, the Team was left to develop its scheme according to its own interpretation of the *Policy Statement*. Throughout development, the roles of Team and Consultative Committee were kept quite distinct. Nyholm's attitude was quite clear on this point. The Team's job was to decide in detail what should be taught, whether it could be taught, and how it should be taught. The Consultative Committee's function was to ensure that what the Team suggested was good chemistry[35].

Like the Consultative Committee, the Team was built up gradually, starting from a nucleus of four members: the Organizer, E.H. Coulson, Dr Gordon Van Praagh and M.J.W. Rogers. Others were added as new needs arose. They were B.J. Stokes, R.W. Tremlett, J.C. Mathews and two men seconded by Shell International to give specialist help, H.P. Oliver and D. Segaller.

The final size was not fixed in advance and the figure of four at the outset represented only a viable preliminary or initiating group. In contrast to the physics and biology sections, where predefined content areas were allocated to individuals or groups, numerical constitution in the chemistry section was determined largely by the types of resource materials planned. The difference reflects the very different orientation of the three teams and differing working methods adopted by the Organizers. It probably also reflects differing attitudes to the overall nature of the range of resources regarded as desirable.

As a matter of deliberate policy — which also proved to be a useful expedient — the chemistry Organizer wanted his Team members to be seconded part-time (more accurately, not entirely full-time), so that each could remain in active, if limited, teaching in his own school, 'so that they didn't forget what it was like to have children in front of them ... and so that they could try out the things we had talked about at Nuffield Lodge'[36]. Secondment was for a year in the first instance, though it was not long before the possibility of a second year was mooted. As a Nuffield Fellow, each was paid his current salary plus an honorarium.

The Organizer himself had twenty-five years' experience as chemistry master and headmaster as well as Chief Examiner, and twelve years of university experience as a lecturer in chemistry and education. Besides an interest in the wider aspects of education he had retained an interest in research, evidenced by publications. The teaching experience of the six schoolmaster members of the Team ranged over maintained grammar schools, technical colleges, a comprehensive school and independent schools. Of the first four, who were responsible for the basic planning that determined the main features of the Project, two were grammar school and two independent school masters, and three of the four had, between them, close on ninety years of school experience and were very well-known figures in the field of school science. The fourth was, intentionally, a younger man. All except one Team member had published material behind them, and of the entire Team, five had produced books on school chemistry. Thus they had a fair amount of writing experience. As schoolmasters, all had been responsible for examination preparation to S level, whilst Coulson had for many years been heavily involved, in various capacities, in the work of examination boards, including that of Chief Examiner in chemistry. Whilst there was no obligation for the Organizer to include members of the science teachers' associations, all four members of the nucleus were, indeed, active members of the Science Masters' Association and all had been on the Chemistry Panel, at least towards the end. A leading member of the Association of Women Science Teachers was invited to join, but she declined, although she gave help in many ways, including writing part of the *Handbook for Teachers*[37].

> A piece of quite important policy on my part was the devolution of authority and responsibility ... But then, that was the way I had been treated by the Foundation.[38]

It began with the very first step, that of selecting the Team. Halliwell recalls: 'I decided that I must have Ernest Coulson, then *we* decided that we would have ... '. From that point on, conscious effort was made to ensure cooperative decision making and devolution of authority and responsibility in all aspects of the Team's work. It extended right through the organizational network of the Project.

> But I didn't want 'Yes' men: I wanted people who believed in the objectives ... But who would always be prepared to say, 'Ah, well, I wouldn't do it like *that*; I would do it like this ... '.[39]

All major matters of policy were discussed and argued over by the Team, starting with debate on the fundamental framework for the Project, set out in Halliwell's four *Memoranda* (see p.117). Discussion with the Team and with advisory bodies such as the Consultative Committee and Ministry of Education was founded on the work of the Chemistry Panel, but here ideas had to be developed and made far more explicit. This wide-ranging discussion was clearly extremely valuable for raising new ideas, for providing special insights or experience and for clarification. But decisions eventually had to be made. The Organizer defined the overall pattern he had in mind for the Project, and from that point most decisions evolved naturally from group discussion. Where consensus was not entire, or agreement or compromise could not be reached, he had to make — and did make — the decision. Nevertheless, in interviews with Team members, it became obvious to me that on most occasions all their views had been given fair consideration. Whyte views this type of behaviour as evidence of skilful leadership — the avoidance of discussions that will needlessly antagonize the team, the careful weighing of ideas and advice[40]. Maintenance of a friendly, cooperative and involved climate ensures acceptance of the leader's ultimate authority. Speaking of the group discussions, the Organizer recalls,

> Don't imagine that we just sat around, churning the stuff out. There was a great deal of argument (sometimes heated argument) about the proposals — for example about the

introduction of conductivity and electrolysis very early on, even before ions — before many areas were decided on.[41]

And a Team member recalled, quite independently,

> ... *great battles* — but not unfriendly — were fought over whether you could teach the sort of thing suggested at a particular level, or what the approach to a topic should be ... To people outside, we seemed to be getting nowhere in those first months ... but, in fact, we'd been getting all this arguing and talking about things done, and this unified the group and made for greater speed when things got going.[42]

All this preliminary debate meant a fully argued basic framework on which all subsequent work was built, giving the materials a fundamental unity. Yet each different resource had a different editor and authors for, once the basic pattern of production of items emerged, responsibility for one was given to each individual Team member. Provided that they worked within this agreed framework, Team members were free to develop materials as they saw fit. If Halliwell did not agree with what was written, he would say so, but it was the Team member concerned who made the final decision. Team members have been unreservedly unanimous in agreeing that their contribution was indeed a personal one, within the basic framework of the *Memoranda*, and that the final publications reflect their individual contributions within an overall unity.

Chosen because of their perceived professional competence for the task in hand, the Team nucleus consisted of members of the Chemistry Panel, and so the Organizer knew a good deal, from the outset, about their attitudes and beliefs, about the sorts of decision that would be acceptable to them and those that would not (even though they might give them formal assent). He sought consensus only in terms of the *Policy Statement*, of the Project's ultimate aims, and of his interpretation of these in very broad terms (that is, that which subsequently went into the *Memoranda*, and even these were debated by the Team). In fact, he appears positively to have sought out and encouraged individuality of approach, a factor which is of considerable significance in ensuring that controversial issues will be thoroughly thrashed out in a non-threatening climate. In an authoritarian climate such a team approach would be quite unworkable.

The non-authoritarian and essentially cooperative climate

emerges very clearly in consideration of the Organizer as group leader. In an ambiguous and uncertain situation, the Organizer's ability to create and sustain a climate in which 'mistakes or tentative thrusts do not result in loss of esteem or status', and in which it is safe to try out new ideas, as well as to admit that they have been mistaken, is of crucial importance[43]. It is worth considering, then, how far Halliwell's particular structure of responsibility was the cause, and how far it related to personality factors.

A powerful recollection of excitement, involvement and total commitment in a unified group is characteristic of all Chemistry Team members, without exception. Spontaneous comments kept cropping up in the course of interviews (which were actually intended primarily to establish historical facts where records were incomplete). The Organizer's support for his group's efforts were mentioned again and again. All Team members stressed the feeling of support for their efforts, with comments like: 'There is no doubt about it at all. I would have folded up *many* times without it.' Again, 'he was totally approachable at any time', and Team members felt that they knew exactly where they stood. In a small group, with strong commitment and yet some basic differences of viewpoint, conflict was bound to arise, yet anyone whose ideas had been shown by group discussion to be inadequate or impracticable was offered reassurance and encouragement immediately after the meeting. Asked what aspect of their Organizer's leadership enabled them to work most effectively, answers were remarkably uniform. Team members commented, especially, upon his enthusiasm, the intellectual stimulus he provided, the responsibility he accorded to them, the way he united the group, and his personal qualities. There seems little doubt that the climate created by Halliwell for his particular Team was particularly conducive to the maintenance of the group and to the overall achievement of the specific goals of the Project as far as these were realizable. His behaviour kept interpersonal relations pleasant, arbitrated disputes, encouraged, stimulated self-direction, gave minority opinions a hearing and increased interdependence among members of the group — all factors operating in favour of cooperation, individual satisfaction and efficiency. Much of it was probably not even conscious, for it reflected, very clearly, his personality and his philosophy. It is borne out, too, by letters to the Nuffield Foundation from Project personnel in America after his visits.

In the interviews it was difficult to evoke criticism. After this lapse of time, one would expect only those reactions with greatest emotional content to survive, and therefore to hear the best and the worst aspects of the experience. All Team members had been aware of tensions either in relation to the work they were undertaking, or between themselves and others concerned, but all felt that Halliwell had done much to reduce these, rather than ignoring or exacerbating them. When criticism did appear, it was confined to detail. One Team member, for instance, was not seconded at all, continuing with his teaching at some distance from London, and he felt his isolation keenly, probably because he was in a particularly exposed and vulnerable position. Nevertheless, he added immediately, both Organizer and Deputy Organizer had given him considerable support and encouragement so far as this was possible at a distance. His other comment is interesting, because it appeared again and again, but always with the same qualification about the 'extraordinary complementarity' of Organizer and deputy Organizer: '... a great ideas man, with a tremendous capacity to fire the imagination, but a great reluctance to put pen to paper ... but complemented by the calm, utterly dependable, practical man behind him'[44].

5

Nuffield chemistry: establishing the framework

Background to Nuffield O level chemistry

The framework for the entire O level Project was formulated between mid-September and early December 1962. Decision making never starts from scratch: it starts from ideas of 'what is' and of 'what might be', both of which incorporate all manner of facts, beliefs, opinions, assumptions, value judgements and attitudes, themselves the products of experiences and of individual personalities. This is not the place for a discussion of the phenomenological complexities involved, but it is necessary to remember that each participant in the complex web of negotiation that lay behind all decisions came to discussions with his own 'acquired habitual modes of understanding', with his own 'store of previously evolved meanings, or at least of experiences from which meanings may be educed'[1] — and that these were different in every case. In the case of the Chemistry Project decision making was to a very considerable extent a group affair, and all major matters of policy were discussed and argued over by the Team. There was much debate with advisory bodies and individuals, too.

Nevertheless, though deliberately starting afresh, the pattern of work in the Project was not suddenly thought up:

> ... it was a continuation of the work of the SMA Chemistry Panel and the outcome of more than a quarter of a century of professional exploration and thinking by many teachers.[2]

In order to understand the evolution of thought underlying the Chemistry Project, then, it is necessary first to explore two fundamental elements in this background: the work of the science teachers' associations' Chemistry Panel, and the pre-Project events and influences which constituted Halliwell's own starting point.

The work of the Chemistry Panel of the science teachers' associations

The Panel was one of four set up in late 1957, soon after the publication of the Science Masters' Association's *Policy Statement*, and it held its first meeting on Saturday, 25 January 1958[3]. Before the meeting the chairman sent out to members a document giving the terms of reference, and notes to serve as the basis for discussing policy. The terms of reference were:

> ... to examine all aspects of the teaching of chemistry in schools of the grammar school type in the light of the recent Policy Report ... to consider mainly the content of teaching syllabuses ... [4]

Because it was so fundamental, many of the decisions taken at that first meeting underlie everything that followed, up to and including the work of the Nuffield Chemistry Project, so it is worth including the agreed tenets relating to O level work in full:

1. 'We should attempt at first to rid our minds of preconceived ideas arising from what is done in schools at present (which may possibly be survivors of worn-out traditions) and consider afresh what ought to be done in teaching chemistry, (a) to equip the future citizen entering on an era of nuclear power, and (b) to equip the future scientist.'
2. The principal justification for teaching chemistry was seen as: (a) its contribution to general culture, 'representing as it does the study of the composition and interaction of the matter of the universe', (b) its uniqueness as an 'exemplar of inductive logic', and (c) the 'understanding chemistry affords of many substances of everyday importance and of many industrial processes of great social significance'. Any syllabus should therefore include all three aspects.

3. The O level course should be complete in itself since, for many pupils, it represented all the chemistry they would ever study. Further, the teaching of chemical theory would need a complete reappraisal. The complete, logical and experimental development of nineteenth-century theory via Dalton, Avogadro, Cannizzaro, etc. was now of mainly historical interest and it was too difficult and too lengthy an argument to present in the course if pupils were to be equipped with concepts more relevant to the twentieth century.
4. Whatever theoretical structure was finally agreed for the O level course, it should, as far as possible, arise from experiments performed by pupils or teachers.
5. The choice of factual content should be determined by its relevance for the development of theory, and the extent to which it incorporated substances or processes of everyday or industrial importance.[5]

Each practical problem, such as social implications, experiments to support theory, and O as against A level syllabuses, was now allocated to an individual, who was to study it and then put his ideas on paper for circulation to the others before the next meeting. Successive drafts followed the same pattern, but were produced by different Team members, so that the final product was very much a joint venture.

The first O level syllabus was produced by E.H. Coulson, who started from two basic questions raised by the premiss that the course should be designed for all pupils, whether or not they were to become specialists. These questions were:

1. What does the 'educated citizen' need to know?
2. How much that is meaningful can be given at this stage?

Consideration of the second question made the Panel aware of two consequences: that what is meaningful must also be examinable (for it was crucial to convince others that the proposals were both desirable *and* practicable); and that to be fully practicable, teaching sequences would have to be considered as well as a syllabus[6].

At the Panel's second meeting a third question was added: if they believed that children should experience 'the science of the scientist', that is, if the course was to have 'scientific method' at its core, should this not be made explicit, instead of being left in the form of nebulous statements[7]?

Coulson now undertook to convert his proposals into a teaching sequence and, at the next meeting, to cast this in two columns, 'sequence' and additional 'explanatory notes'. When the product was discussed at the fourth meeting, there was general agreement on some basic ideas, such as that the first year's work should lay the foundation of experimental skills, should contain no theory, and should be concerned with the 'alchemy of stuffs'. Theory should be introduced only during the second year, by the end of which simple conceptions of the atom as a nucleus with positive charges and associated electrons, should be attainable. Beyond this point agreement became more difficult. After every Panel member had worked on a draft proposal and submitted it for discussion at the next meeting, the second draft was prepared. Two more drafts were added to the list: one dealing with the 'special needs of girls' schools' (which was concerned with staffing, timetabling and laboratory problems, not with girls and science as such), and a second on 'the further development of the treatment of theory in the course'[8].

By the time that these drafts were ready, the Panel was beginning to seek outside comment and criticism as a basis for revision before publication. The O level syllabus draft was first commented upon by a number of grammar school teachers, then by four 'special visitors', who were invited to a Panel meeting, each of them subsequently submitting a resumé of his views[9]. Next, the draft syllabus was circulated to all members of the two associations who had responded to a notice in the *School Science Review*, fifty of whom sent in written comments. The drafts were mulled over again at the Science Masters' Association Annual Meeting in January 1960, and at local meetings of both associations. Next, the Panel's chairman drew up a summary of all comment and criticism for consideration by the group. Most criticism had centred upon the 'excessive length' of the proposed course, and on the content and timing of theory, particularly with regard to atomic structure[10]. These were not new areas of disagreement, the second having proved particularly intractable all along, since much of what was being proposed was both innovatory and highly controversial as material for pupils at this stage, and there were major differences of opinion, even on the numerically small Panel.

It soon became apparent to the Panel that there was another major difficulty ahead: that of getting the appropriate orientation clear to teachers so that 'process' as well as content was built into the course. The problem became apparent very early on, and it was a major factor in producing a steady escalation in the amount of teacher-information deemed necessary. This gradually grew from syllabus, to syllabus with teaching sequence, then to the addition of explanatory notes, then to their extension in proposed appendices, and finally to a plan to publish a greatly expanded Teachers' Handbook as Part II of the exercise. Ultimately, it led to the Nuffield Foundation Science Teaching Project.

In 1960 all sections of the syllabuses (Part I) were discussed and redrafted, more than once, and by different individuals. The final draft of the O level syllabus was considered at the thirteenth meeting of the Panel, almost three years from the start of the venture. Final copy was prepared, circulated to the rest of the Panel for approval and then published along with the corresponding biology and physics syllabuses and the revised *Policy Statement*, in February 1961[11]. Over and above the framework of the report, some of the important issues raised during this pre-publication period have already been mentioned. The return of comment and criticism from teachers had made it clear to the Panel that there were five interrelated areas to which careful and specific consideration would have to be given. These will be dealt with in some detail here because the fact that they had been discussed at length by the Panel meant that the Nuffield Chemistry Team had much ground cleared before it even started.

Curtailing the overloaded syllabus. Although much had been cut out, new material had been introduced. The Chemistry Panel acknowledged the problem this created and agreed that it might be met by introducing 'options' in certain areas[12]. The idea constituted a major part of the strategy developed by the Nuffield Team.

Achieving a meaning, in classroom terms, of the intention that pupils should learn how to be scientific in tackling a problem. The Panel's minutes bear no record of discussion here, but it is possible to trace something of their thinking by comparing the agreed points from the first meeting with the final Part I publication, and by looking at the 1957 and 1961 *Policy Statements* which, too, show subtle differences.

The 1957 *Policy Statement* argued that practical work should be seen by the pupil as a means of solving problems by the use of correct techniques, rather than of verifying previously stated facts. It should lead to the formulation of empirical laws and hypotheses and, eventually, to 'simple ideas of great and far-reaching generalization such as the kinetic and atomic theories'.

By the end of the O level course pupils should perceive, to some extent at least, the importance of distinguishing clearly between (a) observational facts and the generalizations arising from them, and (b) theories, which 'may be no more than convenient fictions'[13]. That this was still a rather limited view seems to be borne out by the statement on the aims of science teaching at the end of the report:

> ... to lead pupils to observe, and to solve problems by controlled experiments, to draw conclusions from observations, and to appreciate the systematic laws and principles of science.[14]

At the same time the statements are very general and could incorporate rather different views of the 'science of the scientist'. The Chemistry Panel stated specifically that chemistry is a 'unique exemplification of inductive logic'. By 1961 this had been altered to 'inductive and deductive reasoning', although the discussion of scientific method further on in the report indicates that more than merely logical processes are involved:

> The process of theory-making involves also creative imagination and the product is no more than a corrigible human creation. Theories must be thought of, not as knowledge, but as tools which in the hands of the scientist enable him to ask of Nature the right questions ... Theories can never be proved ... (they) must be realized to be provisional, good enough for the particular job in hand and subject to modification or even to rejection ... Theories are to be used, not accepted ... their validity should be tested by using them to make predictions to be tested by further experiment. It is in this way that the bounds of knowledge have been extended.[15]

The Science and Education Subcommittee's 1961 revision of the *Policy Statement* also inserted the expression 'disciplined speculation' into its description of scientific investigation and the adjective 'provisional' for theories[16]. Even these descriptions of the science of the scientist were probably clearer to the informed than to the uninformed, however, and the problem still remained of whether many teachers would like — or need — to be shown how to exemplify this in their teaching.

Translating modern conceptions of the atomic theory into a form needed by, and suitable for, school work. Considerable controversy surrounded this area of school work, as the Studley Conference had shown. The question of whether or not atomic theory should be introduced at this level and, if so, how, and how fast, had been a topic for debate for many years — articles had appeared in the *School Science Review* in the early 1940s. There was certainly no unanimity of opinion among members of the Chemistry Panel. Throughout the entire period of syllabus generation and during the revision and final drafting of late 1960, the Panel moved some way towards a solution, but the product was inevitably tentative, partly because of opposition and partly because so much of it was untried at this level. Many teachers, therefore, were bound to express reservations, or even hostility. Certainly, the Secondary School Examinations Council's Science Panel expressed 'much concern' at this period over proposals to include atomic structure in O level syllabuses that were then emanating from a number of examination boards[17].

By the time that the Chemistry Panel's proposals had been submitted to the first outside criticism, the Panel's chairman was suggesting that atomic structure might well be written into the syllabus as an option and that science teachers should be encouraged to experiment with methods of teaching it. Some members of the Panel, including Halliwell, argued strongly for its retention as part of the main syllabus, however, on the grounds that, if a proper understanding of the nature of scientific theories was to be developed then such notions should be introduced, as they provided a satisfactory model to account for many important and familiar phenomena. One Panel member agreed to try to work out a possible teaching sequence and this was then discussed by the Panel. But opinion on its suitability, and on the feasibility of trying to introduce it at this level, remained divided[18]. In the event the section was included in the syllabus with a note expressing the hope that teachers would experiment with various methods of teaching the topic. In the introduction it was pointed out that

> ... the phrase 'structure of the atom' in a syllabus evokes in the mind of readers models of widely different degrees of sophistication. It would therefore be easy for our intentions to be misunderstood and we hasten to claim that we are not offering free rein to the happy theorist.[19]

Inevitably, the problem of its appropriateness before O level, and of its treatment if included, became a focus for discussion and dissension when the Nuffield materials were being developed.

An issue which became particularly acute with the introduction of 'modern concepts' at the pre-O level stage was the need for coordination with the physics course and, in other areas, with the biology course, to ensure that material had the requisite theoretical bases at the time of introduction to pupils, to consolidate understanding and to avoid unnecessary overlap. In the case of physics and chemistry, however, this proved a good deal less easy to achieve in practice, for some of the necessary physical experiments, such as those involving introductory concepts of atom, molecule and electron, together with their extension into discussion of the physical behaviour of gases, simple electrostatics and current electricity, fitted into the physics course only at a later stage. Physicists were, understandably, equally concerned about the logical structuring of their materials. Maximum correlation was desirable if duplication of experiments in the two courses was to be avoided, and if pupils were to achieve coherent and integrated understanding of, for instance, atomic structure. The problem remained somewhat intractable in spite of representation of sectional interests at appropriate Panel meetings, and it was evident that compromise was necessary[20]. Thus the final teaching sequence notes refer to relevant sections in the other syllabuses, leaving questions of 'how' to teachers. The section on atomic structure was annotated as 'requiring a combined operation' with physics teachers, since much of what appeared in the syllabus would no doubt be dealt with in physics lessons[21]. What was abundantly clear was that more practical experience in actual teaching situations was required. The Nuffield Chemistry materials tested one such approach in their trials.

Getting the proposed approach across to teachers. It has already been suggested that the steadily more apparent need to provide amplification and explanation for teachers was ultimately an important factor in the setting up of the Nuffield Science Teaching Project. Early recognition of a need for explicitness both in terms of approach and of sequencing of material, was the first step in an evolutionary process of escalation. Confirmation of their belief that more than a mere syllabus was necessary came with the first feedback on the Panel's tentative proposals of the second draft. The author had circulated this to chemistry teachers in grammar schools, including his own, in his home area. Comments were generally favourable, but it was

clear that 'individual interpretation of the extent and depth of treatment for different parts of the syllabus' varied greatly, and that some method would have to be found of overcoming this. By 1960 it was clear that far more detailed help would be needed by teachers, and the *Science and Education* subcommittee issued the directive to complete and publish the syllabuses as Part I, and to relegate all detailed exposition to a subsequent Part II[22].

The question of teaching sequences in the syllabus remained. To suggest possible sequences was relatively straightforward, although the Report stressed that 'great flexibility of treatment' was still possible and that, in many cases, topics collected under one heading might be developed at various stages of the course[23]. (This was, of course, quite true, but it was also a recognition of the ethos of teachers as arbiters, and a reassurance that the Associations were not trying to dictate matters.) The *Policy Statement*, on which recommendations were based, advocated a topic-based course of Natural Science at the introductory level, preferably taught by one teacher, whose 'ability to teach in an interesting and stimulating manner is more important than his academic competence'[24]. By 1961, however, the *Science and Education* subcommittee was advocating a broad and non-compartmentalized course, with no mention of staffing by one teacher, though they recognized that both the organization of work and its distribution among staff varied from school to school. The stress on a topic approach was also lessened[25]. Under these circumstances provision of a teaching sequence would have been unrealistic, and so the Chemistry Panel decided instead to list the kinds of topic which could be incorporated into an *integrated* course of introductory science. Nevertheless, in advocating six periods per week they were thinking in terms of two periods per week equivalent for chemistry[26] which was, in fact, what many of the larger grammar schools were providing.

In January 1961, shortly before the syllabuses were published and just after the Studley Conference, the Science and Education Subcommittee reallocated some of the work for Part II in each section to a number of new panels. With this reallocation it was hoped that Part II, which could now begin in earnest, might be completed at a proposed long meeting at Barrow Court, near Bristol, in August/September. After discussing what needed to be done to prepare these teachers' guides at their February 1961 meeting, individual members of the now enlarged Chemistry

Panel prepared draft notes on the agreed sections of the guide. These were circulated before the next meeting and covered 'Rates of Reaction', 'The Chemical Industry', 'Examples of Teaching by the Method of Discovery' and 'Class Experiments in Electrolysis and in Organic Chemistry'[27].

Panel members were beginning to find the pressure of work onerous, yet they were extremely anxious that the venture should not falter. In mid-1961 they agreed that a letter should be written to the chairman of the Science and Education Subcommittee, expressing their strong feeling that an approach should be made to the Minister for Science for a 'substantial sum of money to organize a programme of writing and experimentation involving schools, industrialists and university teachers'[28].

The conference at Barrow Court served to underline the problem still further, and immediately afterwards active steps were taken to obtain the necessary funding for full-time working parties. Once these got under way, the Panel considered the desirability of issuing an interim report, but decided that the most useful step would really be to collect and publish details of experiments that could be used with the new syllabus. This exercise was carried out with expert and financial help from British Petroleum. A leaflet was prepared and circulated to all members of the science teachers' associations, asking for details of class or demonstration experiments suitable for use in teaching the new syllabus, for volunteers to try out, and possibly to modify, such experiments, and for suggestions for newly devised (and preferably tested) experiments.

More than 300 replies were received and these were sorted out and dealt with by the Panel. Finally, accounts of appropriate experiments were edited, and these were later published in 1964 as a section of Part II of the *Science and Education Report*[29]. In the meantime, all relevant material was sent on to the Nuffield O level Chemistry Team, who were by then working to build up a comprehensive index of experiments in school chemistry.

The problem of examinations. It was recognized at the outset (1958) that, if teachers were to be convinced, examinations must reflect the aims and objectives of the proposed syllabus[30]. If, for instance, the establishment of general principles was the aim, then questions should be framed to test this. Once the basic principles were determined by the syllabus, an element of choice could be introduced in terms of the detailed factual knowledge used by a teacher to illustrate them[31].

New methods of examining had been around for some time, though not much used by examination boards. The Panel discussed different 'new-type' techniques and then tried to draft, and to answer, questions of different types, suitable for testing the new skills, such as, for instance, 'interpretation' and 'comprehension', and relying less on rote memorization. This task proved far more difficult than they had anticipated[32], however, and the Panel was still wrestling with it two years later in 1961[33]. Though there was general agreement that 'no real estimate' of the nature of their recommendations could be made unless they could also produce appropriate sample questions, their attention was by this time focused on the scheme as a whole. At Barrow Court, questions and mark schemes were prepared, but after brief discussion the Panel agreed that the matter really needed much more time than could be given just then. They did, however, agree that a good examination would test comprehension, memory, the ability to express ideas clearly and without irrelevance and to detect and interpret relationships between facts[34]. *Chemistry for Grammar Schools*, their Part I report, pointed out that their suggestions implied a change of emphasis in the questions set by examination boards. They hoped that boards would experiment with questions that would offer considerably more flexibility to teachers by dealing only with general principles or substance types. Candidates should be able to illustrate their answers by reference to examples chosen to meet their own particular needs. This would, the Panel believed, encourage more honest experimental work and discourage rote memorization of facts. They hoped, too, for questions requiring interpretation or application of data[35].

At Barrow Court, one evening was devoted to a discussion of examinations in physics and chemistry. The principal speaker was Coulson, by that time E.W. Moore's successor as chairman of the Panel. He discussed the problem of examinations as a whole. Most objections to the current system, he claimed, stemmed from the problems produced by an examination which had to cater for a very large number of candidates. Marking had then to be rationalized and this meant that it was impossible to set open-ended questions, or those requiring discussion. Further, the system prevented experiments with teaching methods because it was still the case that examinations dictated both curriculum and approach.

In contrast, he cited the method used for the National Certificate in chemistry, which was based on an internally determined syllabus and internal examinations, externally moderated.

There seemed to him to be little valid argument against introducing such a system into schools. It would certainly give greater flexibility all round. Schools might be grouped as units to help overcome variations in teacher ability and 'keenness'. This would serve, too, to encourage collaboration between schools and teachers. After considerable discussion, most of it very favourable, the meeting decided that this important suggestion should be drafted as a document by a small subcommittee set up for the purpose. It should then be sent to all branches of the associations for consideration and comment. This was done and, to everyone's surprise, local branches rejected it, with only one exception[36]. (This is an interesting reaction from teachers, for the idea was, in fact, strongly in line with the ethos of teacher autonomy and of professional status.) Nevertheless, these ideas were kept in mind, as is clear from some of the proposals put forward by the Nuffield O level chemistry section[37]. They bore fruit, eventually, in A level chemistry, by which time, of course, a system very similar to that proposed by Coulson's subcommittee was being established as Mode III in the Certificate of Secondary Education (although teachers have tended to drag their feet over Mode III CSE, too).

For more than four years this small group of chemistry teachers had been thinking, debating and re-thinking the problems of chemistry education. While this had certainly resulted in a good deal of clarification of ideas, it had also served to highlight the formidable problems involved in curriculum change, even within a single subject. Just how formidable only became apparent with the advent and experience of the Nuffield Foundation Science Teaching Project.

The Nuffield O level Chemistry Project had Halliwell as its Organizer, with a Team drawn, initially, from Chemistry Panel membership. It is pertinent, then, to look briefly at the personal position from which Halliwell approached the Project and which formed the basis — within the context of the Panel's work — for the preliminary discussions that established its framework.

Early foundations for the framework of the O level Chemistry Project

Particularly significant for Halliwell was his experience in Northern Ireland in the 1950s[38]. In contrast to its counterparts in England and Wales, Northern Ireland's Ministry of Education was, through its various departments, responsible for

the different types of school which existed in the public sector, for the syllabuses and types of demand made in public examinations, and for the running of inservice courses in line with all of these aspects. A Bill in 1947 established new Secondary Intermediate schools in Northern Ireland, which corresponded more or less to the secondary modern schools of England and Wales, and in 1948 the Ministry set up inservice courses, under the direction of its inspectorate, to prepare some of its primary teachers for work in the new schools. Among these was an inservice course in General Science and, closely coordinated with it, another in Rural Science.

In 1949 the Inspector in charge of science inservice courses was R.J. Doolan. Before the war Doolan had been biologist in the school science department of which Halliwell had been senior science master, and he asked Halliwell to help him with the science courses. Both regarded this as a splendid opportunity to introduce new purposes into school science, for the group of teachers they would be training would have no preconceptions about the 'science' that was appropriate for young people of this age group, and the course could train them along new lines. A note about the new directions envisaged for school science survives from this early formative period and in it are the germs of many of the ideas incorporated in Nuffield chemistry a decade later. Drafted by Halliwell and Doolan, it starts with a statement of aims:

> If a science is to have an educational value, its study at school must at least do two things: (i) give experience in investigating problems and give practice in a critical concern with proposed explanations; and (ii) at the same time be not only a self-contained unit for those whose interests and activities will in future lie in other fields, but must also be a sound basis for those continuing their science at post-school level. With these aims in view and as a basis for further considerations, a personal plea is put forward for the following points:

1 An increase in the use of investigations in the laboratory and of training in separating facts from interpretations.
2 The deliberate stress from earliest lessons of the linkage between chemistry and electricity.
3 The introduction of the concept of atoms in its own right and earlier than, and independent of, the concept of molecules, so that ions and molecules can be introduced at the same time as explanatory models.

4 Training from early days in the use of g-atoms, g-molecules and g-ions as normal working quantities.
5 The early introduction of pH and a more modern approach to acidity and alkalinity, oxidation and reduction and the activity of metals.[39]

From these ideas grew the new inservice courses and the scheme of work for the secondary intermediate schools. The ideas were tried out over a period of some five years by a group of very enthusiastic teachers, suggested modifications were made through follow-up visits and inspections, and there was every appearance of overall success. The pupils concerned were of 'average' or 'below average' ability, yet the ideas were to be the subject of controversy when they were proposed for the most able pupils a decade later in Nuffield O level chemistry. Halliwell remains convinced that these 'less able' pupils in Northern Ireland showed grasp and understanding of the basic ideas in their ability to apply them in concrete, everyday situations and that, given an appropriate approach and a clear sense of purpose, there should have been little difficulty in taking the work still further in grammar schools. In the secondary intermediate schools the scheme worked because suitable approaches had been developed in carefully formulated inservice training, and because the teachers did not anticipate that the conceptions they were introducing were going to be 'too difficult':

> What the innocent welcomed gladly (you could say that they had no millstones round their necks; or you could say that they did not know any better')—that took ten years to become acceptable to those experienced in traditional ways (either at school or university).[40]

During this period Halliwell was Chief Examiner for the Junior Examination (roughly equivalent to O level) in chemistry, in Ulster. A new type of question was set in the examination, which matched the aims of science teaching. The result was 'a teacher revolt', and a return to traditional work (minus the innovating Chief Examiner!). Halliwell sees this as an illustration of the influence of what he has often described as the 'straitjacket of acute success' on the part of the recently successful ('the old scheme got me a first class B.Sc., what's wrong with it?'), and the 'straitjacket of chronic success' on the part of experienced, successful teachers ('why change?'). He believes, too, that it illustrates the contention that a comparatively small-scale Ministry's direction and control of innovatory activity has a great deal of value, although it might equally well be disastrous. What is clear is that many innovatory topics had been tried successfully in Ulster at least eight years before he urged their value to the Chemistry Panel[41].

By 1960, as we have seen, there was much concern about the need for reappraisal in school science. Decades before, Halliwell's professional training at the then London Day Training College had brought him into contact with a man who was to be a major influence on his teaching life, Sir Percy Nunn. Like Nunn he believed that 'science-for-teaching' was that which would provide pupils with experiences that would enable them 'to be scientific about a problem that has become a personal one'. Halliwell's excursions into the history and philosophy of science, and his reflections upon the translation of 'being scientific' in classroom terms, had informed his own teaching. Now, in the late 1950s, his close links with those who formulated the science teachers' *Policy Statements* and the ensuing debate helped him to clarify his ideas very considerably. The germ of the Nuffield Chemistry Project was expressed very clearly in a lecture that he gave at Dudley Training College in 1960:

> The human activity known as science can be seen to have two characteristics:
> 1 Arising from curiosity and a 'wondering if ... ', it searches for patterns of behaviour, and offers explanations for them in terms of models which *not only* explain, but also coordinate and are, therefore, suggestive. The interplay between hunch and the growing body of factual information is of greatest importance. [Here he introduced the scheme illustrated on p.125, and subsequently reprinted in the Project's *Introduction and Guide.*] [But] ... the patterns that we see change with the years ... the explanations put forward alter ... The model used for explanation is that which is good enough for the moment, and the criterion of acceptability is effectiveness within a framework of logicality. It is, however, man's disciplined speculation and creative imagination that fathers it ... Where is 'scientific truth' to be found in this?
> 2 Such activity has been found to give power—power to do good or to do evil—but it does not supply the means of distinguishing between these alternatives.[42]

Halliwell was suggesting here that the social implications of science involve moral issues, which are quite distinct from scientific problems and which cannot be answered by 'scientific' means, and that recognition of the difference is important.

Teaching science in schools should, he continued, reflect both characteristics, and it should therefore aim to give pupils an understanding, first, of what it means to approach a problem scientifically and, second, of when it is appropriate to do so. Nevertheless, he warned, the way in which this new educational opportunity might be provided in a classroom had yet to be worked out. In his view it depended quite fundamentally upon an approach which stressed the interplay of speculation and fact finding. In spirit, he recalls, neither of these ideas was new. Centuries before, Newton had written in his *Book of Opticks:*

> It seems possible to me that God in the beginning formed matter in solid, massy, impenetrable, moving particles, of such sizes and figures and with such properties and in such proportions to space, as most conduced for the end for which He formed them.[43]

That approach, Halliwell claims, is what the Nuffield Chemistry Team tried to recapture: the interplay between actuality and imaginative thinking, between 'the bench and the blackboard of the mind' was what they wanted to get into the classroom[44]. Underlying it was the attitude expressed in the nineteenth century by Kekulé at a meeting of the German Chemical Society given in his honour:

> Let us learn to dream, gentlemen, and we may perhaps find the truth, but let us beware of publishing our dreams before they have been tested by a discerning mind that is awake.[45]

Translation of the brief into a programme

The brief given to each O level Organizer was:

> ... to provide an integrated range of tested teaching resources for a modern approach to chemistry, physics and biology, designed to be equally suitable for future science specialists and for those who later specialize in other subjects or who leave school at the age of sixteen. It will be intended primarily for use in the first four or five years in grammar schools and the upper streams of secondary modern schools and will offer to all who might normally study for the GCE O level (or Scottish O Grade) examinations some insight into scientific thought and method. The programmes are based upon, and are intended to consolidate, the work which has already been done, in Britain and elsewhere, in revising school science curricula.[46]

The first months of the programme were spent in administration, mainly in negotiating the secondment of Team members, in finding and making arrangements for 'second-line helpers', and in holding discussions about the basic proposals. These took place between the organizers themselves and with a wide circle of interested people and groups. During the first month, a series of meetings with officials of the Royal Institute of Chemistry, the Curriculum Study Group and other Ministry of Education departments, and with visual aids experts at Shell International, helped to establish the nucleus of a vital communications network, and informal discussions with chairman and members of the Consultative Committee helped to shape the basic proposals on approach. The Team also studied and discussed American and Scottish curriculum reform programmes.

It was, by all accounts, a memorably lovely autumn and Halliwell and Coulson spent much of their time walking about the beautiful gardens of Nuffield Lodge, deep in discussion. There would then be further discussions with others on the Team. At mealtimes there would be more talk, often with members of biology and physics teams.

> We walked round and round those gardens trying to make explicit to ourselves, and justifiable to others, our criteria for decisions. Whatever we did, it was to be on the basis and in the spirit of the science teachers' *Policy Statement*. To that we were both committed and, indeed, Coulson had played an important part in its production. However, we decided that the unique opportunity which the Foundation was creating must be met by starting afresh, from scratch. We tried to imagine anew what the *Policy Statement* would mean in the classroom if we and our colleagues really tried to implement it and were free from restraints of existing examination patterns, restraints of unavailability of resources and (chiefly, perhaps) the restraints of what I often referred to as the 'straitjacket of chronic success'.[47]

The first step was the production, between mid-September and early December, of a number of documents: four *Memoranda*, produced by Halliwell, and ten *Notes for Discussion*, written by him and by other Team members.

The *Notes for Discussion* were intended to facilitate communication and coherence between and within Projects. *Notes 1, 2, 5* and *6* dealt with systems of nomenclature and notation and with the presentation of quantitative results; *Notes 3* and *4* explored the treatment of basic theory; and *Notes 7* to *10* outlined plans for the production of the resource materials. All were written between October and November 1962, and all were constructed on an agreed pattern[48], similar to that used by the Organizer in writing the *Memoranda*. Starting with a clear statement of the purpose, aim or problem concerned and of any intentions for change, each *Note* continued with the Team's analysis of the problems, conflict or confusion, expressed in terms of the probable source of the trouble and of what should be done. The third section gave either explicit but tentative proposals for action, or a call for help.

Though each *Note* was written by one Team member, they were, like everything else, essentially a cooperative product. They were normally generated in the course of three meetings. At the first the group discussed the topic and the author-to-be made copious notes from which he then drafted a document. This was circulated before the next meeting, at which discussion was tape-recorded. This recording was used by the author to draft the final *Note*, which was then confirmed at a third meeting. After typing and duplication each *Note* was then ready for circulation and discussion with a wider circle of people, as appropriate.

The four *Memoranda* are particularly important and fundamental documents. As an explicit and comprehensive 'platform', they provided a closely argued basis for discussion with the Consultative Committee and others, and for everything that followed. Translating a policy statement into action always involves decision making in areas in which ideological beliefs and assumptions operate, in which knowledge is fragmentary and sometimes contradictory, and in which alternative courses of action are possible. Although the *Memoranda* represent a distillation of knowledge and experience and a breadth of perspective that were the products of some thirty years of chemistry teaching on the part of both Organizer and Deputy Organizer, although they were firmly based on the work of the science teachers' associations, the proposals had a character of their own which derived from a *particular* interpretation of policy, and which would inevitably become a target for criticism from whose who, while in basic agreement with the original policy, differed over interpretation.

The four *Memoranda* were:

I No title, but concerned with the four areas in which immediate action was necessary: examinations; liaison with biology and physics teams on matters of common concern; the characteristics of a modern approach to the teaching of chemistry and how this would differ from the traditional approach; and the proposed programme of action. (17 September 1962)

II *A modern approach to education through chemistry* discussed, in detail, the aims and the pedagogical implications of an approach based on stressing the interplay between speculation and fact-finding. (October 1962)

III *The form of the publications* discussed the range of resources to be produced; their orientation towards the teacher in order to underline the flexibility of the proposals; and their appropriate use as a set of resources. It argued against the production of a textbook for pupils. (November 1962)

IV *Form and content of the proposed syllabus*. The proposals here were quite novel, and utterly unlike the Chemistry Panel's syllabus, in spite of the fact that both were based on the *Policy Statement*. Ten years earlier Halliwell had urged the Science Masters' Association subcommittee responsible for the production of a syllabus for secondary modern science to base the syllabus upon pupil activities rather than upon content (in terms of specific chemicals)[49]. This idea had developed in Halliwell's mind over the intervening years, and it found expression in a Nuffield O level chemistry syllabus that was based on the idea of chemistry as process and product, and that did not contain the name of a single chemical. This *Memorandum* also contained an account of the developmental model that would underlie planning over the age range.

The three-year programme of action

Three major phases were anticipated during the first year (1962/3). The first three months were to be a period for 'consultation, appraisal and decisions', a period spent almost entirely in planning and establishing approach and content, in consolidating the earlier discussions of the Chemistry Panel, and in planning strategies, which ran as follows.

From November 1962 to May 1963 the first drafts of much of the classroom material needed for trials would be prepared in typescript form. (This was not as unrealistic as it might now sound. The experience of the Chemistry Panel and of other working parties made it appear quite feasible in relation to what was then intended in the way of resources, especially since the Team planned to use temporary working parties of teachers to help deal with the bulkiest tasks — the preparation of the *Handbook* for teachers and the organization of the experimental work. In some of the corresponding American projects, including the two major chemistry projects, intensive initial planning conferences had enabled large writing teams to produce draft materials in a matter of weeks.) During this period it would be necessary, too, to establish contacts for the school trials due to begin in pilot form in the autumn of 1963, and to organize extensive experimental work.

In May 1963 draft material was to be put aside temporarily and two members of the Team were to travel outside Britain to see what was going on elsewhere and, if it could be arranged, to take part in teaching programmes. This would enable them to revise the first drafts with the benefit of enriched experience and of time for reflection. Rogers would go to Germany, where he had contacts. Coulson would go to the United States for a month's teaching in two schools with excellent reputations, one heavily involved in work with the *Chemical Bond Approach* project, the other with *CHEM* Study.

In June and July typescripts would be revised and materials prepared for the 'pilot' trials in the autumn. These would be followed by 'main' trials, which would occupy the rest of the year 1963/4 and which would be organized on a system of local centres. Draft chapters would be put to critical test by trials teachers and pupils, with follow-up discussions by groups of teachers under the direction of members of the Headquarters Team. It was intended at this stage in the planning to include a second group of trials teachers, who would have no previous experience of, or contact with, the Project, and no guidance other than that afforded by the draft materials; in other words, teachers whose situation would be that in which many others would find themselves once the materials were published. This group would therefore test the coherence with which the proposals were presented in the resources. During the summer term of this second year, 1964 — which would be the last term of Team members' two-year secondment — the revised final version of the typescript would be produced. The third year, 1964/5, would be occupied in preparing materials for publication. Figure 5.1 shows the planned time-scale and should be compared with Figure 6.2 (p.148) which shows what actually took place, for as

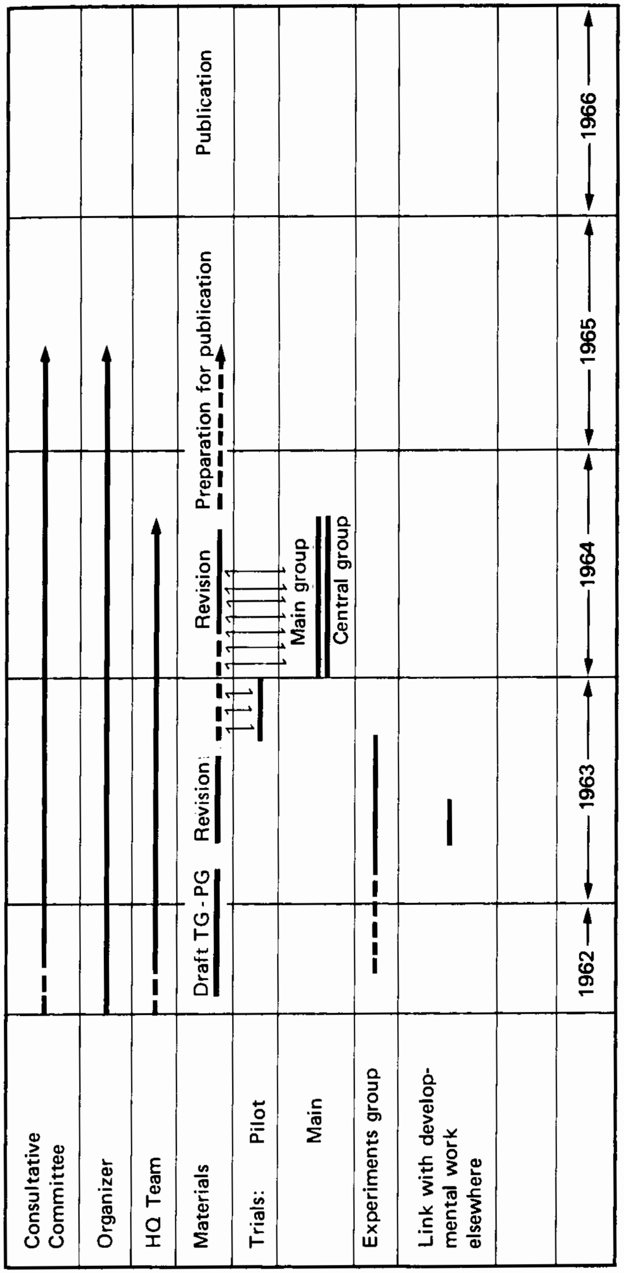

Fig. 5.1 Initial planning, October 1962

things turned out, right from the pilot trials period feedback from teachers showed a quite unanticipated need for more and more detail, and this timetable had to be extended. So had Team secondments. The pressures on time that this need produced were considerable, and one unfortunate outcome was the abandonment of the plan to carry out trials using unbriefed teachers.

Liaison on matters of common coverage

Memorandum I stressed the importance of liaison to ensure that topics common to two or more projects should be both consistent and mutually reinforcing. The most formidable problems lay between chemistry and physics because several topics, notably electrical conductivity, thermal capacity, energy and the kinetic theory, raised questions of approach, of treatment and of timing, and because elementary chemistry differed from much of elementary physics in requiring particulate explanatory models.

Notes for Discussion 1, 2 and *5* sought a unified system of nomenclature and notation. At that time pupils were using various different units, symbols and abbreviations, even within a single school. What was required was that all projects should use those approved by scientific bodies — unambiguous, systematic, simple and easy to remember, and not expensive and difficult to print. Above all, they should be suitable for children being introduced to science. The *Notes* concerned proposed a system suitable for chemistry, and intended for discussion with the physicists. In the same way, *Note 6* dealt with the desirability of a single scheme for the presentation of quantitative data and of agreed treatment of the significance of error and of the concept of mathematical models.

Notes 3 and *4* made proposals with regard to the treatment of theory in relation to the structure of matter and to energy changes, which also required joint discussions for a consistent and complementary approach, since differences in timing, perspective and treatment obtained between that which a chemistry or biology teacher needed and the requirements in physics. If any sort of synthesis was to be achieved by the three projects at O level, then teachers and, through them, pupils must be enabled to see that the 'differences, which in many cases are fundamental and desirable, are but different and complementary ways of handling a common concept'. The work in school should therefore be shared by chemistry and physics teachers, each dealing with material more appropriate to his course at the earlier stages, but each ensuring at the same time that the necessary concrete experiences for later and full understanding were being provided at appropriate points. There was much to be said in favour of such complementary treatment, Halliwell argued in *Note 4*, provided that each group of teachers knew what the other was doing and could refer to it sympathetically and with understanding. Looking back, Halliwell maintains that he has never believed that it is necessary for physics and chemistry teachers to do a particular topic at the same time. For example, the fact that, on the whole, physicists do not want the electron mentioned until quite late on in the O level course, whereas the chemists want it quite early, does not seem to him to be at all insurmountable. What matters, he believes, is that the pupil should not get the idea that chemist and physicist never speak to each other. The pupil ought to see that the 'way he looks at a common topic reflects the different jobs of chemist and physicist'. Physicists, for example, are 'interested in density, chemists in the reciprocal; they're interested in electrical resistance, and we're interested in the reciprocal, in conductivity; they're interested in properties per kilogram or per gram, and we're interested in properties per mole.' Halliwell was not seeking for a uniform pattern, therefore. For him, 'cooperation' meant that physics and chemistry teachers 'could still do things at different times and in different ways', but with a clear understanding that the other man's way of doing it was appropriate to his job, and that the pupil learned which was which[50].

In *Memorandum I* Halliwell expressed a hope for opportunities for forging a close link with the work of the Nuffield Unit in the History of Ideas, then being developed by Toulmin and Goodfield. He also added the caution that by the time the Nuffield O level projects could have an impact on school programmes, the traditional separation of school science into physics, chemistry and biology at that level might have been superseded.

A 'modern approach to chemistry'

The essence of an approach that would be both an educative experience in its own right and a foundation for further studies for the specialist was, Halliwell believed, the introduction and development of experiences that would enable pupils to 'be scientific' about a problem and, at the same time, to build up an understanding of chemistry as a product of scientific investigations, their own and those of others. This conception of chemistry as process and product had come to Halliwell from a paper by J.S. Richardson, published in 1959:

> Science is a way of thinking, an attitude towards the solution of problems, a means of solving problems as well as a product of the investigation of natural phenomena ... Each new advance demonstrated anew that science is both a process and a product. But the manner of our teaching tends to treat science only as a product. We must dedicate our teaching as well to the process of science.[51]

Memorandum II carried an explicit statement of the philosophy underlying the Project, and it is clearly a development of the ideas put forward at Dudley in 1960:

> The intentions are largely based on what 'being scientific' means to the scientist: the importance of the hunch, the feeling of exploration, the readiness to make apparently unwarranted jumps, but knowing how to check on their worthwhileness ... Of course ... a fertile, creative imagination is a feature that great scientists have in common with great, creative artists. Scientists are, however, concerned with different fields of interest and they discipline their creative activity in a different way. The development of science arises from the interplay of fact, patterns of fact, and speculative explanation, an interplay which can be represented as in Figure 5.2. The basic attitude that stimulates this interplay is that of the quotation from Kekulé.[52]

The implications for the classroom of this view of 'being scientific' were, *Memorandum II* stressed, revolutionary. It demanded experimental work that was (a) truly exploratory and investigatory, (b) the basis of honestly creative speculation, (c) a medium for training in the disciplining of speculation, and (d) a medium for learning how to judge whether one's statements, and those of others, were acceptable or not. It demanded a marked break, in many cases, with traditional practice — certainly with 'cook-book' practical work. Hence, the *Teachers' Handbook* would have to deal very fully with the organization of school laboratory work.

'Being scientific' was one aspect of the work; 'learning about the results of science' the other:

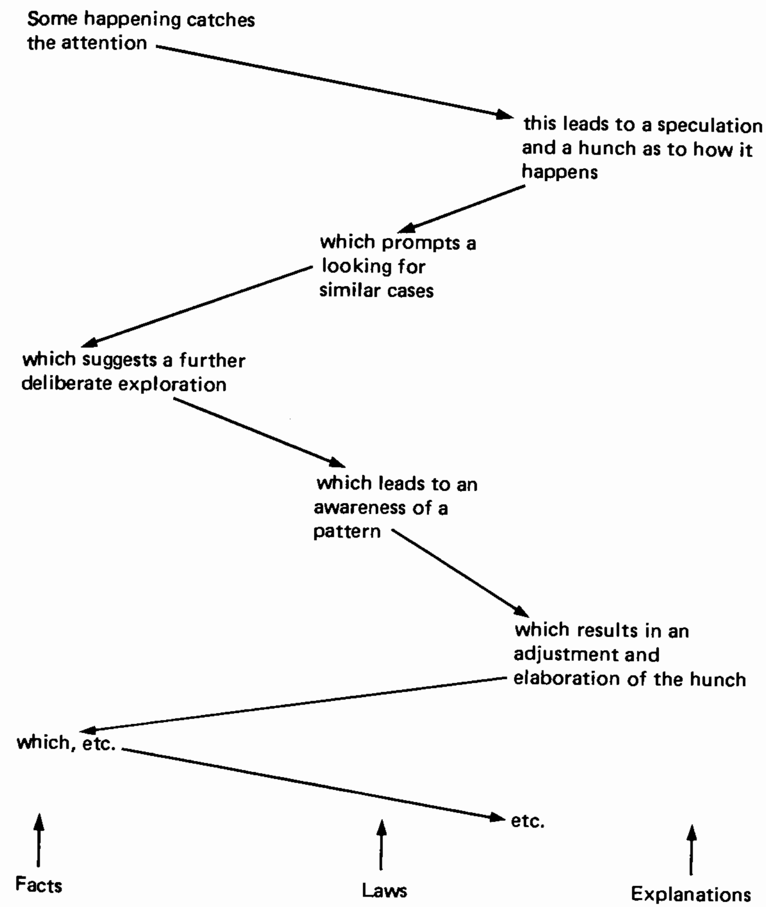

Fig. 5.2 (From *Memorandum II*)

> Chemistry is concerned with the alchemy of stuffs and its explanation in terms of a speculative model. However, the type of stuff that chemists are interested in, the way the alchemy is achieved, and the details of the speculative model, change from decade to decade. The pupils should be aware of present-day interests; new techniques and new materials must be incorporated in his scheme of work if there is to be a feeling that chemistry is alive.[53]

Selection from the broad principles and overall patterns that would provide the course's framework must reflect mid-twentieth-century science and, in particular, two major practical activities underlying recent progress: the development of the experimentally based consideration of energetics, and the concomitant 'experimental probing into the behaviour of stuffs' and discovery of materials whose existence was not only quite unexpected but had hitherto been quite inexplicable. These two experimental activities had become a combined and much sharpened tool for the disciplining of speculative explanation. The relationship that would form the basis of an approach to course content according to the broad principles and overall patterns of modern chemistry could be expressed diagrammatically. (Figure 5.3b. For the sake of comparison, the diagram given in the *Memorandum* is here set alongside a diagram, Figure 5.3a, which, Halliwell argues, represents the older pattern of treatment.)

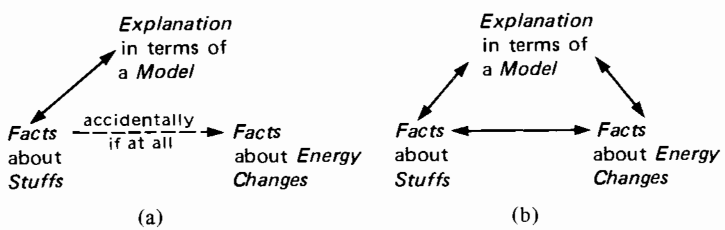

Fig. 5.3 An approach to course content (a) The older pattern of treatment (b) Nuffield chemistry suggestion

A fundamental aim of the Project was the growth of understanding of chemistry as process and product. This was, the Team believed, to be achieved through an operational approach to teaching which would enable pupils' understanding to grow in richness and precision from the first 'vague concepts' to a final

critical awareness which would, inevitably, be developed to differing extents by pupils of differing abilities. No concepts should be introduced until the pupils' own experience made it desirable, experience that should come from the pupils' own experimental explorations, from the teacher's experiments (demonstrations) and from accounts, either in words or in pictures, of other people's experiments.

These ideas were discussed at greater length in *Note 3*, which stressed that concepts should be *used*, and that a 'new concept can sometimes be appreciated as easily by using it as by following the sequence of events by which it is evolved'. In the early stages of the course, the powers of young pupils to 'sustain and appreciate a lengthy argument' would be limited. For them, short and, at times, 'necessarily incomplete excursions into theory' were preferable to a more rigorous treatment. Rather than providing evidence leading to an inescapable conclusion, as in following an historical sequence, an approach through 'that which is reasonable' would often be more stimulating and useful. In addition, the Team believed that *use* of a concept often provided additional insights.

In using this approach, the *Note* continued, three important provisos would need to be kept in mind. First, the explanatory model set up on limited evidence should, wherever possible, be tested by using it to predict consequences capable of experimental investigation. Second, the early models must be no more complex than is required. Third, a more rigorous approach to the concepts used earlier should be undertaken when the pupils were sufficiently mature cognitively, but at the same time it should be recognized that this would not always be possible by the end of the O level course, for all the concepts that the Team might wish to use. The *Note* provided an example to illustrate what was meant. It showed a 'spiral' approach to concept building that was well in line with psychological theories of learning and the awareness of the conceptual difficulties of some of the material has not always been recognized in criticism of the Project. Finally, and for full understanding, *Note 3* urged that the study of chemistry be set in its human and social context:

> To say ... that a pupil should be familiar with a few examples of the work of people other than themselves does not imply a course in potted biography. The examples of excited and exciting minds, of the flash of genius, of the fact that science is a product of human activity, puts analysis and control of

> material changes into a human perspective. A pupil should have some knowledge of the way that, for example, the concept of elements, the concept of atoms, the concept of energy, have developed.[54]

At the end of the course, the exploration of the behaviour of stuffs should be linked with other scientific studies so that science was seen in relation to the life of the community, not only in the sense of direct application, but as an addition to a body of experience which vastly affects our lives and the development of values.

Course objectives

If the aim was to produce pupils well educated in chemistry, then by the end of the O level course pupils should be able to demonstrate a number of achievements:

1 They should have developed certain 'critical and appreciative attitudes towards scientific affairs'. (It can be argued that negative attitudes should be acceptable provided that they are based on accurate knowledge. That is, teachers should not feel that it is necessary that *all* pupils develop positive attitudes to science but, rather, that dislike of science, or neutral feelings, where they exist, should be the product of informed opinion and genuine experience of science.)
2 Pupils' work should have afforded them 'such delight and satisfaction as will ensure the further development of this attitude' whatever their future interests. (Compare John Wilson's, 'He will not merely be well-informed, or able to use his knowledge when required, the form of understanding and the general attributes of rationality will be a part of him he values and *uses* in his everyday life'[55].)
3 Pupils should have developed judgement and discretion as to whether a question can be answered by scientific investigation, and as to the pertinence of the evidence offered and the acceptability of deductions made when it is so investigated.
4 They should have had opportunity for sufficient experience, personal and vicarious, to enable them critically to distinguish between facts, patterns of facts, and speculative explanations.
5 They should also be aware of, and expect, the development of a science that arises from their interplay. They should, therefore, have had opportunities for creative thinking, for engaging in the planning of experiments to discipline speculation and for learning the necessary manipulative skills, as an essential and deliberate part of the scheme.
6 Pupils should also have the beginnings of an awareness that this interplay arises from the work of people and teams of people all over the world — both in the past and in the present.
7 They should be familiar with some of the broad principles and overall problems of mid-twentieth-century chemistry.[56]

'Flexibility within a framework': the O level chemistry syllabus

Memorandum IV pointed out that it was clear that a chemistry syllabus that was the product of considering 'chemistry as process and chemistry as product', would be very different in appearance from traditional syllabuses, which dealt with long lists of concepts and specific chemicals.

> The thing of which I'm very proud — but nobody pays attention to it — is an examination syllabus in chemistry that doesn't mention a chemical.[57]

Since it would be concerned with two related questions, namely, what the pupil should be able to do, both with materials and with ideas, and what kind of information he should be familiar with, the syllabus could be expressed in skeletal form, providing thereby a flexible framework upon which many individual, yet correlated teaching schemes could be built.

The basic intellectual and manipulative activities of 'chemistry as process' could be classified under four broad headings:

1 Getting new materials from those available (making the change happen, and knowing whether something new has been obtained).
2 Looking for a pattern in the behaviour of substances (representing and interpreting qualitative and quantitative results, and finding and seeking major patterns of behaviour and assessing their importance).
3 Explaining the changes in terms of atoms and electrons and learning how to check theory by fact.
4 Using energy changes as another means of checking theory by fact.

In each category the activities were now spelled out in some detail[58], to provide a framework upon which to build a coherent conception of chemistry as product. The basic information used here would in many cases be the same as that given in traditional syllabuses, but there was still much room within this for teacher choice to meet the needs and interests of particular pupils. Less traditional areas would also need to be included, such as electrochemistry and corrosion, polymerization and carbon chemistry, but here again there was room for choice in terms of specific substances. This should enable teachers to take a 'worthwhile and constructive part' in working out the syllabus in their own schools.

Nevertheless, a 'single, clear-cut and practicable scheme' would be needed to illustrate and to test the proposals, both in the classroom and in examinations, and the Team would have to provide this. Care would have to be taken, however, to ensure that this scheme did nothing to obscure the fundamental aim of flexibility. One way of trying to ensure this would be to include several outline sample schemes in the *Handbook for Teachers*. In all cases, the *Memorandum* warned, it would be essential to remember that 'the growth in chemical experience and maturity of outlook of the pupils must be taken into account at all stages of the course'. In the development of the trial sample scheme from the syllabus the Chemistry Project would regard the abilities of pupils as developing in three stages over the five years of the course. This was no new idea, the *Memorandum* emphasized, although the use made of the stages was new.

Stage A (age about eleven and twelve): activity would be focused chiefly on the empirical chemistry of stuffs, for it was a time for 'doing experiments'. It must, however, form a coherent experience as a basis for Stage B. It was a time for acquiring basic experimental techniques, and for beginning a training in discipling speculation — at this stage, chiefly speculation about what was happening.

Stage B (age about thirteen and fourteen): this would be characterized by the turning of attention to explanation in terms of atoms, ions and molecules. Such explanations should be developed only when they would be used. Practical work should now be slanted much more to the testing of suggestions, and there should be a more marked concern with the energy changes involved. It was very important to ensure that this stage did not become 'pencil and paper' chemistry, and new experiments, especially those involving electrical phenomena, should help to ensure this.

Stage C (age about fifteen and sixteen): this would be characterized by the development and ripening of experience of the interplay of fact and speculation, and the provision of maximum opportunity for different treatment via the introduction of a series of options.

Memorandum IV made it clear that whilst this represented the developmental conception underlying the teaching scheme, optimum methods of fitting the course to pupils of differing ability and interests would still have to be worked out. In the event, however, and probably inevitably, this was left to individual teachers.

Providing an 'education through chemistry'

Whatever the Chemistry Team or, for that matter, the science teachers' Science and Education Subcommittee before them wanted, there was no choice but to start from the existing situation. In education, as in many other fields, this is always one of considerable complexity, with large areas of uncertainty and ignorance, with conflicting values, beliefs and practices. Like all systems of ideas, it embraces all manner of assumptions about society's needs, about the relation of education to society, about worthwhile educational knowledge, about the nature of science, the nature of human learning and of effective teaching, about change and processes of change, about the evaluation of educational activities, about the abilities, attitudes, interests and activities of teachers and pupils — and about the interrelations of all of these factors. It assumes the absoluteness of certain inherent values — or, at least, that they need not be called into question. In formulating and discussing a problem, many ideas become accepted as unproblematic, 'background' knowledge, constellations of beliefs and opinions that become, for the moment at least, settled facts and a firm basis for action. Clearly, if confidence is misplaced, the cost of taking so much for granted can be very high, for the complexity of this assumed ground-base may affect outcomes in all sorts of ways, many of them quite unanticipated. Nevertheless, where there is a strong component of practical experience, the risk is somewhat reduced, especially if evaluation is really rigorous, and if changes are small-scale and serial.

The Chemistry Team took for granted, and used as their starting point, the assumptions contained in the *Policy Statement* of the science teachers and, in particular and over and above the wider educational assumptions, the central belief in an 'inquiry' approach to science teaching and learning. Halliwell maintains that development was based in particular upon two statements from the revised *Policy Statement* of 1961, one of which has already been quoted:

> Science should be recognized — and taught — as a major human activity which explores the realm of human experience, maps it methodically but also imaginatively, and by disciplined speculation creates a coherent system of knowledge ... The effects of science on human lives and thought have become so great, and are potentially so much greater, that those who have no understanding of them and of the science which produced them cannot be considered properly educated or truly cultured and therefore are unable to participate in the life of their time. Present 'scientific illiteracy' is, in part, due to a lack of factual knowledge, but is much more the result of a lack of understanding of the basic nature and aims of science.[59]

This frame of reference remained a set of principles to be thought, not *about*, but *in terms of*, and so it made possible the definition of goals within a limited context of 'if ..., then ...'.

Halliwell is quite clear — and the documentary evidence supports his contention — that he viewed the entire enterprise as a parallel, in many ways, of a scientific process of continuing hypothesis-generation and testing and of subsequent revision, modification, extension or abandonment of ideas. The basic hypothesis was that it is possible, given appropriate teaching methods and materials, attitudes and values — the means — to introduce and develop experiences that will enable pupils of this age and ability range to develop specific intellectual and manipulative skills as well as a measure of understanding of twentieth-century science — the ends. The ends were then translated into broad objectives in the *Memoranda*, and policy making continued this step by step and systematic process of clarification. As choices became necessary over all manner of philosophical, psychological, sociological and pedagogical matters, a particular model of the science teachers' associations' conception of the desired approach emerged: 'It was not *the* way; it was *a* way: not *the* philosophy of science education; but *a* philosophy of science education.'[60]

Most fundamental here was the view of the nature of scientific activity or inquiry as exemplified in chemistry. Though the level was largely puzzle-solving, the hunch — the imaginative leap — and its subsequent disciplining were of central importance: pupils should come to view discovery in science as an interplay of speculation, critical testing and adaptation. The approach was essentially hypothetico-deductive and internalist. (It is worth noting here that the Project has been criticized on the grounds that it uses a confirmatory approach to scientific investigation, although there is an admission that this is tacit rather than explicit[61]. There is, however, explicit evidence to contradict this assertion in terms of the intentions.)

The next step was to look for critical methods of testing the model and its structure of hypotheses, because long experience in classroom and laboratory, though valuable, affords only subjective judgements. The most obvious means was that built into the brief, namely the production of syllabus and exemplifying materials and their testing in many schools, a process which, in itself, involved hypothesis-generation as ideas were made explicit, and testing based on 'if ..., then ...'. Evaluation of these materials could, in theory at least, derive from critical feedback from teachers involved in the trials, from observation of the approach in action in trials classrooms, and from assessment of the hoped-for outcomes in terms of pupils' knowledge and understanding, skills and attitudes. In addition to these practical tests, the Team was concerned to have critical discussion of all proposals and to extend the debate as widely as possible in the hope of eliciting errors, deficiencies or contradictions in the work. So scientific and pedagogical issues were well aired. The major apparent omission was criticism from philosophers, psychologists and sociologists. A meeting of the three O level Organizers with a number of very well-known educational psychologists did, in fact, take place in November 1962[62]. Its purpose was to discuss possible research on the intellectual development of children and adolescents, and the relevance such research might have for the Nuffield projects. Participants were also asked about immediately available sources of information appropriate to the work of the O level projects, but the general impression given was that little 'hard' advice was possible at that time, since so little research had, as yet, been undertaken with British children and, in particular, with British adolescents. It was emphasized that opinion among psychologists on the matter of learning and teaching was still very divided. American projects of that period had been given similar advice[63].

Experts were also consulted on the matter of testing and examinations. Apart from these moves, however, there do not appear to have been any attempts to involve experts in philosophy and the social sciences in decision making. There are a number of possible reasons for this omission, among them:

1 The pragmatic, action research approach to the production of materials, which should have helped to identify difficulties and make improvements possible.
2 The strong belief that final responsibility for decisions about what can be taught, when and how, lies with the individual teacher in his own unique classroom situation. The resources would focus on the similarities between individuals; the teachers could focus on individual differences, and adjust appropriately.
3 The approach through the 'structure of the discipline' was part of current educational 'good practice' (see, for instance, the discussion at the Woods Hole Conference in 1960, reported in Bruner's extremely influential book, *The Process of Education*[64]).
4 The criticism of the Team's interpretation of 'science' by research scientists with long experience in the socialization of young scientists into the profession, that is, of 'initiation into the discipline'.
5 The psychological nature of most of the relevant knowledge in the social sciences at that time, with a focus on the individual and on the development of individual capacities, rather than on the social setting in which teachers and pupils interact. British sociology of education was still focused largely on social class/home/educability factors and on organizational studies of schools.
6 The pedagogical orientation and the experience of Team members who, between them, possessed a very great deal of practical knowledge of classroom life.

As a result, however, analysis was limited to what was familiar to the Team. They used what, to them, were the soundest, most testable models, and these were derived largely from pooled experience, reading and reflection.

The Team was fully conscious of the fact that the work involved more sophisticated ideas than had previously been required of pupils of this age, but they also believed that their own experiences vindicated their decision to include them. Further, curriculum development work in America and elsewhere was beginning to provide some evidence to support the contention that, in the past, insufficient demands had been made

on able pupils[65]. Halliwell had already contributed in this area in his work with American project teams. His *Memoranda* had warned, quite specifically, that the ability range of pupils must be kept in mind and that a course designed to cover five years from eleven to sixteen would have to provide for considerable intellectual growth. Consequently, all work was deliberately aimed, as we have seen, at a gradual building up of concepts from early intuitive understanding via the provision of concrete experiences, to individually variable degrees of 'critical awareness'. Experiences were carefully structured, and these and the demands made upon pupils were to match the three-stage pattern of development that the Team accepted. This pattern corresponds roughly with Piagetian levels of attainment for above-average children (the client population), and for pupils with whom the Team had experience. This was a common developmental conception, however, and owed nothing to Piaget[66].

From the ideas discussed in this chapter, the synthesis of years of reflection and experience and interaction with others, and from their knowledge of children and of teaching, the Chemistry Team gradually built up the basic framework, a specification that was sufficiently precise and explicit to ensure its communication to everyone who took the trouble to read the materials and to reflect upon them, and to make possible the effective carrying-out of the development exercise. The ordering of problems could not be fixed at this early stage in anything other than a broad and tentative manner for, as the Team recognized, even this might have to be varied according to emergent needs and to modification imposed by situational constraints. Moreover, while many issues crucial to the task could be identified and stated explicitly at the outset, others could not be anticipated and could only be defined in very vague terms and then left to emerge from the welter of issues, central and peripheral, as time went by.

Although it was built upon a framework of past reflection and experience, the Chemistry Project was not just a 'finalized summary of past deliberation'. For,

> ... throughout the life of the Project, feedback from some sixty or seventy teachers, from some three or four thousand pupils, from the Consultative Committee and from the Inspectorate, continually resulted in readjustments. The main guidelines and principles were established in the first few

months — the details evolved (and often became adapted or rejected).

Nor was it ever intended to be THE WAY. The Director of the Foundation, Dr Leslie Farrer-Brown, stressed that the whole undertaking should be regarded as a jumping-off board for future developments. We who were closely linked with the working-out of the Project intended it to be, through resources and examinations, and for those who were looking for one, a viable alternative to the traditional teaching approach, and one which tried to implement the *Policy Statement* more fully than had, perhaps, previously been possible.[67]

6

Nuffield chemistry: curriculum development in action

Producing the resource materials

By early December 1962 the basic 'platform' and patterning of the Project was fairly clear, and each different aspect of the work from then on proceeded under the direction of the Team member who had been given responsibility for it. Nevertheless, regular meetings of the Team and continual informal contact kept members of the group closely involved in the work that was going on in all areas.

Memorandum III had discussed underlying considerations and basic plans for the resource materials, although much would have to await firm decisions about the framework of the scheme and the means used to ensure flexibility within it. The scheme was going to involve new approaches over the whole age range, new aids, and new ways of tackling laboratory work, and teachers would need guidance if they were to be able to use the materials effectively. Pupils, in turn, would have to be provided with stimulating experimental work. Although plans should remain flexible throughout production, Halliwell anticipated that teachers' needs demanded the inclusion of an *Introduction and Teachers' Guide*, a *Teachers' Book of Experiments* and a collection of visual aids. Pupils needed experimental instructions, a *Handbook of Numerical Data* and a set of *Background Readers*.

Early 1963 saw a considerable expansion of activity as decision making and information collecting reached a point at which a start could be made on the materials. Because feedback led to a radical modification in terms of both range and content of these resources, each must be dealt with separately in what follows. Figure 6.1 shows the chronology of the development work and gives an idea of the continual interaction between those responsible for its various aspects.

The Introduction and Guide and the Handbook for Teachers

A single volume was anticipated as the core of the Project. It was to consider in detail the new attitudes and approach to chemical facts and theory, the organization and teaching of lessons, sources of supply and use of information and of materials, and matters such as standard notation and nomenclature. It should also indicate a number of possible routes through the syllabus in the form of outline sample schemes. Plans were spelt out in *Note for Discussion No. 8*, prepared by its editor, Coulson, in November 1962. This included a list of twenty-three proposed chapter topics and four appendices.

Twelve part-time assistants were recruited from schools, university departments and technical colleges in late 1962, and they were provided with all the discussion documents so far produced by the Team. Other useful material from American and Australian projects and from the Organization for Economic Cooperation and Development, OECD, was available for reference. After being allowed time during the Christmas holidays for reading and reflection, the assistants were sent a tentative sample scheme, which indicated that many of the chapter themes in the *Handbook for Teachers* were concerned with basic themes running through the teaching programme. Each assistant was given one or two chapter themes to develop in the form of a report; guidelines were supplied on the sort of advice that should be given to teachers to help them to weave their own course into a coherent whole. Assistant writers were also asked to devise a sample lesson where appropriate. (Only two were actually produced, but both were included in the eventual *Sample Scheme*.)

The achievement of cross-linking and continuity was helped by holding group meetings at regular intervals, and ensured by subsequent editing. By July 1963 sixteen lengthy reports had been produced, and Coulson used these, along with a considerable

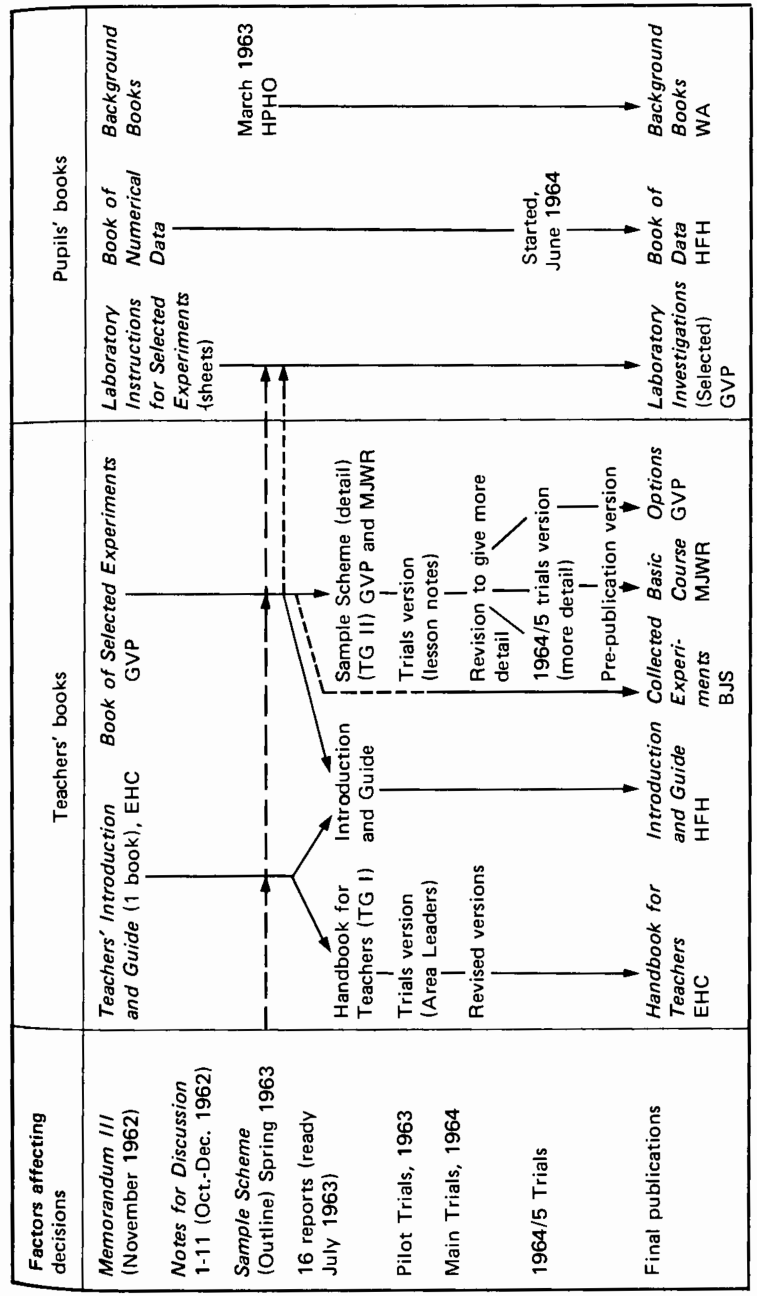

Fig. 6.1 Development of materials

amount of material of his own, to complete the *Handbook for Teachers*.

By the spring of 1963 it was becoming clear that trials teachers would need a written and explicit account of the intentions, approach and basic syllabus, and that this would, therefore, have to be put together quickly. A suitable redrafting of appropriate parts of the four *Memoranda* was carried out by Halliwell, and this and the outline sample scheme devised for the trials was put together in time for the 'pilot' trials in the autumn. The production of this material as a separate unit from the *Handbook for Teachers* was, at that time, viewed simply as a matter of expedience, and the intention to incorporate it in the single volume for teachers remained. Subsequently, however, and on the basis of experience with trials, it was decided to retain it as a separate and crucially important publication, the explicit statement of the underlying ethos and fundamental patterning of the project materials, upon which everything depended.

The Sample Scheme

If the Team's ideas were to be given a fair trial in schools during development at least one sample scheme would be necessary, translating the syllabus into a three-stage sequential scheme covering all five years. After some months of discussion, drafting and redrafting, agreement was reached upon an outline which had then to be translated into a sequential series of topics. While the Team was still at work on Stage I an opportunity arose to provide an illustration of the flexibility possible even within a single scheme. The Team had discussed and agreed upon a modified heuristic, step-by-step approach, proposed by Van Praagh. Coulson was in America at the time, and on his return he argued that children often grew bored with a logical presentation that occupied a long period of time. He believed that many pupils would find a series of topics more stimulating, and he insisted that careful planning could provide the same basic experiences without any loss of coherence. Accordingly, he produced an alternative scheme for Stage I, and since this proved just as acceptable to the Team Halliwell suggested that both be included as alternatives. It would, he argued, serve to illustrate not only the principle of flexibility, but also their adherence to it.

Once the outline had been agreed, work could begin on the preparation of lesson summaries, which also included appropriate experimental work. This entailed close liaison between the Team members responsible for these two aspects of the scheme, Rogers and Van Praagh respectively, as well as lengthy discussions by the whole Team as materials were drafted and redrafted. At this pre-trials stage no great detailing of lessons was anticipated. The Team was 'convinced that teachers did not want to be told exactly what to teach ... They were accustomed to developing their own courses from a brief syllabus[1].' This supposition proved to be completely unfounded, however. Early feedback in the autumn asked for far more detail about approach, about timing, about the depth to which topics were to be pursued, about methods of putting over specific points and about details of the experiments suggested. Yet these same teachers had been hand-picked for the exercise, and those helping with the 'pilot' trials were particularly experienced. Why, then, was there so much apparent difficulty? Several reasons immediately present themselves. The type of exercise was novel. Teachers were under considerable pressure in coping with new materials and approaches, so they may have found little time for the careful reflection necessary at the outset. (Although they had been given the *Introduction and Guide* when they were briefed in the summer, and although the underlying philosophy had been discussed with them at some length, it may be relevant to note Shipman's observation, in another context: 'Again and again the same sequence occurred. The teachers started by doing it and only then looked for an explanation of why they were doing it that way'[2].) Again, the lack of something more concrete to work on may have produced a substantial measure of insecurity. Whatever the combination of causes, the outcome was a sample scheme that grew steadily more bulky and detailed. In the end, two whole volumes were needed to contain the detail (in place of a chapter in the teachers' *Guide*), and two Team members had to divide the labour between them in order to cope.

Collected experiments and pupils' laboratory investigations

Van Praagh had initial responsibility for all experimental work, for the *Teachers' Book of Collected Experiments* and for the *Laboratory Instructions* for pupils. His plans were outlined in *Note for Discussion No. 10.* The starting point for action was the compilation of an index of experiments, drawn from textbooks, journals and teachers' own original experiments, and classified under the 'themes' already identified in the syllabus.

The work was carried out by six chemistry teachers, working part-time, and it went very quickly. Testing of experiments started in March 1963 and was carried out by thirty teachers, who worked through to the end of the summer. At that point a new Team member, R. Tremlett, took on the work. For one academic year he spent half of his time in the laboratories at Westminster School, London; the remainder of his time went to carrying half of Coulson's work in the latter's school. During the subsequent year he worked full-time on testing and devising experiments, trying out ideas for their practicability and developing work in phase with lesson themes under preparation; eventually he worked through most of the experiments in the book. After this, experiments were tried out by those Team members who were still working (part-time) in schools. Tremlett also investigated the safety aspects of all experiments, and so safety measures, too, could be included in the books. He devised new apparatus and liaised with manufacturers on its production. Once feedback started coming in from trials schools he checked it for comments on the efficacy, reliability and suitability of the experimental work, as well as for suggestions from teachers for improvement, and for new apparatus or experiments.

Next, Rogers and Van Praagh wove into the lesson notes of the growing *Sample Scheme* appropriate experiments that had survived the rigours of testing. Again, teachers asked for more detail; again the *Sample Scheme* grew longer. The proposals for a 'Teachers' Book of Tested Experiments' began to look redundant, and it was dropped from the scheme. As the *Sample Scheme* took shape during 1964, however, it was clear that there were many more good tested experiments than could be used, and so these were collected into a single volume, *Collected Experiments*, edited by another recent member of the Team, B.J. Stokes, who had edited the *Tested Experiments for Use with Chemistry for Grammar Schools*, published by what was by this time the Association for Science Education.

Pupils' experimental instructions were started in draft form by Van Praagh in 1963. They were never intended to be comprehensive. Experimental work was to be closely bound up with the testing of hypotheses and their predictions, and it was clear that many experiments would be best developed in class or individual discussion. Laboratory instructions for pupils were therefore regarded as necessary only where pupils were likely to experience difficulty without them; for example, through forgetting what they had heard in discussion, or through not knowing the names of some of the apparatus. However, once trials started, it soon became clear that teachers wanted quite structured worksheets for many more experiments than had been anticipated, and these, too, were provided. The belief that separate sheets, rather than a book of instructions, should be provided was supported by trials teachers, so this was the form adopted for publication.

The Book of Data

This was to be something 'quite new in the field' (*Memorandum III*). Its contents were not intended for memorization, but were to fulfil three main purposes: as a source of reference; as a major teaching aid from which problems for discussion could be derived; and as a means of incorporating problem-type questions in examinations which allowed its free but intelligent use. Halliwell detailed his intentions in *Note for Discussion No. 7*. Basically, what was needed was a book that was easy to follow, inviting and extending. Its information should be classified in terms of five major questions that should be asked in chemistry, at any level, about the changes taking place in a flask or test-tube:

1 What is changing into what, and how much are we getting?
2 How far does the change go, and how can this be altered?
3 How fast does the change take place, and can I speed it up or slow it down?
4 What energy changes accompany the material changes?
5 What changes are there in electrical properties that might help me to understand the reaction?

Finally, it would be important to indicate whether the data referred to the properties of materials on a bench or to the model which was used to explain their behaviour. Work on the book started in June 1964, and it was edited by Halliwell.

The Background Books

The Project aimed to stimulate pupils to read about all sorts of chemical topics not covered in class, and a series of small supplementary books were accordingly to provide suitable material. Halliwell developed his plans for these in *Note for Discussion No. 9*. What he had in mind was something similar to the popular 'I-Spy' series: small books cheap enough to sell readily, and available from every bookstall. They should therefore be as attractive as possible, with coloured photographs, maps and charts, and they should cover historical, biographical, sociological and industrial topics in an interesting fashion. Their range should be very wide, covering many interests and ability levels, so that teachers could select them as appropriate and use them to provide stimulus and interest. Forty-one possible titles were listed in *Note 9*.

Work on the books started in March 1963, under the editorship of Hugh Oliver. This task was subsequently taken over by William Anderson, who joined the Science Teaching Project as a member of the new editorial staff in 1964. Few of these books were available for the trials, so there was little possibility of modification on the basis of feedback. Over succeeding years a wide range was produced, with a variety of authors, including some eminent scientists. Halliwell's dream of a chemistry counterpart for the 'I-Spy' series was not realized, however, for 'by the time they had been produced and allowance had been made for overheads and profit, they'd been virtually priced off the market'[3].

The question of 'other publications'

Memorandum III discussed the question of other publications, including Halliwell's decision not to include a pupils' textbook in the range of resources. It was crucially important that the Project's publications should avoid perpetuating a dogmatic approach to the subject, and providing a textbook would, he believed, put this major aim at risk. It would also indicate a failure on the Team's part to recognize that teachers should be free to choose any textbooks they thought appropriate as sources of reference and consolidation, rather than that they should be tied to what might come to be seen as a 'single, authoritative source'. Pupils would have their workbooks for reference and revision. At no time during development, therefore, was the Team prepared to view a textbook as a desirable component of the range of resources, although they supported the idea that others might be stimulated to produce new textbooks to widen the range of those available.

In *Memorandum III* Halliwell also suggested that many teachers would welcome monographs on specialist topics such as modern chemical theory or industrial applications, but he did not believe that they were part of his brief. The Royal Institute of Chemistry had already published some suitable monographs,

and he expressed the hope that more would follow, especially in those areas being taught by teachers taking up the Project. Having such information readily available might encourage teachers to experiment with new methods of presenting it to suitable classes, and this in turn would be in the interests of continuing innovation.

Visual aids

The Nuffield Foundation developed a general policy for the production of visual aids when work on the projects got under way early in 1963. Within this policy the Chemistry Project planned to provide films, film loops, charts and models. Although exact requirements could only become clear as the work proceeded, Halliwell stressed, in *Memorandum I*, that two factors were of overriding importance in every case: clarity of communication and singleness of teaching purpose.

The *Handbook for Teachers* dealt at length with the question of using models in teaching chemistry, suggested satisfactory commercially produced components, and gave descriptions for making models in school. The Project also introduced a simplified Periodic Table in 'long' form, that is, based on expanding regularity, for the 'value of the story of the Periodic Table lies in the search for the pattern based on the conviction that there is one'[4]. The major innovations, however, were the diffraction grids and the film loops.

The diffraction grids derived from a mass experiment demonstrated by Sir Lawrence Bragg at a Mitchell Memorial Lecture at Hanley that Halliwell had attended. To illustrate the principle of X-ray crystallography, Bragg had his audience looking through their handkerchiefs at an electric lamp on his desk, and Halliwell wanted an equally simple means of showing pupils that it is possible to make deductions about structure that cannot be seen from the pattern that can be seen. (In the Chemistry Project the phenomenon of diffraction patterns is used even before their explanation is taught in physics.) Using a combination of drawing, photography and reduction, a master negative was produced, and this was then handed over to the publishers for mass production.

By far the major output among visual aids, however, was the film loops, used with daylight 8mm projectors, which had very recently appeared on the market. When the Project started, Shell International had seconded one of their cameramen, D. Segaller, and had put their film unit at his disposal. Work started early in 1963, and the first eight loops were ready for the 'pilot' trials in the autumn. Each dealt with the chemistry of a specific substance, or a chemical concept or process. Some were intended to be used directly for teaching (for example, those with animated diagrams), others were to amplify or extend lesson materials. Each loop was designed to run for three-and-a-half to five-and-a-half minutes, the length being determined by the idea being put across — and by how much could be fitted into a cassette! Colour was used for most films, although black and white films were made when colour afforded no definite advantage. Because they were silent, teaching notes were essential, but teachers were advised, and expected, to adapt these to suit their own pupils' levels of sophistication. A few loops also had a wall chart provided.

Tremlett had overall responsibility for the loops, and he went to great lengths to obtain advice from experts in the field of both education and chemistry before deciding what was to go into each loop. Decisions had to be made about, for instance, the content required to illustrate the concept or process adequately, about sequencing to ensure maximum impact, about the flow of sequences, and about the use of animated diagrams. When the film was ready for editing it was seen by two or three Team members, one of whom was usually the Organizer, and then a master copy was put together. From this point on, little alteration of the film was possible, but the teaching notes which accompanied each loop were sent out to trials schools in duplicate so that one copy could be altered as each teacher thought fit and then returned to the Team. Notes were then altered on the basis of all feedback.

The history of the development of the resources is, clearly, one of having to provide a steadily growing amount of detail, mainly in response to pressures from teachers. As a result the initially proposed four main books became, in the end, six much larger books, in addition to the range of *Background Books*. This put the Team under quite unanticipated and constantly escalating pressure. For Halliwell it is, in retrospect, the only real constraint upon what they were trying to do; for Team members, it is the only aspect of their involvement which is remembered with anything less than pleasure. At times the pressure of work became quite intolerable, for in addition to this unanticipated demand for ever more detailed specification there were also requests for information and discussion from a wide

variety of sources, offers of help to be answered and talks to be held with numerous overseas visitors, anxious to find out what was going on — and these took up hours of precious time. In the last two years in particular there were continual requests for talks by Team members just at the time when pressures were at their greatest. There were negotiations — from scratch, since these were the first projects — with publishers, film laboratories, and scientific instrument makers and suppliers, and there was a host of problems to be solved on the matter of public examinations. Figure 6.2 shows the way in which the undertaking escalated, and should be compared with Figure 5.1, p.121.

Almost inevitably, then, certain intentions became submerged. One was the plan to have a control group of 'unbriefed' teachers. Another was the intention to include the social relations of science in the broad sense outlined in the *Memoranda*, as well as the applications, which were covered to some extent by the 'Options'.

At that time the 'special problems of girls schools' tended to be seen largely in terms of (a) the long-standing difficulties of recruiting women graduates, especially high-calibre women graduates, in chemistry and physics[5], (b) timetabling in girls' schools, and (c) laboratory accommodation[6]. When the needs and interests of girls were raised as a possible area of concern during this period, it was pointed out that girls would be following the same courses as boys at university, and would be taking the same school-leaving examinations and that, therefore, no special modifications should be contemplated[7]. (The possibility of pressing for changes in examinations and university courses was not, apparently, mentioned in this connection.) The Studley Experiment seemed to consolidate the belief that the problem was situational, for a report on it stated that where the teaching was of good quality, girls were having no special difficulty with modern physics[8]. Where possible motivational and attitudinal differences *were* suspected, suggestions for improving the situation tended to remain content-bound. It is apparently only comparatively recently that differences in social conditioning have come to be seen as important factors which may influence the way in which girls in school respond to interpersonal relations and to teaching approach and which may, in part at least, account for many teachers' complaints that 'girls cannot use the open-ended Nuffield approach'[9]. It is interesting to note that in September 1964 a confidential report by HMIs on the three O level projects suggested that 'it could well be that

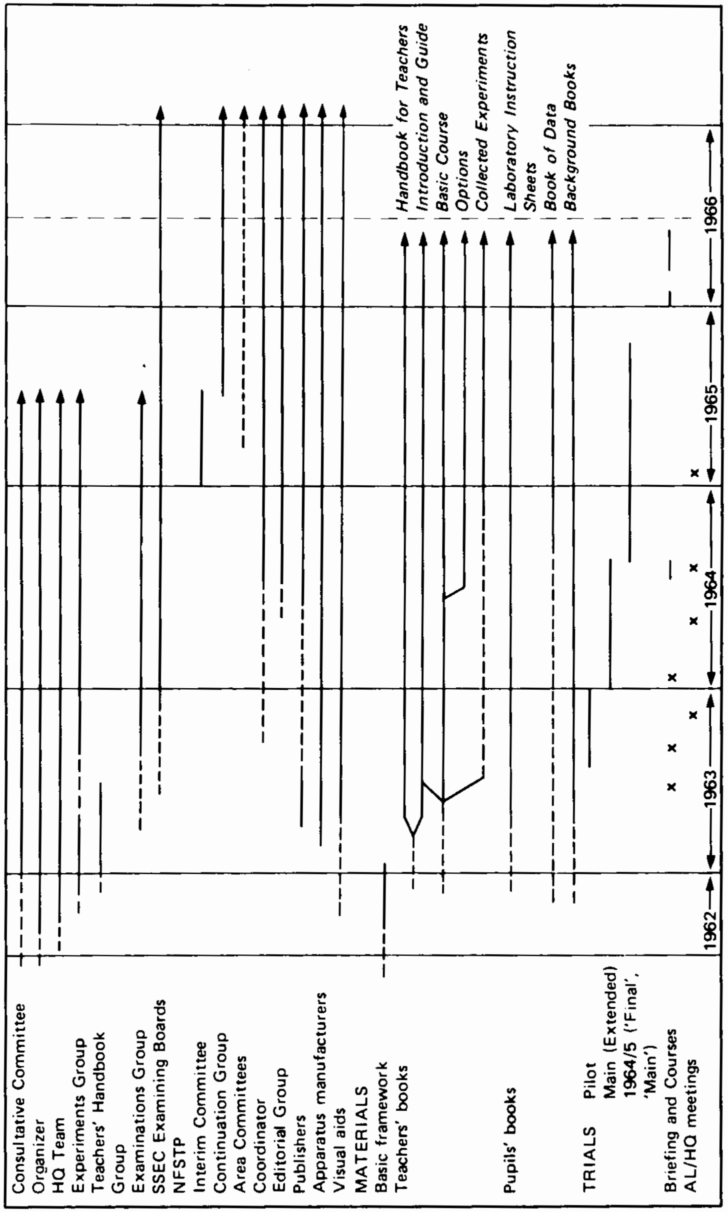

Fig. 6.2 Flow sheet to show chronology of aspects of development

girls in particular might be less attracted to chemistry' as a result of the heavy emphasis on experimental work, although no reason was given for this opinion[10].

Reconstructing examinations

The science teachers' panels had been only too aware of the need for a new type of examination and of the formidable issues that still remained to be solved in its administration. High priority was therefore given by the Nuffield Foundation Science Teaching Project to a successful marrying of schemes with examinations and tests of all kinds, including homework questions, and to the establishment of close working relationships between the Teams' Examination Groups on the one hand and the GCE examining boards and Secondary School Examinations Council on the other. This concern was stressed in every published statement, from the first press release on.

In the *Memoranda* Halliwell anticipated that the issue would be sufficiently important and difficult to warrant what was, in effect, a 'complementary project'. Reorientating the course towards what pupils could do, rather than what they could remember, would demand not only different types of question, but careful appraisal of what it was intended to measure. Theory papers would need to measure the ability to discuss, criticize, interpret and speculate about results obtained at the bench. Practical examinations would need to aim at discovering whether pupils could obtain experimental results in a relevant form. In addition, teachers and all others concerned would need assurances that pupils' chances of examination success would not be jeopardized in any way, either during trials, or in the post-publication period. Whatever the inherent difficulties, however, the approach proposed by the Project, with its flexible framework would, he believed, ease two major difficulties. The need to cover a set syllabus in detail, or even to adhere to it rigidly, would now be obviated; and the problem of how and what to 'prune' would lose much of its force[11].

Direct attention turned to examinations in the summer of 1963, with the establishment of an Examinations Group by each of the O level projects. The effectiveness of the groups was clearly crucial to the whole enterprise, and it depended very much on their skill, their ability to collaborate successfully with experts in the field of evaluation and assessment, and their public relations capabilities. The constitution and operation of the Examinations Group differed considerably between projects, as did the use of expert help, but in every case the first task was the same: to define exactly what was needed, and to collect a representative set of sample questions to illustrate it.

Nuffield personnel held informal talks with Ministry officials in October 1963[12], after which proposals for discussion with Secondary School Examinations Council and examining boards were drawn up. Following much deliberation, a tactfully brief memorandum went to the Syllabus and Advisory Committee of the Secondary School Examinations Council before a special meeting held in early December. It pointed out that there was an urgent short-term need for assurances to schools that a means had been found for safe-guarding the examination interests of trials pupils, many of whom would be taking O level examinations in June 1965. Further, it was vitally important that such assurances be *seen* by teachers as emanating from the examining bodies, and not merely from the Nuffield projects. In the long term the Nuffield Foundation Science Teaching Project was, and would be, seeking advice from the boards; but in return they hoped that the fruits of their own researches would be of mutual use[13].

The Advisory Committee met on 4 December, and proved sympathetic, so on 12 February 1964 the memorandum went forward to a joint meeting of the Secondary School Examinations Council and the Secretaries of the eight GCE boards. With it went a background paper setting out some relevant and fundamental issues, including the then controversial question of internal assessment with external moderation, and an appendix containing some sample old- and new-style questions[14].

Although the memorandum was couched in very general terms, Nuffield personnel were quite clear in their own minds about their needs. The Studley scheme had run into difficulties as a result of having the three boards who were involved set and mark their own papers. The aim now was to persuade all — or as many as possible — of the boards to agree to common alternative papers for each of the O level schemes, a plan for which the School Mathematics Project had provided a precedent. The Studley Experiment had indicated, too, that it might be profitable to press for a collaborative enterprise between the Nuffield Examinations Groups and a joint working party, set up by the examination boards, to set and mark the experimental papers. There was also a strong wish to work towards internally assessed, externally moderated examinations, but it was considered politic to keep this issue at the level of intention only for the time being since it was highly contentious[15]. (It was to be a feature of the CSE examinations then under consideration — but for a different section of the age group.)

Between December and February there was much informal activity, and as a result the meeting passed smoothly and ended in a unanimous undertaking to cooperate on the setting of special Nuffield papers for 1965. These were to be prepared by a joint working party, whose membership was drawn from boards and Nuffield Examinations Groups. The all-important assurances to trials schools were also given, the boards agreeing, for instance, to correlate the marks with the school's previous performance in science[16], and a letter to that effect was sent to heads of all trials schools[17]. Details were to be discussed at the annual meeting of examining board Secretaries in Cardiff, on 8 April, and Organizers were asked to submit, before then, suggestions for special chief examiners and moderators to conduct the special alternative paper for trials schools in 1965, along with some kind of syllabus. Difficulties over the last request were touched on at the February meeting, and as a result a senior official from the Department of Education and Science (successor to the Ministry of Education) informally sounded out the Secondary School Examinations Council and examining boards about the likely reaction to a 'highly unconventional form of syllabus' in place of the normal list of topics. On his advice each Team produced a document stating the aims of the course and suggesting how examinations might best assess the achievement of these aims[18]. With it went relevant materials, such as the Chemistry Project's *Introduction and Guide* (which was, at that point, effectively the revised *Memoranda*), and an outline Sample Scheme. An accompanying letter admitted that this was a somewhat unconventional syllabus, but expressed the hope that the boards would find it an acceptable basis for judging whether the proposed alternative examinations deserved their support. It added that the Secondary School Examinations Council had indicated that they would accept it, provided that the boards did so. There would be relatively few candidates in June 1965, the letter went on, and it therefore seemed likely that one chief examiner and one moderator could cope satisfactorily with the machinery of the examination.

The problems of trying out new techniques were greater. In order that this might be handled satisfactorily, the letter suggested the creation of an advisory committee of up to eight members, other than the chief examiner and moderator, and including, if possible, the Organizer. This committee should include members with a wide range of experience, especially first-hand experience in working with project materials. To this end, they would like it to include members of the project teams, one or two trials teachers, and some chief examiners from boards other than that chosen to administer the examination in the subject in question. Although the people concerned had not yet been sounded out, names were being suggested for the committee in each subject[19].

At the Secretaries' meeting[20] the names proposed for chief examiner and moderator in each subject were accepted without question, as was the proposal that the Organizer should be an *ex officio* member of the committee. For the rest, although the people suggested were acceptable, the Secretaries chose to leave open the question of how teachers participating in trials could participate in the discussion of examinations. Nuffield personnel felt quite strongly that since the teachers concerned with Nuffield trials were the only people with first-hand experience of the materials, they should be involved in this way. They also saw it as the first step towards their goal of internally assessed, externally moderated examinations, and so they pressed for continuing negotiations between Organizers and appropriate boards on the matter[21].

The idea that it would be most practicable for one examination board to undertake responsibility for running the joint examination in each subject had been mooted at the February meeting, and the London University Board had agreed to take care of chemistry[22]. At the Secretaries' meeting in April, the boards agreed that the Oxford and Cambridge Joint Board should administer physics, and the Northern Universities Joint Matriculation Board, biology. Since all eight boards wished to be publicly associated with all three examinations, no announcement of the arrangements was to be made[23]. It was evident that all eight Boards could not participate actively in setting and administering all three examinations, and a certain amount of 'parcelling-out' was done. Although only one board actually carried out the administration of the examination, two or three 'linked' boards dealt with each Project. Linked boards had a nominated member on the appropriate advisory committee. Marks were to be accepted by all eight boards as commonly valid. It was also agreed that trials examinations would follow this pattern for a few years, until the number of candidates made reversion to standard procedures desirable. Since all boards would be collaborating during this interim period the eventual changeover would be straightforward[24]. 'We have every reason to be encouraged by the friendly and cooperative attitude which the examining boards have shown', commented a member of the Nuffield Foundation personnel in a letter to the Organizers[25].

The go-ahead having been given and approval of the syllabus formalized by the Secondary School Examinations Council, each Project proceeded individually with its negotiations with its own linked boards. In the meantime, the work of devising tests and examination papers and of analysing answers and results was continuing. Trials examinations were held in March and June 1964, and in February/March 1965 (including mock O levels). On each occasion the moderator produced a full report which was then circulated to all interested parties.

The Chemistry Project's Examinations Group was established in the summer of 1963. In July Coulson produced a paper, 'The Preparation of Specimen Examination Questions', which included sections on the relevant aims of the Project, needs with regard to examination questions, the use to be made of specimen questions and proposals for getting the Group under way. Letters were sent to Dr F.H. Pollard, Dr E.J. Spice, J.C. Mathews and G.D. Cast, inviting them to join the group. All were experienced in examining and in preparing pupils for examinations and, in addition, all were believed to have the 'necessary flexibility of mind and willingness to experiment'. The need for illustrative questions was stressed in the letter[26] and in Coulson's paper, which accompanied it. The range of questions, Coulson suggested, might include essay, multiple choice, open-ended short answer, comprehension and data interpretation types. They would be needed for the trials and for use in negotiating with examining boards and the Ministry of Eduation. Questions illustrating the different types were more important than coverage at this stage, Coulson claimed, and he proposed that the group concentrate on producing some twenty to thirty questions, covering the different types, but confined to only five or six topics. The standard, in terms of level of difficulty was, for the moment, of secondary importance.

The Group met for the first time on 2 September 1963, by which time they had received copies of some of the draft materials, and also had at their disposal testing programmes issued by American chemistry projects, other test material from the United States, question papers used in pilot schemes for the new CSE in England and Wales, testing materials used in the Scottish Education Department's new chemistry programme, and reports on new-type question papers tried out by individual teachers in Britain. Spice had been to America during the summer on a prearranged visit, but during the course of it he had undertaken to collect as much information as possible, especially any relating to the advantages and disadvantages of multiple choice questions. Coulson had sensed a 'measure of informed opposition', emanating, in particular, from Banesh Hoffman, author of *The Tyranny of Testing*, during his stay in America in the previous year, and he was concerned to have this followed up[27].

The first meeting of the Examinations Group illustrated the type of structure of delegated responsibility referred to earlier. Halliwell spoke briefly and in general terms about what he wanted and then Coulson and Rogers outlined the actual analysis they had produced. The Group then worked for three days under the chairmanship of Pollard, on the rationale, the aims to be assessed and thence the objectives, the types of question to be used and the problems of practical examinations. Pollard undertook to write up the deliberations in the form of a general policy statement[28], while the others set about devising questions along the lines agreed before the second and final meeting of the Group in October.

In formulating their objectives the Group decided that they should be testing how far the pupil had benefited from the course, that is, not just the thoroughness of his understanding of the subject matter. Pure recall should, they thought, account for not more than 40 per cent of the total mark allocation. This amount would enable hard-working but less able candidates just to get through. The examination should test the pupil's skill 'in the process by which the scientist explores the universe around him', and if possible, whether the student had the ability to go further in science. The examination should not be allowed, however, to become a race against the clock.

The types of question proposed were those on Coulson's list, and some questions were also designed to test familiarity with chemical materials and equipment as distinct from actual manipulation. This last type was viewed as a corollary to practical examinations, which might help to overcome some of their problems at this level. Practical examinations had come in for much recent criticism because they restricted the scope of experimental work in school chemistry to that which was likely

to be examined. This limitation, the Group believed, would now be particularly significant. They considered two alternatives: a practical examination in which manipulative skills and, possibly, simple analysis could be tested; and assessment of the pupil's experimental skills by internal examination in consultation with an external examiner from the Board, as used by other educational institutions. This was the alternative favoured by the Group, who also agreed that the written paper could cover other desired skills, such as experimental design.

Setting the questions was going to require expertise which few teachers possessed. The Group therefore proposed that a scheme be devised for releasing a number of teachers each year to carry out the work full-time. This plan did, in fact, eventually materialize in the form of item-writing workshops. Multiple choice items were, they warned, in particular need of specialist attention, and would therefore be expensive.

The document that Pollard produced formed the basis of the chapter eventually included in the *Introduction and Guide*. When Pollard became seriously ill in the spring of 1964, Mathews was asked to take over and to build on and extend what Pollard had written. It was at this point that the London University Examinations Board took on responsibility for Nuffield chemistry examinations. Mathews was appointed joint chief examiner with J.H. Strawson, chief examiner in chemistry for the Board, who had many years of examining experience behind him.

Aims into objectives

At the first meeting of the Examinations Group in September 1963 Halliwell had impressed on the group that it was no use resorting to vague phrases like 'enable the child to understand that ... ', or 'to appreciate the difference between ... ', but that they must state clearly what it was that children must *do* if they were to be able to test whether pupils had learned how to be 'scientific'[29]. The Group therefore drew up a list of skills and abilities and these 'ultimate goals', or objectives, were used by Mathews in constructing his first examination. The three sets of objectives, those in *Memorandum II* of October 1962, those in the draft produced by the Examinations Group in late 1963, and those appearing finally in the published *Introduction and Guide*, are shown in Figure 6.3.

Comparison of columns 1, and 2 or 3 indicates that, of

Memorandum II, 1962	Examination Group, 1963	Introduction and Guide, p.124, 1966
Development of:	Examination should test achievement of:	Development of:
1 certain critical and appreciative attitudes to scientific affairs;	1 factual knowledge and the power of recall of such knowledge;	1 facility in recalling information and experience;
2 such delight and satisfaction as will ensure further development of this attitude whatever their future interests;	2 skill (i) to use and classify information or data, including graphical presentation of physical data and arithmetical calculation of experimental results; (ii) to handle materials or manipulate chemical equipment; (iii) to make accurate observations;	2 skill in handling materials, manipulating apparatus, carrying out instructions for experiments, making accurate observations;
3 judgement and discretion as to (i) whether a question can be answered by scientific investigation, (ii) the pertinence of evidence offered, and (iii) acceptability of deductions made;	3 ability (i) to interpret information with critical judgement and assessment (comprehension); (ii) to apply what has been learned in the context of a new situation and to show creative ability;	3 skill in devising an appropriate scheme and apparatus for solving a practical problem;
4 (as a result of sufficient personal and vicarious experience) the ability critically to distinguish between facts, patterns of facts and speculative explanation;	4 the efficacy of communication, both in writing and orally and in this to show the ability to report, comment or discuss matters of chemical interest as well as an appreciation of the use of chemical phraseology or terminology;	4 skill in handling and classifying given information (including graphical representation and quantitative results);
5 an awareness, and expectation, of the development of a science that arises from the interplay of facts, patterns of facts and speculative explanation, and hence	5 awareness of the place of chemistry amongst other academic subjects and in the world at large.	5 ability to interpret information with evidence of judgement and assessment;
6 ability to think creatively;		6 ability to apply previous understanding to new situations and to show creative thought;
7 ability to plan experiments to discipline speculation;		7 competence in reporting, commenting on and discussing matters of simple chemical interest;
8 the necessary manipulative skills;		8 awareness of the place of chemistry among other school subjects and in the world at large.
9 an awareness that this interplay arises from the work of people, past and present, all over the world;		
10 familiarity with some of the broad principles and overall problems of mid-twentieth-century chemistry.		

Fig. 6.3 Aims into objectives

Halliwell's criteria for the achievement of the Project's aims as set out in *Memorandum II*, three were omitted when these were converted into specifications for examination purposes. This was either because they were related to long-term ends ('that it should have a lasting effect'), or because there was no means of testing for their achievement that would be acceptable to examining boards[30]. Examinations test, in varying degree, knowledge and skills; they do not test attitudes and interests. So the criterion relating to aesthetic appreciation and appropriate attitudes was not included, and this aspect must inevitably have faded into the background or, at best, have been left to the subjective judgement of individual teachers. Although the Team subsequently asked for feedback about pupils' reactions to the materials, no specific investigation of attitudes and interests was undertaken by them; this would have involved a research undertaking in its own right, continued over a longer term, but it would have been a valuable one to have had built into the programme (subsequent moves in this direction are discussed in Chapter 9). On the other hand the Hawthorne effect[31] might have interfered with efforts at this period.

A major criterion for successful achievement of the Project's aims was the ability to discriminate between problems to which a scientific approach is appropriate and those to which it is not. It was crucially linked to skills and abilities that the examination was testing, yet it was not included. Halliwell was extremely concerned about this, but was unable to secure its inclusion. Although today there is growing recognition that teachers can no longer ignore the moral and ethical problems and issues raised by the applications, real and possible, of science, resistance of the type, 'Yes, it *is* important, but it isn't science', is still raised at teachers' meetings. The 'discipline' focus of the period, in conjunction with traditional examination stress on subject knowledge, may have produced a blinkering in those concerned of the need for its inclusion, or even, perhaps, a justification for its exclusion.

Because of these omissions pupils were being assessed on a limited range of the intended outcomes, a range that was essentially cognitive. This is, of course, what examinations set out to test. The principal use of examination results is, normally, pupil assessment and selection, and the primary focus of those working on examinations in the Project was the innovatory work required to devise efficient test items that would satisfy examining bodies and that would be seen by teachers, pupils and their parents as 'fair', that is, of validity and reliability comparable to that of traditional examinations. Whether or not this mattered in the long term depended upon the wider interpretation of feedback from examinations, and, even more, upon the use or non-use of other approaches to evaluation, such as attitude and interest inventories and, most important, open-ended classroom observation, especially in those projects whose pupils were less bound to a public examination system.

Throughout the period during which objectives were being formulated there had been no recourse to Bloom's *Taxonomy of Educational Objectives*[32]. Like most others in Britain at the time neither Mathews nor, apparently, other members of the Team knew about this work. Mathews recalls that it was Nyholm who first commented on the correspondence between the Project's scheme of assessment and the *Taxonomy*, and that this enabled him to state the weighting specifications in 'Bloomian' terms. But the items used in assessment were based on the Project's aims and objectives.

Halliwell and Mathews were both committed to the idea of including some element of objective testing, whatever the final format of the examination. Considerable enthusiasm for objective tests existed in certain quarters, not only on educational grounds, but because they overcame the difficulty of finding a sufficient number of competent examiners for marking conventional scripts. There were, in fact, those who argued that they might be the sole means of examining. Others, however, were strongly opposed to their introduction, and Mathews believes that such resistance was very valuable in those early days, because it resulted in a far more extensive thinking-through of the use of objective tests than might otherwise have been the case.

The situation was a highly experimental one, and the types of test item used were simply those that looked satisfactory. They had not been validated under British conditions, for there was no suitable pre-test population. For the first time round, then, the questions could only be pre-tested by Mathews's own pupils who were neither trying out Nuffield materials nor taking the Nuffield examination, but who were being taught along 'Nuffield' lines because this was the orientation of their chemistry department. With each additional examination, however, the situation improved, as answer sheets were analysed, level of difficulty of items determined, and faulty items amended or eliminated. A most valuable source of help and expertise had been provided by a research unit set up not long before by the London University Board, under Dr Keith Millar. His first assistant was Dr Carol Tittle, who had worked with Bloom in Chicago, and the unit proved invaluable, especially on objective testing. With Millar's help item-writing workshops were held which trained item-writers and built up a nucleus of objective test items[33].

Late in 1964 Mathews was joined by another helper, D.M. Stebbens, who was very interested in objective testing and who subsequently acted as first leader of the marking team in 1964, and then as moderator for the examinations (including mock O level) in March 1965[34]. From this point on, work on examinations was closely bound up with trials, and must be looked at within this context.

The trials: testing proposals and organizing feedback

The involvement of schools

In the preliminary planning, two waves of trials were anticipated in 1963/4. A 'pilot' trial in the autumn would be followed by 'extended' trials between January and June. The materials were still highly tentative and the purpose of the trials was: first, to test the feasibility and practicability in the classroom of the new ideas; second, to test whether or not the approach could be transmitted to, and put into operation by, a range of teachers of varying expertise; and third, to obtain feedback for rewriting, so as to increase the effectiveness and acceptability of the materials.

Very careful consideration of schools, teachers and Local Authorities was necessary in the face of somewhat conflicting demands. It was most important that the materials be given a fair trial, and communication, in its fullest sense, was obviously central to achievement of this aim. A representative sample of schools, teachers and pupils was both desirable and necessary, as was as wide as possible a geographical distribution of schools.

For the pilot trials in the autumn of 1963 twelve schools — independent, direct grant, maintained grammar and secondary modern — were chosen because of the teachers in them. Here, selected parts of the still embryonic sample scheme (mainly Years I and II) were tried out. The aim was two-fold: to provide feedback about the nature and content of the materials and, especially, to set the pattern for the extended trials[35]. Two briefing conferences were held during the preceding summer, both in London. At the first, teachers and Team discussed the philosophy of the project, and the implications of this philosophy for experimental work, and for the use of questioning techniques. They also discussed and amended weekly report forms to be used by trials teachers. At the second meeting, the twenty-six participating trials teachers and the Team were supplemented by three members of the staff of the Nuffield Foundation, two headmasters and three HMIs. Plans for the publications were outlined, and further queries about such matters as feedback were discussed, but most of the day was focused on the teaching materials[36].

Teachers started the term with the second draft of the *Introduction and Guide*, and lessons were based on outline lesson notes and six of the film loops. Feedback was carefully sifted as it came in and appropriate action taken. This sometimes meant scrapping whole lessons but, in the main, the two major problems that emerged were the demand from teachers for more detailed lesson notes and their complaint that the work could not possibly be fitted into the allotted time. The real extent of the problem was difficult to assess, though, for teachers were coping with new material and, in many cases, a new approach, and they were anxious to play their part in the testing exercise. Both factors would affect their efficient use of time, and these problems would probably be less the second time round; this would need to be taken into account in any modifications made.

The trials: the channelling of localized criticism

Preparation for the extended trials got under way as soon as the pilot trials began. Their establishment was, however, along quite different lines from that of the pilot trial. Some detail of the procedure used will be given, for it is yet another example of the devolution of responsibility within a framework of control which characterized the Nuffield O level Chemistry Project.

First, the Headquarters Team, with the close help of the Royal Institute of Chemistry, the Inspectorate and the branch secretaries of the Science Masters' Association, drew up a provisional list of chemistry teachers who were keen to take part in the trials. All were visited by the two Team members who were establishing links with schools (Rogers and Van Praagh) and twelve were finally selected on the basis of personal merit and geographical coverage[37]. The group was complete by the autumn and had its first meeting in London on 23 November. They were told of the progress being made in producing materials and of the

pressures created by teachers' demands for more detail. They were then briefed on the procedures for obtaining trials teachers in schools in their area, which was to be their own responsibility, and urged to get this under way as soon as possible. They were asked to select their own teams of, on average, five local teachers, whose headmasters or headmistresses would be friendly and who should represent, if at all possible, a cross-section of schools. Priority should be given to people with whom the 'Area Leader' could work and who could be relied upon to collaborate and to give the material a fair and yet critical trial. After matters had been cleared with Local Authorities by the Area Leader, the Organizer would write personally to the headmaster or headmistress of each school, asking whether he or she would allow (and encourage) the chemistry teacher and junior forms to participate.

As far as administration of the trials was concerned, Area Leaders were told that they would be sent copies of the current drafts in December, together with weekly report forms, the revised film loop report forms and a revised list of apparatus. They would also be sent a photostat copy of a 'good' example of a completed report form. Participating trials teachers, they were told, would be briefed at a meeting at University College, London, on 4 January 1964.

During the trials, Area Leaders would be responsible for the collection of weekly reports and film loop reports from their groups of teachers. Weekly reports should be summarized and sent to headquarters during the first week of every month along with an overall report of their own and all film loop reports. Regular meetings of Area Leaders and their teachers were also needed, to ensure full feedback. In the case of the draft *Handbook for Teachers*, material would be sent out in duplicate to all participants. Feedback here was to be sent in the form of one copy of the typescript, altered as they thought necessary or desirable:

> We said, 'If you don't like anything, put a line through it and write on the opposite page the actual words that would please you.' By insisting on that, we had only twelve copies come back from the Area Leaders, although they had collected the opinions of some sixty teachers ... Later, two copies of the amended version went back to teachers again, and again they would discuss it and, again, the Area Leader would send it back either altered or with a tick at the bottom if it was

> acceptable ... Such a scheme of feedback made our life much easier ... It also focused their attention on what the wording should be. We didn't want them just to say, 'This is too difficult'. If they rephrased it carefully in the way they thought proper, we had something ready for the printers, and it also meant that any of the sixty teachers who helped us could go through the text and find wording that *they* had suggested. They were involved.[38]

The full-scale conference for all trials teachers was held, as arranged, on 4 January 1964. The major topics for discussion were the purpose of trials, the publications, apparatus and film loops and examinations. Details of the Area Leader organization were also clarified. The meeting proved to be a very difficult one for the Team. They had just returned from the Annual Meeting of the Association for Science Education in Birmingham, at which Halliwell had spoken, and they had been responsible for the Nuffield chemistry section of a display of experiments that formed part of an exhibition on 'future trends in science education'. The pressure of work was considerable. They were very tired, and they were possibly less than tactful in their approach to a mixed group of teachers meeting the ideas for the first time. Whatever the cause, there was some initial antagonism. However, the situation improved once teachers were meeting and talking to their Area Leaders. It was clear though, that this type of briefing exercise was quite inadequate for the task, and that a different approach was needed in future[39].

The extended trials were based on the third draft of the *Introduction and Guide*, draft chapters of the *Handbook for Teachers* appropriate for all three stages and made available as the trials proceeded, sections of the *Book of Data* and the *Pupils' Laboratory Instruction Sheets*. Background Books were also circulated to schools and the number of film loops grew steadily.

Feedback from Area Leaders came in monthly, based on their teachers' written criticism of each lesson, recommendations for modification and suggestions for suitable homework. Some reports were encouraging, others quite scathing; some dealt with trivia, others with fundamental issues such as the apparently 'wrong' sequencing of a topic. All criticism had to be evaluated: did complaints that 'this takes too much time', for example, reflect too much material for the time allocation, or the fact that it was being taught for the first time? Or did the report form

need amending? Sometimes comments from different schools were contradictory, some teachers complaining that materials or experiments were 'useless', others saying that they were 'very good'. This type of feedback was dubbed the 'Nuffield self-cancelling factor' by the Team. The feedback from Area Leaders was carefully sifted by different Team members for all comments relevant to their particular responsibilities. Everything related to teaching material was filed according to topic, so that all comments on any particular topic were readily available at any time, including problems with experiments.

Area Leaders also met in London at intervals of about a term, so that progress could be assessed, improvements suggested and problems given an airing. The Team found these sessions particularly valuable, especially one held at the end of the extended trials in June 1964. Final trials were to start in the autumn and since the year 1964/5 would also see the materials put into a form ready for publication, it was important that as many major amendments as possible be made straight away, in the hope that the coming trials' feedback would then indicate a need only for relatively minor changes. The main purpose of the meeting was therefore to discuss the structure of the course. A paper sent out in advance reported that the extended trials had indicated two major problem areas: too little time was being allocated for adequate coverage of topics, and Topic 11, *About Atoms*, was producing a number of difficulties in schools. It was proposed that the course be rescheduled so that the introductory stage would now be extended to cover two full years. The former Years II and III would now occupy Years III and IV, and 'Options', Year V. Area Leaders were asked to reflect upon a series of questions posed in the light of these proposals, and to come to the meeting prepared to discuss them. Would any part of the scheme still be too long? Was any part still too demanding? Insufficiently demanding? Had Topic 11 thrown up problems? If so, was this because the area was unfamiliar to teachers as material for this level? Or were the concepts too difficult for pupils? Were aids needed here? Were the film loops and their notes useful, and were their teachers using them in the 'right' way? Were their teachers happy about individual publications[40]?

These issues were all discussed at the meeting. Area Leaders reported that the new time schedule seemed about right, although some regarded it as too generous. Given this extra time they believed that the level of difficulty, too, was 'about right'.

Many of the difficulties with Topic 11 and subsequent topics appeared to them to be mathematical in origin. In fact, they reported, mathematical weakness was proving to be a handicap throughout the course, especially where proportion was involved. Visual aids were, in general, satisfactory. The problem of practical examinations was discussed, and agreement was reached on the content and format of individual publications. Much talk centred on the need for an interim A level course for schools wishing to continue Nuffield-type work through into the sixth form before the A level materials became available. This matter was now beginning to appear pressing, since some pupils would be taking O level in a year's time[41].

The trials: the Loughborough Conference

The Chemistry Team had not anticipated trials in 1964/5. The year had been scheduled for revision and preparation of the resources for publication and for further work on examinations, on apparatus and equipment, on experiments, and on visual aids. But the issue of further trials emerged during preliminary discussions about inservice courses, and the training of personnel to run them. In June 1963 proposals were put forward for a course/conference in September 1964, just before the main trials for the Biology and Physics Projects. By October 1963, it was definite that the conference would take place; it was planned to take the form of two week-long courses, run concurrently by each of the three Projects with the help of HMIs. To encourage consideration by LEAs of teacher applications for help with fees and subsistence, it was suggested that they should be designated 'Ministry short courses', and that each should be under the general direction of a member of the Inspectorate. Recruitment was to be by invitation only, and limited to trials teachers, along with a few representatives from other institutions and, possibly, one or two Local Authority science advisers. The search for a suitable venue proved a difficult one, but eventually a definite offer from Loughborough College of Advanced Technology, in December, made further planning possible.

The Chemistry Team had at first resisted the idea of yet more trials, but they now conceded that in spite of the anticipated workload in 1964/5, and in spite of the fact that the value of feedback for revising materials would fall sharply as the year passed, there were also advantages, and they were therefore prepared to fall into line. The extra year would have some sales

value in preparing the ground for reception of the materials in 1966; it would help inservice training, and it would allow time for more visits, advice and consultation to schools. Nevertheless, they argued that from their point of view at least, the course at Loughborough should be more than a briefing session for the 1964/5 trials. Unlike the other sections, they could make profitable use of it for obtaining feedback, but they (and perhaps other sections, too) should use it to initiate a 'chain reaction' for increasing the number of teachers conversant with the aims and content of the Project. By using it to train a selected small group of Nuffield-experienced teachers in the art of running a course for teachers they could lay the foundations for an 'apostolic succession' for inservice training. In a persuasive memorandum they proposed that the first week should be devoted to experienced trials teachers, who would then be trained to handle a much larger number of 'newcomer' teachers during the second week. The scheme would, they added, have the merit of freeing the Headquarters Team to circulate and so establish contact with a very large number of teachers[42].

The chemists were also concerned that participants should be given an opportunity to hear about, and exchange views on, other projects, so as to put the whole Nuffield Foundation Science Teaching Project into perspective. As a result of discussions held between Organizers and HMIs at the end of January 1964 a coordinated framework was planned for the Loughborough Conference, to make such interdisciplinary sessions possible. For most of the time, however, the sections worked separately, and planning was in the hands of individual Teams. For a variety of reasons the chemists were forced to modify their plans, so that far fewer teachers than they had hoped were able to participate, but the basic training idea held good. During the first week, the Headquarters Team ran a course for Area Leaders; during the second week, Area Leaders ran it for other teachers, including newcomers[43].

A list of new topic areas was circulated before the conference so that teachers could familiarize themselves in advance with the Project's handling of them. They were also asked to bring with them any available samples of pupils' notebooks from the 1963/4 trials[44].

At the conference, lectures were given on 'non-traditional' aspects of the Project, on examinations, on film loops and on feedback. The rest of the time was spent in laboratories, mainly in experimenting with 'kits', participants working in pairs. Each pair was able to carry out any of (almost all) the experiments from Stages I and II, and from three of the Stage III options, the only proviso being that they try to cover the materials they would be teaching in the trials. The organization of this sort and scale of experimental work was a very formidable task, yet it was all undertaken by a single Team member, Tremlett, and it went very smoothly.

> We showed the teachers what the proposals meant, not by lecturing to them, but by getting them to do the proposed experiments, while we went round, asking them the kinds of question we hoped *they* would ask the children, and which we hoped the children would be encouraged and trained, eventually, to ask themselves.[45]

This, the Team hoped, would avoid any tendency to treat the experimental work as an obstacle race to be got through, rather than as a sequence to be thought through.

Experience in the 1963/4 trials had indicated the desirability of finding a more unified system of trials for the three sections in 1964/5. Accordingly, ten areas were selected in England and Wales, with one or two key people already in them. By a fortunate coincidence each area turned out to be in a different inspectoral district. Each of the three subjects was not, however, tried out in all ten areas because, again, the availability of Area Leaders was the basis of decision. For each Project a range of some ten schools was selected for each year, and between them, all five years of the course were tested. To ensure consistent and careful feedback it was important that teachers should not be overloaded by having to take more than one trials class and that each class, in turn, should be taught by only one teacher in the subject concerned.

For the chemists this did not mean any significant alteration to the pattern of the earlier trials. Some fifty-six schools participated and, of these, forty-four were visited by Van Praagh, to see the materials in use. With a more detailed and tested *Sample Scheme*, and with better apparatus, feedback was now more confined to specifics, as was the revision of the drafts[46]. Other changes would now have to await the revising committee that was already under consideration. (No revision was undertaken until the early 1970s, however.)

The year was one of varied and sometimes frenzied activity, but the materials gradually reached more or less final form. HMIs produced a confidential report in September 1964[47], and this, too, provided some feedback. University scientists were sent pre-publication copies for comment upon academic respectability. Examinations and tests provided feedback for the Team but were, perhaps, even more important at this stage in shaping teacher perception of their comparability and validity — a factor which could make or break the entire enterprise.

Trial examinations for the pupils

The first examination was held in March 1964, at an early stage in the trials. Forty-one questions, covering Years I to IV, were distributed to schools, who then selected two. All but six of the questions provided were used, and only one school complained that none was suitable. When sending in scripts, teachers were asked to comment on the questions and, as a further guide to their perception of the satisfactoriness or otherwise of questions, were asked to give estimates of the expected mean mark for each question.

Answers were marked by four specially appointed markers, and a moderator then analysed the results and circulated a report[48]. In a number of cases there were too few schools and far too few pupils for the statistics to have much value *per se*, although they were useful for the design of items in the future when used in conjunction with markers' comments. In spite of this, several tentative conclusions were possible. Teachers' estimates for mean marks had been surprisingly close to 50 per cent for each question, an indication, presumably, that they regarded the questions as satisfactory. But the correlation between the mean mark actually obtained and these mean estimates was low. This did not necessarily mean that questions were faulty, as the moderator pointed out. The low correlation might well be due to the fact that pupils were unaccustomed to the demands made by some types of question. Their marks tended to exceed teachers' expectations on questions (or parts of questions) requiring only recall, while on one question requiring considerable clear thinking and little recall, 250 pupils earned no marks whatever. It was therefore proposed that teachers be asked to give pupils regular practice with questions requiring skills other than recall. The other comments in the report dealt mainly with teething problems such as ambiguity or complexity of questions. The need for analysis had led to long delays before papers went back to schools and, the report suggested, 'the only way to solve this seems to be to ask teachers to mark the questions themselves'. This would entail the preparation of far more detailed marking schemes, but the idea was adopted for the end-of-year examinations in 1964[49].

This time booklets of questions were sent to schools; once again, teachers could select from them. Many of the questions were entirely new, but several had been given in March and were being repeated either because more information was needed to indicate whether they were, in fact, good questions, or because they were being re-tested after modification. Answers were marked by teachers and then a sample including at least two scripts was taken from every class involved and marked by the marking team. The moderator reported that modifications to questions had on the whole been vindicated, but that there were still some questions which very few schools had used, or pupils had attempted. All questions had given a suitable spread of marks, and it was now becoming clear that papers containing a good proportion of questions of an objective type were satisfactory, and discriminated well among candidates. Far more questions appeared to have been too difficult than too easy; once again, the cause might in many cases be the novel form of the questions rather than the level of difficulty. Problems of balance still remained, however. There was some evidence of poor and erratic marking by teachers, and it was also clear that the specification of mark schedules needed more attention. This might be helped in future by having Area Leaders more closely involved in the marking.

Stage I seemed to be going very well indeed, but rather less information was, as yet, available on Stage II. Certainly, the idea of g-formulae did not seem to be getting across satisfactorily. Yet evidence from the examination papers that apparent difficulty in comprehension did not correlate with 'general brightness' of the pupil suggested that it was the teaching of the early part of Stage II that was at fault, rather than any sharp rise in the level of difficulty in the *Sample Scheme* at this point. Further evidence for or against this hypothesis would have to await the February 1965 examinations. (Area Leaders at this period saw the difficulty as having its roots in shortage of time and in pupils' mathematical inadequacies rather than in teachers' unfamiliarity. The latter problem would, of course, be remedied by time. They were apparently not asked whether some more fundamental teacher-based difficulty might be operating.)

In 1965[50] the moderator again reported that the g-atom approach was 'still not getting across' to many pupils who were

'now able to carry out routine operations, but do not appreciate the significance of the concept'. Since the concept was fundamental, he added, this was worrying. By this time, however, a new moderator had taken over analysis of the scripts, and there is no record of any follow-up. It is no longer possible to estimate whether this was because the same discrepancy did not show up and that, consequently, this question was not raised, or whether it was simply ignored or neglected because of Area Leaders attitudes (p.163) or because of the pressures on time. Certainly, probing during interviews failed to elicit any recollections of the matter. In the light of subsequent criticism, especially that emanating from Shayer *et al.*[51], the failure in 1965 to explore this further may have been a very unfortunate one, for the long-term consequences have been considerable.

For the February/March 1965 examination, five papers in booklet form were devised and printed to try to overcome earlier problems with poor duplication by some schools. Although certain schools had not covered enough of the work to take any papers, thirty-nine had, and these included 3,800 pupils. Each paper was divided into two sections, Section A containing twenty multiple choice questions and representing 40 per cent of the marks, Section B containing questions requiring more traditional, longer answers, from which pupils had to choose three. One paper contained a Section C, bearing a wider choice of questions requiring longer answers, but aimed at testing pupils' ability to express their ideas. Mathews was interested in the development of such free response questions which, he believed, should encourage children to write creatively and discursively[52].

Teachers received a detailed marking schedule and they were asked to consult their Area Leader. Scripts and marks also went to the Area Leader this time, and some of the Leaders held discussion meetings with their teachers. They then sent a random sample of up to seven scripts per class to the Team, along with the mark lists and teachers' comments. The marking team then re-marked and reported on the scripts for 2,006 answers.

Although some points about the question papers received adverse criticism, moderator, marking team and teachers all agreed that they were, in general, 'very good, probing quite deeply and sorting out those pupils who had understanding from those who had only factual knowledge'. Teachers' marking was much improved, although many had still not complied with instructions. The moderator commented wryly that some schools had become 'well known, perhaps notorious is a better word, for the individuality of their approach to anything smacking of regimentation'.

Not surprisingly, the biggest deviation between teachers' and examiners' marks was in Section C. In the case of one question here the deviation rose to 40 per cent for one third of the marks and 20 per cent for another third, an unacceptably high level, which was made all the more disturbing by the underlying cause, especially in the light of the Team's concern to propagate the idea of internally marked, externally moderated examinations. The question concerned had asked pupils to 'describe an experiment *you have performed*...'. Scripts indicated that many pupils had made up the answer, for the experiment that they described does not, in fact, work in the way discussed under normal laboratory conditions and could not, therefore, have been performed. Worse still, many teachers had marked these accounts as correct, so that they, too, had never tried to carry out the experiment and must have known that the pupils had not either. This, the Team believed, was not just an academic point—it was contrary to the whole spirit of the Project. Various interpretations can be put upon this occurrence: that the teachers lacked real understanding of the Project's aims; that their sense of commitment to the ideals of the Project was less developed than that to examination success; that chemical ignorance, combined with a desire not to be found wanting by Nuffield headquarters, blinkered their objectivity in marking. This last and very human fallibility was not, however, likely to account for the magnitude of the problem.

Apart from the problem with g-atoms, some sections of the examination paper indicated that pupils were not really thinking about their experiments and the implications involved. The moderator reported:

> It appears from several ... parts of the examination that we are tending to produce chemists who are no more than technicians. They may be able to carry out the instructions in the students' recipe book, but they do not think what they are doing. We must beware of developing the idea that practical work is fun because one does not really have to think.

The Project had tried to replace the teaching of unrelated facts by principles, but, the report recorded, there was much evidence that principles had not been grasped and that necessary facts were not known. The mathematical standards of pupils was a

clear handicap to what could be expected. Section C indicated deficient descriptive powers among pupils. Several teachers had expressed concern over the way that the other Nuffield papers failed to demand the writing of a coherent account. This, they argued, could affect the emphasis placed on coherent writing in schools. No evidence appears to have been produced by these same teachers, however, to show that Nuffield pupils were, in fact, any more deficient than others, and whether many schools do really place much emphasis on coherent writing, except in the form of teacher-produced worksheets or teacher-produced notes copied from the blackboard or its substitute.

All these issues were, however, indications that, even with hand-picked teachers, the teaching-learning context might still be a very important variable. This had very considerable implications for attempts to reorientate a wider range of teachers in the pre-publication and subsequent inservice courses. Failure to follow up the pointers may have been unfortunate for other reasons as well. These same trials teachers were providing evidence of the feasibility and suitability of the materials, and yet their ability to carry out the task in the spirit of the Project had to be taken for granted. Steps had been taken to ensure a reasonably representative sample of schools and pupils, but choice of trials teachers had presented rather more problems. Materials must be given a fair trial if adjustments were to be satisfactory, and so it had been necessary to look for teachers who were believed to be appropriately orientated and who would also be able to judge the materials critically. Inevitably, the sample was unrepresentative, but it was assumed that this was compensated for by the concomitant reduction of one of many possible sources of error in locating problems, the teaching component. (A similar logic had to operate in selecting those classes with older pupils. Here previous experience of an appropriate kind was assumed on the grounds that their teachers were believed to be appropriately orientated.)

Faith in trials teachers' ability to implement the scheme appropriately was, no doubt, often vindicated, but it was not tested. Halliwell had warned in 1963 that the 'difficulty we all experience in seeing old familiar material from a new point of view must not be underestimated[53]' and more than one member of the Headquarters Team has since commented that very few people in the team had any teacher training experience to go by and that they possibly underestimated the difficulty of transmitting the 'message', thinking that it was clearer to the uninitiated than it actually was. The decision to produce films showing the approach in operation in actual classrooms (see chapter 8) was possibly more significant than they realized. One Team member recalls that teachers who had already gone through briefing exercises and some trials would often exclaim on seeing the film, 'Oh, that's what you've been talking about!' The possibility that they might also be contending with a whole range of teaching styles which might quite fundamentally affect classroom interaction does not seem to have been anticipated — possibly because this would probably have been far less important had the initial scope not escalated as it did. Nevertheless, some safeguards were provided by the fact that Team members continued to teach part-time and were therefore testing the materials exactly as they wanted them to be used, and their conclusions could be matched with those of other teachers. But the time devoted to this teaching decreased as the workload at headquarters increased.

The need to ensure that trials teachers really understood the underlying philosophy of the new approach became increasingly apparent — and vital — as teachers embarking on its use became further removed from the centre of activity. During trials, the Area Leader system afforded opportunities for small-group discussion, but even here orientation was heavily dependent upon people at one remove from headquarters. In spite of the extensive briefing that Area Leaders had been given, the possibility of differences, at least in relation to relative emphases, remained.

As feedback came in from trials schools and from individuals such as HMIs, texts and other resources were slowly built up. Devising lessons that would allow the Team to test its assumptions again involved it in implicit if not explicit hypothesis-generation, choice-making and empirical predictions of the 'if ..., then ... ' type. Where weaknesses or mistakes showed up, modification and adjustment of these was made and the materials were then subjected to further trials for as long as this was possible, that is, until the summer of 1965. Some material, in fact, went through three or four major modifications in the trial period[54]. The incorporation of trials into the development process and the pragmatic adaptation of both resource materials and specific goals (such as those relating to conceptual development) allowed for a steady and fairly rapid interchange of feedback with modification, kept particular changes small and made possible the establishment of some causal relationships. Yet it seems clear that the excessive pressures on time, and a focus on the production of resources, were obscuring a number of important wider issues.

While it is essential for adapting resources, and for demonstrating the feasibility of the proposals, feedback of the kind used by the projects presents a number of problems, which may be inherent in the method. Teachers' motives for joining a project will be mixed and will vary between individuals, but by and large there is a strong wish to help to achieve success. This may be both a help and hindrance. On the one hand, the 'pioneers and enthusiasts they attract can make the innovation work, can produce results that make early evaluations positive, and can serve as a seedbed for its spread elsewhere[55]'. On the other hand, deficiencies may be overlooked by these enthusiasts in their concern to find positive results and so to demonstrate feasibility, and provision must somehow be made for this. Again, what works with enthusiasts may fail with teachers who lack their skill and their commitment.

The Hawthorne effect was another likely factor in the lives of both teachers and pupils. This was the first major exercise of the kind in secondary schools, and the sense of excitement and commitment — and flattery — at being involved (augmented by the fact that teachers were specifically chosen and did not apply to take part) must have been very rewarding, and so facilitating, to the project. Even here, however, important and constraining aspects could operate, for while the enthusiasm of the teachers was very valuable, it could motivate them to look only for evidence of 'success' and it may also have produced some confusion as to the roots of genuine success; first, because there are no absolute standards of success and second, and more importantly, because success might have emanated as much from an unusually high level of personal attention given by teachers to lesson organization and presentation, and to individual pupils.

Again, in reporting back, teachers' attention was focused on the resources. Trials were feasibility studies, as a result of which texts and other resources were to be made as 'right' as possible. So focus would tend to be on 'rightness', and on the identification of textual errors that could then be remedied. Overall, then, orientation was towards the internal logic of the programme and its 'feel' in the classroom. It is easy to see how attention of both teachers and Team could be distracted away from the desired outcomes of the project (in terms of pupils' achievement of a range of cognitive, manipulative and affective objectives), towards the *means* to these ends — and only part of the means, since teacher-pupil interaction was not being evaluated. This is not to say that outcomes were ignored, or even neglected, but that pressures on time and focus on materials restricted evaluation to what could be measured by available instruments. Much then depended upon the instruments themselves, and upon the comparability of assessment in terms of pupils' examination success. Yet those concerned with examinations were concerned primarily with the viability of the new-type examinations, rather than with overall and specific achievement of outcomes. In any case, examinations assess achievement of only a limited range of desirable outcomes.

Feedback from the trials examinations was used by the Headquarters Team for evaluating materials, but very largely only for confirmation of other feedback. The use of examination results for evaluation of project resources does, of course, present immediate problems. In the first place, there are considerable dangers in drawing conclusions when there is an intervening component between the material being evaluated and the pupil's achievement, that is, actual classroom interaction. In the second place, the availability of evaluation techniques defines very closely what can be tested. In the event, the study of pupil outcomes was only partial, and subsidiary to the rest of the work. This was understandable in the context of projects set up to produce a set of resources in a very limited period of time; a set of resources, moreover, that was to be subjected to revision as these very difficult problems received continued attention. It is important, therefore, to judge the resources in terms of what they were intended to be — a first approximation to efficient means towards the attainment of desired ends — and not in terms of a finished and definitive product (if any such thing is attainable). Admittedly, the desired ends had their roots in a particular ideology, with all its inherent assumptions, but all policy making is ideological. What was essential at this stage was that the basic framework for the model presented should be worked out as carefully and explicitly as possible. The details could then be developed and adapted in successive revisions as more experience was acquired.

The Organizer's hindsight on processes of change

Speaking at a conference[56] in 1972, Halliwell drew upon his experience as a curriculum developer to reflect upon processes of

change in science education. In any country, he said, it was necessary to focus attention on what the educational system was 'trying to do *to*, and *with* and *for* its young people'. Within this context, it was necessary to have at least a provisional hypothesis about the good that the chemistry taught (if any) might do to a particular group of pupils, and about the approach to be used. Once these had been made clear, on an 'if ..., then ...' basis, then every attempt must be made to see that they got it and not something else. This, in turn, required paying attention to the 'four As of the curriculum' (Figure 6.4) and their interaction, to which he had often referred.

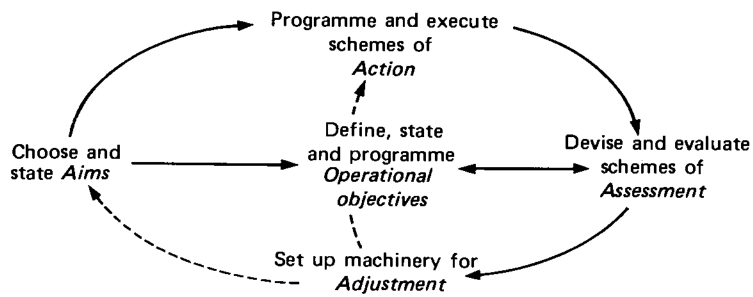

Fig. 6.4 The four As of curriculum reform

No matter how effectively curriculum developers themselves might have demonstrated their ability to achieve their objectives in the classroom, no matter how meticulously worked out their schemes might have been, the fact remained that widespread implementation of change was heavily dependent upon an unpredictable variety of factors. In Halliwell's view these could most easily be appreciated in diagrammatic form. Figure 6.5 shows the collection of vested interests, of prejudices and of ingrained habits involved, and demonstrates the range of problems that had to be tackled in development work.

Of all the factors shown here, hindsight suggests that the most significant factor, by virtue of its complexity and hence intractability, is the problem of providing effective inservice programmes. Initially, the organizers of inservice courses were concerned simply to reorientate teachers, in a belief that they would be able to take away the new materials and then implement them, increasingly effectively, in their own classrooms. It was also believed that continuing classroom experiment and

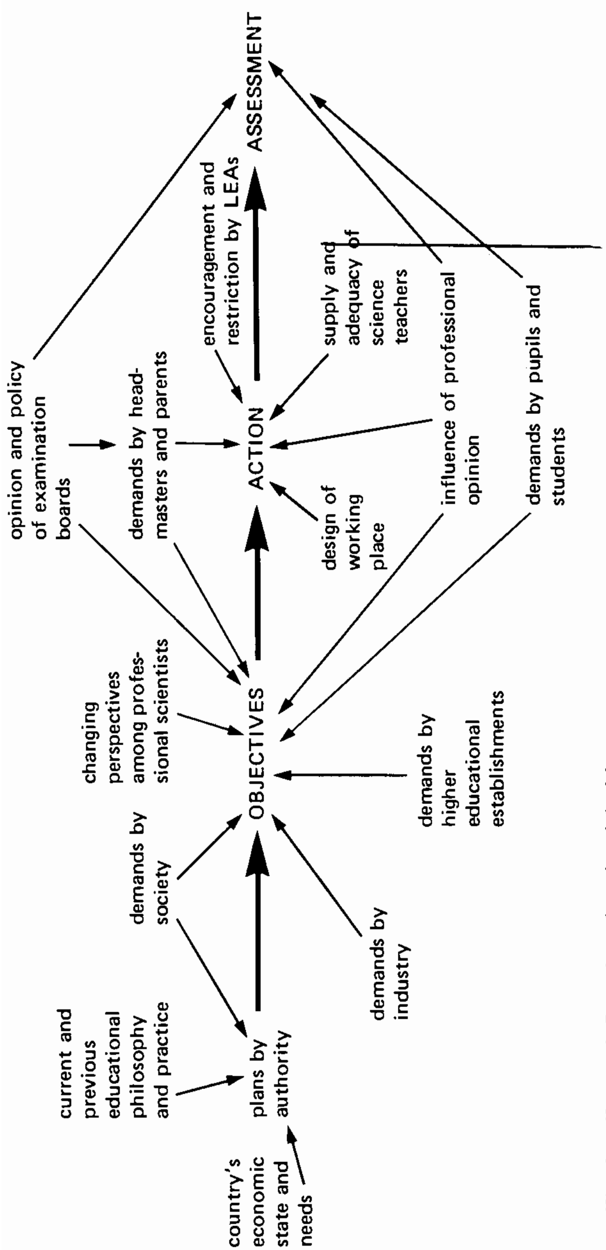

Fig. 6.5 Factors influencing educational decisions

progress would be fostered as developing professional skills enabled teachers to adapt and modify materials to suit their own particular needs and solve their own particular classroom problems. Research in the 1970s, however, has shown that such beliefs are founded on too simplified a view of the nature of classroom situations and interactions. As knowledge of classrooms grows so, too, does recognition of the existence of a considerable number of 'non-trivial' variables, all showing all manner of interrelations, many of them not fully understood. Even where identical materials are in use by teachers who have attended special courses on their 'appropriate' use, every lesson is different, and for a different combination of underlying reasons. These findings have considerable implications for those who would attempt to achieve widespread and continuing curriculum change, and will be considered again in chapter 8.

7

Coordination, communication and dissemination

Administrative and other support

For the first eighteen or so months administration and coordination of the projects had rested with the Director of the Foundation, Dr Farrer-Brown, and his Assistant Directors. In 1963 plans for primary science (Nuffield Junior Science) and mathematics courses began to take shape, and in November Trustees agreed to go ahead with A level courses and with secondary science for eleven to sixteen year olds of 'average' and 'below average' ability. Proposals for a science course for non-science sixth formers and for an integrated science course for more able pupils were put aside for the time being.

Two major problems immediately presented themselves: the need for more accommodation and for the coordination of all the work being carried out. Up to this time Project Team members working in London had been accommodated at Nuffield Lodge, but in January 1964 Trustees agreed that the Nuffield Foundation Science Teaching Project should be established as a separate, but temporary, organization in new and larger premises. The National Institute for Social Work Training made space available, and Teams were lodged at Mary Ward House, Tavistock Place, London.

Dr Farrer-Brown was within three months of retirement as

Director of the Foundation, and the extension of the Science Teaching Project to A level, primary school science, and secondary school science (for 'average' and 'below average' children) had been agreed. In January 1964 the Trustees accepted that there was a need for a coordinating organizer to assume day-to-day responsibility for the whole Project. John Maddox, Science Correspondent of the *Guardian*, was appointed with effect from July 1964. He remained with the Project for two years, after which he left to become Editor of *Nature*. His successor was Professor Kevin Keohane, Professor of Physics at Chelsea College, University of London, who saw the Science Teaching Project through to its conclusion.

The total support that he and his Team received from the Nuffield Foundation, both moral and material, has Halliwell's unrestrained praise. Finance was never a problem: the Foundation was 'very generous'. Halliwell had budgeted carefully, and unforeseen and additional requests made necessary by the expansion of the exercise were readily acceded to. Secretarial and administrative help was adjusted to changing needs. Accommodation for Team and helpers was adequate, although 'house moves' became necessary as the scope of the Nuffield Foundation Science Teaching Project expanded.

Other institutions and organizations also gave considerable support. Generous help over laboratory accommodation, for example, came from Westminster School in London. Since the emphasis on practical work made new demands on school laboratories, the Ministry of Education seconded an architect for three months to work on problems of design, space and storage. Ministry officials, especially those of the Curriculum Study Group and Inspectorate, were in contact with the work throughout, though their role was essentially neutral and advisory. Inspectors and the Schools Council (which took over the role of the Curriculum Study Group in 1964) helped with courses for teachers as part of their overall concern for the dissemination of new ideas, although the Inspectorate was explicitly concerned not to be seen as advocating this, or any other, single approach. The Secondary School Examinations Council and examining boards, though cautious, were cooperative and encouraging. University interest was, in the case of O level projects, confined largely to the provision of individual help and advice on scientific matters.

Having contributed in a major way to the establishment of the Project, the Association for Science Education was prepared to stand aside, though members were in constant contact at both group and individual levels. Projects were deliberately based on the Association's *Policy Statement*, and so there could be an assumption of consensus, at least in general terms. But individual O level projects' interpretation of the *Policy* was another matter, and here the Association maintained an independent platform for debate, both during and after development.

Other groups, such as scientific instrument makers and suppliers, publishers and industrial firms had more vested interest in what might prove to be a major publicity and revenue making exercise, although even here the goodwill exhibited went well beyond mere self-interest.

Publication of material

From its inception, Nuffield personnel had been aware that the Science Teaching Project was going to involve a unique and extremely large publishing programme, and that major issues, both administrative and ethical, would be raised. They and the Trustees believed that the products of a programme funded by a charitable trust should not be offered for normal commercial exploitation. They were advised, therefore, that publication should be on a commission, rather than a royalty, basis (a decision later reversed), and that publishers should act merely as the Foundation's agents in publishing and marketing the materials. This would ensure full control of the copyright and of pricing and other matters of policy. Trustees accordingly allocated £250,000 to finance production costs, the sum being recovered, eventually, from revenue from sales, after deduction of publishers' and booksellers' commissions.

They were anxious, too, to avoid vesting publication in a single firm, for it would give the publisher concerned a considerable and unfair advantage, both commercially and in terms of prestige, especially since it would be convenient to have all projects then and in the future in the same hands. In addition they believed that the scale of the exercise and the limited time span available would put impossible demands on a single firm. The three O level projects alone were going to produce more than 100 titles, and first printing was likely to come close to 3 million books.

After lengthy negotiations with the Publishers' Association it was decided to put the publication of materials to tender by

consortia of publishing firms, and after protracted and detailed negotiations a contract was signed with the Longmans Green/Penguin Books consortium during the summer of 1964. The agreement covered only the three O level projects, so that the policy could be reviewed before other projects were published[2].

Because publication was to be on a commission basis the Foundation was in a position to choose its own design directors. Ivan and Robin Dodd designed all the books and, with their team of artists, were responsible for most of the art work. They brought to the Teams, according to the Editor of Nuffield Publications, William Anderson, 'tremendous enthusiasm, and understanding of the fundamental aims of the Projects, and a freshness of approach to the design of school books'[3].

Soon after the appointment of Maddox in the summer of 1964, preliminary technical discussions with the publishers and the completion of the first manuscripts for publication demonstrated an 'urgent need' for some means of providing careful editing of materials before they passed to the printers[4]. A case can undoubtedly be made for teacher development of new curriculum materials — provided that there is strong expert back-up — but, being an excellent and innovative teacher does not necessarily guarantee possession of the ability to place on record, and in explicit and readable form, what is being done so successfully in the classroom. Curriculum development makes an additional demand: that writers should be able to work as a team and not merely as individual authors. Different projects have dealt with these problems in different ways. In the case of the Nuffield projects there were considerable differences between projects, and very little was made explicit in the early stages about plans for eventual editing. In the case of biology, for instance, Dowdeswell, an experienced author and editor, assumed responsibility for this from the outset. Most Chemistry Team members had proven writing ability, however, and Halliwell was not really concerned that there should be uniformity of style in the different texts, so he did not regard it as a major problem.

Partly because of the variety of styles and expression in the trials materials it was decided to set up a small editorial unit to provide a common service for all sections of the Project. There was also the consideration that there is a difference between material that can be successfully used by enthusiastic teachers who are in close contact with curriculum developers, and that required, once materials are freely available, by teachers of varying degrees of commitment, and who have to rely (in some cases, entirely) on the materials for transmission of the 'message'[5].

Anthea Roberts joined the Nuffield Foundation Science Teaching Project from the Cambridge University Press, and after some initial work on biology materials she took over the editing of Nuffield O level physics. William Anderson took on biology and chemistry materials. An Oxford graduate in history, he had been one of four sub-editors on the *Illustrated London News*, in which capacity he had been responsible for writing on a very wide range of topics. In addition he was a professional author, and was aware of the problems and difficulties of authorship.

The new editors faced a very difficult situation. They had not been able to sit in on discussions in the early stages of the planning and so to 'grow into the Projects with Team members'. They had, instead, to take over established and tested materials, of very variable quality in terms of their communicating power and, using tact and sensitivity, try to alter them so as to ensure coherence and a minimum level of polish in a very short time.

In curriculum development there is no real possibility of rejecting books, for there is a predetermined deadline for completion of the project. So the Team simply had to do as much as they could in the time available. Publication was promised for April 1966, and since the last of the materials was not to be handed over until September 1965 the task was formidable. But this was not all. Anderson had been appointed to edit and, where necessary, to write the materials into a form suitable for publishing. Publishers were to be responsible for copy-editing and for the main sales drive and promotion. However, it soon became clear that however excellent their copy-editors were, they were hampered by the fact that they were operating at a distance, without the necessary daily contact between editor and authors. Inevitably, therefore, Anderson had to take on more and more of the copy-editing. Again, several of the professional proof-readers were not able to cope with the task, partly because two publishers were involved, each with its own particular house-style, and they were unable to achieve the sort of synthesis necessary to suit the special requirements of the projects. It thus became clear that the proof-reading and collating of all the authors' corrections should be done in one office, at Mary Ward House, close to the Teams. So, of necessity, the three main elements of publishing work had now come together under

central direction, for the Editors played a close part in the writing and design of the books; they marked all manuscripts for the printers; and they dealt with all proof-correcting, going through all the stages of publication, in fact, sometimes right up to the writing of brochures to be sent out to the schools.

A very large number of titles had to be produced in under a year and, inevitably, this meant short cuts. Stages I and II, that is the *Basic Course* in chemistry, were not indexed, for example, simply because there was not time. (There was, however, an index in *A Course of Options*, covering both books.)

Once a system of central direction of editorial matters from the Project offices was established, regular progress meetings were held with the publishers, at which every book was discussed and its progress detailed. In mid-1965 these meetings were streamlined by eliminating from them everyone not directly involved. Publishers announced final dates (April 1966) and details of publication early in 1966, but delays and production problems resulted in the first materials appearing late, but heralded by a press conference, on 27 June 1966.

Film loops

Although the physics section resisted the use of film loops, producing a few only towards the end, they were treated as an integral part of the O level Projects in chemistry and biology. By the autumn of 1964 it was necessary to make arrangements for their production and distribution.

Film loops were of relatively recent origin, but they were already being produced by specialized laboratories, and distributed either by commercial organizations or by non-profit-making foundations. Recently, however, book publishers had begun to take an interest in them. After discussing the costs of the procedure, Nuffield staff suggested to the Trustees that the most economical way of getting films distributed would be to try to arrange a partnership between a film laboratory and a distributor, ideally the Longmans/Penguin Books consortium. The latter would advertise film loops, receive orders and collect money; the film laboratory would copy films from master film provided to them, and pack and dispatch them to customers. The distributors would pay the laboratories for their work, retaining a commission on the selling price to cover expenses. The Nuffield Foundation would retain the sole right to fix prices, so that the loops could be sold on an entirely non-profit-making basis. (This was, in any case, a stipulation in the case of chemistry films, because Shell International had made fifty loops for the Project on the understanding that they would be marketed on a non-profit-making basis.) Apart from its feasibility, the scheme had the virtue of entailing no capital outlay on the part of the Foundation[6]. Once approval of the scheme had been given, negotiations went ahead. Discussions were held with the publishing consortium, who agreed to act as distributors, and with a number of film laboratories. The contract was eventually awarded to Humphries Laboratories, a small but technically competent firm, who had taken considerable trouble over their tender. Procedures for quality control were built into the agreement, as was the undertaking by Humphries to load the loops into cassettes and to enclose them in plastic boxes, along with teaching notes supplied by Project Teams.

Apparatus and equipment

All three sections placed considerable emphasis on experimental work, and special chemistry and physics Teams had been set up to develop new items of apparatus and to modify existing ones to suit the course. The first meeting between members of the Nuffield Foundation Science Teaching Project and a number of scientific instrument making firms and suppliers was held in February 1963. The Project's plans were outlined, and participants discussed the urgent problem of obtaining the apparatus needed for the September trials, the element of risk for manufacturers (since the programmes were still highly tentative and some items might be dropped or substantially modified in the future, with resulting financial loss), and the cost to schools, in the trial phase, of a wide range of new apparatus. Most discussion centred on the size of the task and the shortage of time, but everyone seemed anxious to help. The Foundation could not give formal guarantees on the matter of risk, but after some discussion manufacturers agreed that it was small compared to likely long-term advantages. Matters could also be helped, from everyone's point of view, by breaking down as much of the new apparatus as possible into basic units, which could be assembled in a variety of ways; this could lead to the establishment of very large markets for a small number of items, instead of small markets for a large number[7].

The Scientific Instrument Manufacturers' Association (SIMA) placed its information service and its headquarters

organization as a whole at the Foundation's disposal. They undertook, too, to send full specifications of apparatus requirements to members and to firms outside the group. For its part, the Nuffield Foundation Science Teaching Project agreed to allow manufacturers to inspect and to discuss, in confidence, prototype materials at the laboratory headquarters of the Team concerned.

Over the next year or so, and often at very short notice, manufacturers provided the whole range of apparatus needed by trials schools. Teachers saw and used it at the Loughborough Conference. The requirements of the Chemistry Project were far less extensive than those of the Physics Project, and consisted for the most part of large items of apparatus to meet special needs, such as single-pan, direct reading balances, lightweight cylinders of gases and atomic models. The considerable range of expendable materials required consisted very largely of standard products, already available.

At a second meeting, in January 1964, problems likely to arise over the advertising of apparatus and equipment, and over the maintenance of standards in a highly competitive market were discussed. After debating — and rejecting as impracticable — ideas like the registration of a 'Nuffield' trademark, or the award of a 'Nuffield certificate', manufacturers agreed that no item of apparatus should bear the name 'Nuffield' in its title, but that precise terms of reference, such as 'developed, used and approved during Nuffield trials', 'specifically recommended for the Nuffield Projects', were acceptable if drawn from the relevant section of the laboratory guides. Adherence to this agreement had necessarily to remain a matter of goodwill and ethical practice on the part of manufacturers, however[8].

During 1964/5 lists of specifications for apparatus (more than 1,000 items altogether, although most were for physics) were drawn up and made available to manufacturers to enable them to start production, and to schools so that those with the necessary facilities could make equipment for themselves. It was soon clear that schools would welcome further guidance on sources of supply of suitable apparatus, and so an assessment operation was initiated, with the help of the Consortium of Local Education Authorities for the Provision of Science Equipment (CLEAPSE). This body had been set up in 1963 to act as a purchasing agent for its members, in an attempt to rationalize the provision of school science equipment and to economize, and it had its own Development Group. As a consequence of a proposal put forward at the January 1964 meeting, this Development Group was commissioned in 1965 to help Project Teams assess the apparatus being produced by firms. Final responsibility for making recommendations to schools, however, remained with the Project concerned. The outcome was two catalogues of equipment necessary for the courses, which gave, where possible, a list of manufacturers whose equipment satisfied Project requirements. No recommendations were made as to whose equipment schools should buy, choice being left to individual teachers. The first catalogue was published at the end of December 1965, the second in April 1966, just before the resources themselves appeared.

Participants at the first meeting in 1963 had suggested that manufacturers might be prepared to help with costs by viewing pilot items as 'ground bait', to be supplied at nominal cost, and to operate a system of special discounts during the pilot phase. This would, they pointed out, contribute to the philanthropic nature of the exercise, although they were quite open about their recognition that it might, at the same time, serve to safeguard the final price structure, since the market price from which discounts were to be made would now be clearly established at the outset. For the main 1964/5 trials, LEAs were asked to meet the cost of apparatus in maintained schools. Of the thirty-five approached, only two found it impossible to make special provision. In the case of the Chemistry Project matters were considerably helped by a grant from Imperial Chemical Industries, which was used to provide special apparatus and to help with the cost of supplying draft materials to trials schools[9].

The high cost of new apparatus was a continuing preoccupation in the work of the Nuffield Foundation Science Teaching Project, especially in the case of physics. The problem featured in almost all discussions with manufacturers and with teachers, schools and Local Authorities, and there was some public criticism in 1964[10]. In reply, it was pointed out that heavy expenditure on apparatus and equipment was by now a commonplace in any undertaking in science. Care had been taken to make individual items as cheap as possible, and Local Authorities had met the costs involved during trials with a willingness that indicated their acceptance of the new situation[11]. Whether Authorities would or could support equipment buying on the considerably larger scale necessary after publication of the first projects was to be another matter altogether.

Interim arrangements

As the work of the O level sections entered the final year two issues became pressing. The first was the question of who was to deal with matters arising after September 1965, when secondments came to an end. There would be an inevitable gap between this date and that of publication, and it was felt that some means of keeping interest alive should be found. A number of issues relating to dissemination would also become crucially important at this stage, coordination would continue to be necessary on such matters as examinations and the publication programme, and schools continuing with O level chemistry work would be needing advice and support. Public relations exercises would also be vitally important, as would the initiation of teacher training programmes. The issue had, in fact, been raised by the Chemistry Team in December 1963, and at their October meeting in 1964 the Trustees agreed to set aside a further £12,000 for the establishment of a 'Continuation Group' consisting of one member from each of the three projects, who would stay on for an additional year. Van Praagh was chairman of the group, with Derek Harding (physics) and Dr J.J. Head (biology)[12].

The second issue related to the so-called 'interim arrangements' for pupils taking Nuffield O level examinations, until such time as the Nuffield A level courses and examinations came into operation. Many schools had asked for this, and to make it possible, special A level papers would be needed from 1967 onwards, with questions in keeping with those being used for O level. Agreement now had to be reached on a special syllabus for the period in question. The cooperation of examination boards was urgently necessary if these alternative A level papers, common to all boards, and with arrangements similar to those existing at O level, were to be made possible. The Nuffield Foundation was concerned to do all it could to help, besides providing the necessary finance, and by late 1964 ways and means were being explored.

Senior chemistry teachers who had entered their pupils for the special papers in O level chemistry in 1965 and 1966 met in London on 19 and 20 February 1966. Before the meeting they were all sent copies of the A level syllabuses of every board in the United Kingdom. On 19 February, the group decided that since teaching approach was more important than any particular syllabus, intrinsic flexibility should be a major characteristic of any syllabus selected. After much discussion, they chose the

'Alternative T' syllabus of the University of Cambridge Local Examinations Syndicate. A working party of eight was then elected to meet under the chairmanship of J.G. Raitt on the following day, to discuss and to select possible areas of study for the course. Over the next few months members of this working party drew up background notes for teachers and prepared questions and examination papers.

In the meantime, a memorandum had been sent to the Secretaries of the examining boards on 2 February, for consideration at their meeting exactly one month later. At this meeting Secretaries agreed to consider starting a special examination as an interim measure[13]. The working party's proposals, including the *Teachers' Guide* and specimen examination papers, were duly sent to the appropriate subject committee of the Schools Council, which included a representative of each examining board among its members. The proposals were now approved in principle, and the committee agreed that the London University School Examinations Council should again administer the chemistry examination, which was to be available only to the Nuffield trials schools. The first candidates must, moreover, be entered for the examination in 1967.

The Chemistry Advisory Panel for the London Board studied the working party's draft A level paper and agreed to recommend an examination along these lines. Although the recommendation had still to be given final approval by the Council, schools could now be given the go-ahead to plan their interim courses[14].

Channels of dissemination

Public statements

Any change of the intended scope of the Nuffield projects affects three main groups of people:

1 The pupils, whose experience in the classroom and laboratory and in examinations will shape their perception of the course's aims and so their understanding of the nature of science and of its place in society. It will also affect their action in terms of vocational choice and, in the future, their responsibility as decision-making citizens in a scientifically orientated society.

2 The teachers, who will have to decide whether to accept the

change *in toto*, or in part, or not at all, and how to adapt it to their own unique classroom conditions. Many factors affect such decisions. Among them are two that depend heavily upon possession of specific and precise information. First, the teacher's perception of the materials, especially of approach and content, of their suitability for his particular classroom and of their effect upon his role; second, his perception of the relative importance of the many groups in the third category below, and of their relation to the proposed innovation.

3 All those groups whose interests or activities serve to constrain or to facilitate innovation. Especially important here are examining boards, Local Authorities (who provide both resources and legitimation) and other bodies such as the Department of Education and Science, professional associations, universities and the Association for Science Education, whose support serves to legitimate innovation, apart from any practical advice that they might give.

Unless the developed innovation is to be imposed from outside as a 'package', a sensitively balanced and adequate system of communication must be initiated during development, to expedite the whole venture, to establish and maintain goodwill and interest, to satisfy natural curiosity, to reduce speculation and misinterpretation and to allay fears and uncertainty, especially among those involved in the trials.

This was clear from the outset, and the problem then became one of 'what?' and 'how much?' — something which proved to be very difficult to decide, for whatever course was adopted it would be bound to produce its own crop of difficulties and criticism. In the first place, a great many people and groups were involved, and there was already a considerable network of communication in existence between them at both formal and informal levels. As the number of people involved in development grew, so did the links. While informal communication can be very valuable, the information transmitted is liable to distortion, especially where relevant formal communication is inadequate. Apart from the hostility and resentment which they might arouse, such distorted impressions are very difficult to change later on. Yet the work that was going on was tentative and experimental and it was believed that it was necessary to have some measure of protection from over-critical scrutiny, at least in the early stages[15]. This was especially the case with regard to content and approach. The balance between maintaining an open forum for informed debate, and protecting ideas still in embryonic form is a very sensitive one, and the O level Teams had no previous experience upon which to draw. In the event, a fair amount of information actually went out, though its lack of specificity was made more apparent, perhaps, by the fact the restriction lay precisely in those areas of greatest concern to the teacher. Though it was often stated that the major change lay in the approach, and although Halliwell had been careful to point out that the aim was to provide a flexible framework in which talk about specific content was not, at this point, relevant except for illustrative purposes, it is possible that the anxiety level of teachers used to content-bound syllabuses was not fully appreciated. Even if it had been, it would have been difficult to avoid arousing anxiety.

In late 1962 the Advisory Council for Scientific Policy asked for a progress report on the Nuffield Foundation Science Teaching Project, and this was prepared and later made available to a wider audience. From 1963 onwards, however, annual *Progress Reports* were published and sent to newspapers and to appropriate journals (always accompanied by a note to the effect that free copies could be obtained from the Foundation), and to all other interested bodies and individuals. They were distributed at meetings of the Association for Science Education, and the *School Science Review* and the *Bulletin* of the Association carried information taken from it. *Progress Reports* gave the origins, rationale and organization of each group of projects as they got under way, and outlined the current state of progress of those already established, schools involved in trials and preparations for inservice training. They also provided a platform for justifying action, for correcting misinterpretations, for answering criticism and for allaying fears. What they did not give was any explicit statement about the content of the courses, and statements about the approach tended to be expressed in very general terms, like 'giving pupils experience of what it means to be a scientist'.

Some criticism of this 'secrecy' was inevitable — and it was voiced, informally at first, but publicly from about mid-1964. For example, 'Astryx', in *The Times Educational Supplement*, described the Loughborough Conference as a 'private party', and there was further comment in the same publication in October[16]. Questions were raised about the 'secrecy' at the Loughborough Conference itself. In late October 1964,

therefore, it was agreed that, since the main body of each of the projects was now taking shape, the time had come to 'widen the circle of informed criticism' to which the O level materials were exposed[17].

The 1963 *Progress Report* had received only a belated press conference, six months after its first appearance, but the 1964 *Report* was launched with one, at which members of the Press were given copies of the *Report*, as well as a summary of its main features, and the new Director of the Foundation (Farrer-Brown had retired earlier in the year) and the recently appointed Coordinator of the Nuffield Foundation Science Teaching Project directed the attention of the Press to some items of information in the *Report* and then answered questions[18].

Two further steps were proposed at this time: that the Association for Science Education Conference in the following January be used to make public a good deal of information about the content of the O level work[19], and that articles should be written for technical and educational journals, which would give 'points of interest which had arisen from the work of the two preceding years'[20]. An article by Maddox appeared in *New Scientist*[21] with the standard footnote about the availability of the *Progress Report*. Team members were, however, too busy coping with feedback and rewriting materials to prepare articles just then.

Early in 1965 it was decided to produce a Nuffield Foundation Science Teaching Project *Newsletter*. Trials were coming to an end, and it had long been recognized that the period between their ending and publication in 1966 would be one in which interest would be high, but would need sustaining. Teacher preparation during this period would be crucially important, and information of a general nature should be available from a number of sources as a basis for training courses. Copies of the *Newsletter* should, it was believed, continue to be provided free to trials schools and teachers, but for the first time a small subscription charge was levied on others. Three editions appeared in 1965, in March, June and November, and these gave progress reports on materials and visual aids, on apparatus, plans for inservice courses, examinations, and organizational and administrative matters, and two descriptive accounts of Nuffield lessons, one in chemistry and the other in physics. *Newsletters* continued for some years. (They should not be confused with three *Newsletters* produced by the Biology O level Project in 1963 and 1964, which gave a great deal of information about the work of the Team.)

Influential organizations and institutions

The Association for Science Education, with its flourishing membership, was potentially a very valuable agency for dissemination. Science Masters' Association membership had passed the 7,000 mark in 1961, and amalgamation with the Association of Women Science Teachers in 1963 brought this figure to 9,500. Besides giving information about the projects, the associations' journals provided a platform for comment and debate, and the Annual Meetings held every winter, attended by very large numbers of members from all over the country, afforded an excellent meeting ground for all to hear, discuss and see something of what was going on, in the presence of the people concerned. There were talks and exhibitions of experiments from the projects. The Director of the Foundation, Dr Farrer-Brown, had addressed the Annual Meeting in 1963/4, and his talk was published in the *Bulletin* in the following February[22]. Each of the three O level Organizers had also given a (deliberately) general report on progress at the same meeting. At the 1964/5 Annual Meeting, however, the Director and the Coordinator described the aims and the work to date, and then members separated into subject groups to hear details of the schemes and to receive specimens of preliminary materials[23].

There was also considerable communication between the Nuffield projects and a number of other bodies and individuals. Whilst much of this was concerned primarily with matters intrinsic to the developments themselves, the existence of formal links between schools and these organizations and individuals made possible a great deal of indirect communication of Nuffield information to teachers. Obvious examples here are officials of the Ministry of Education (later, the Department of Education and Science), in particular HMIs, LEAs and their Inspectors and Science Advisers, the Secondary School Examinations Council and examining boards. Less obvious, but effective, sources of information were the providers of resource materials — scientific instrument makers, suppliers of apparatus, publishers, industrial firms and the media. Exhibitions of apparatus and equipment at courses and, especially, at conferences like the Association for Science Education's Annual Meetings in the years 1963-6 provided a good communication channel. After publication, advertisements for apparatus and equipment and catalogues were also significant[24].

The close communication established between the Nuffield

Foundation and many large industrial firms has already been mentioned. Several of these firms made specific contributions to materials that were important for dissemination such as Imperial Chemical Industries' and Unilever's films which showed the new approach in chemistry in action in classroom and laboratory, and which are described later.

The publications themselves would clearly form the major channel of communication. Pre-publication copies of the Chemistry Project's final drafts were circulated to, amongst others, the heads of university science departments. There had been much informal communication between Team members and university scientists, and the latter were represented on the Consultative Committee. In many cases they gave a strong lead in local dissemination[25]. In early January 1965 they received the pre-publication copies along with a *Progress Report* for 1964, details of publication dates and a circular letter. This asked them to comment on both materials and approach (to help in the final revision of the publications), and to encourage their students to look through the materials in the hope that some might be encouraged to look favourably on science teaching as a career.

The publishers produced prospectuses for each section just before publication in the summer of 1966, and second issues appeared in the following September, in time for the start of the new school year. Early in 1967 one copy of each book and four representative Background Books in chemistry were displayed at the National Book League's Exhibition. A large number of complimentary copies of the books were also distributed to people who had made major contributions to the work of the projects.

The relationship between the Nuffield Foundation Science Teaching Project and the Ministry of Education was a very close and cooperative one. Because of the status and influence of HMIs, they were very important as channels for communicating information and advice to schools, both directly and indirectly through their courses. Official policy (of 'neutrality') dictated that such courses could not be specifically Nuffield-orientated, however, nor could advice, except in so far as it might be correcting misinterpretation or misinformation.

Informed and sympathetic LEAs were central to both communication and support. Communication channels between the Nuffield Foundation and the Authorities were established in a number of ways: through *Progress Reports*; through negotiations about the secondment of Team members; through negotiations over trials; through the inspectorate and advisory service; through individual contacts with Local Authority officials who were personally involved in the work of the projects; through Chief Education Officers or their representatives on the Consultative Committees; through dealings with CLEAPSE[26]; through negotiations for the financing of briefing conferences and through negotiations over the delegation of responsibility for inservice courses.

From the outset trials were seen as significant for dissemination, for two main reasons. In the first place, as wide a geographical distribution as possible would involve a spread of teachers at an early stage[27]. (In the event, however, some compromise was necessary in the interests of both economy and efficiency.) In the second place, the Chemistry Team believed that wide geographical distribution would create a situation in which, in the future, gatherings of teachers of chemistry in any part of the country would probably have trials teachers in the audience. If such people could add the weight of personal classroom experience to the discussion, this would afford far greater credibility than any amount of talk from the Project's originators — certainly as far as other teachers were concerned[28].

Finally, public examinations have a considerable effect on the classroom experience of their candidates, determining not only what is taught, but how and what pupils learn and how that learning is assessed. Since what the examination rewards becomes the arbiter of 'success' in learning and teaching, it tends to become equated in the minds of pupils — and often teachers — with what is important and valuable. For the pupil at least, then, it defines what 'chemistry' or 'English' or 'history' *is* and what 'being good at' chemistry or English or history involves[29].

From the beginning, therefore, Project Teams were concerned to ensure that the nature of all tests (public and internal examinations, test questions and homework) was in sympathy with and actively encouraged the intentions behind the scheme, as well as assessing pupils' achievement. The way in which they tried to ensure that this powerful influence was harnessed to their aims has already been outlined, and it is only necessary to add here that the policy of close involvement of trials teachers in examinations, together with the boards' assurances about safeguarding pupils' interests, and the examination results themselves, were of considerable significance in ensuring both the acceptability of the projects and the implementation of their aims.

The Area Committees

As the trials moved to their close there was a strong feeling that the valuable communication network that had been developed must not be allowed to lapse and that there would, in any case, be a considerable local need for ensuring that the work did not falter in the pre-publication period. In mid-1965 proposals for locally based dissemination centres, the so-called 'Area Organization', were put to Nuffield Trustees. Their function would be to initiate public discussion and to act as local links between the Nuffield Foundation Science Teaching Project and LEAs. This was particularly important in relation to teachers' courses and conferences, for which they could also act as sources of information about speakers and other resources in the district. These 'Area Committees' were to be built around a chairman (if possible, a member of one of the Consultative Committees) and a secretary, and other members were to be drawn from Area Leaders and other 'second-line' helpers, teachers introducing Nuffield material into their courses, and members of the local branch of the Association for Science Education. The Department of Education and Science's policy of 'no commitment' extended to the Area Committees, although HMIs were prepared to act as 'observers and advisers, where necessary'.

Over the following months the nucleus of a Committee was established in each of Manchester, London, Cambridge, Leicester, Cardiff, Birmingham, Exeter, Leeds, Newcastle, Southampton, Bristol and Belfast[30]. Some of these Committees responded with great enthusiasm and started planning local meetings, but problems soon arose over their exact role, for there was an overlap between their assumed functions and those of the Nuffield Continuation Group[31], and also of the now functional Schools Council's Teachers' Centres. Accordingly, a letter was sent to chairmen and secretaries at the end of January 1966. What was really wanted, they were told, was the provision of 'an easily identifiable organization from which schools and other interested bodies ... might seek information and help on practical matters such as equipment costs and time allocations', and which might put them in touch with experienced trials teachers in the area. These Committees were not expected to take the initiative in beginning meetings of groups of teachers or others. They would, instead, be informed of Local Authority plans for inservice courses and could be of most use in locating and suggesting speakers and tutors, although the Continuation Group should be kept informed of any such arrangements. It was quite clear that their role was really one of liaison rather than of organization. Little formal activity was envisaged, and the budget of £50 per annum underlined this[32]. A meeting of Area Committee secretaries was held in London shortly afterwards, to clarify the issue and to ease the tensions that had been aroused and in particular to start preparations for the first wave of Local Authority inservice courses, planned for that summer [33].

In 1967 the Nuffield Foundation decided that it could not — and should not — go on financing the work of the Area Committees[34], and asked the Schools Council for suggestions for alternative sources of support. The Committees did, or could, meet a genuine local need, but the Schools Council decided that their continuation might be more adequately looked after on a local rather than a central basis, and that Local Authorities or Institutes or Departments of Education should therefore be invited to take over sponsorship of their own Area Committee[35].

Overall, the Area Committee scheme appears to have had varying degrees of success, partly because of the overlap and the sometimes ill-defined functions and resulting tensions, partly because of the importance of individual personalities at the centre of the venture. Whatever the factors involved, it seems clear that some operated successfully, others only for a limited period, after which they fell away or were absorbed into other groups. Some did not even get off the ground.

Teacher training courses

Projects were avowedly attempting 'not so much a change of content ... as a change of approach'[36]. Explicit communication of the nature of this change of approach was therefore of considerable importance. As a first step each Project Team planned to produce *Teachers' Guides* as part of their range of resources, to 'help teachers to see what this means *in terms of classroom situations*'[37]. In general, this meant that it was necessary to provide a discussion of the aims and underlying philosophy and, to some extent, the implications in terms of alternative classroom activities and experiences. No one was entirely sure, however, how much detail and emphasis would be necessary, nor were there any guarantees that what *was* provided

would be carefully read and/or interpreted in the way in which each Organizer and his Team intended. It was accepted, therefore, that the new orientation required more direct communication in the form of lectures and group discussions and by a trying-out of experimental work along the new lines advocated. Later on, the value of filmed material showing actual lessons was recognized, and action was taken to provide this. What was needed was a massive programme of courses for teachers, and discussions between Teams, HMIs and the Association for Science Education began in mid-1963. One of the Organizers expressed some concern that the 'new philosophy' should be made available before teachers were confronted with the distractions of new information and materials; that is, before such courses, and certainly long before publication. Consequently the first revelations, at the Association for Science Education Annual Meeting in 1963/4, were deliberately very general in character, an approach also demanded by the 'secrecy' restrictions.

As soon as talks on inservice courses started, it became clear that the problem was going to be enormous, involving whole series of courses. The financial implications were daunting. By March 1965 it was estimated that some 2,000 teachers might be wanting short courses before the autumn of 1966 if figures for schools which had expressed their interest in starting Nuffield courses immediately after publication were anything to go by[38]. Nuffield Trustees had been quite clear all along that responsibility for inservice training was not theirs and, in any case, providing anything like the necessary number of courses would have to be the responsibility of a number of bodies. In short, the Ministry, university departments, colleges of education and Local Authorities would all be involved.

The first step would be attention to the running of a few initial courses, which would establish patterns for others to follow and at the same time ensure that a number of people would be trained to help staff subsequent cycles of courses. The ideal time for the major provision of courses would be the summer of 1966, just after publication and shortly before the start of the new school year.

It was clear that teachers engaged in development could not possibly constitute an adequate staff to man the full-scale exercise now being envisaged, so Nuffield Trustees agreed to sponsor 'advance' courses to train more tutors. Nuffield personnel were to run these courses, but the Schools Council and LEAs provided the necessary finance. The 'tutor training' courses were held in six centres, two per subject, in January 1966. Biology courses were held at the City of Portsmouth and City of Sheffield Colleges of Education; chemistry at Manchester and Leicester Universities' chemistry departments, and physics at the City of Leeds and of Worcester Colleges of Education[39].

Two hundred and fifteen prospective tutors attended these courses, 70 in each of the three subjects. The Nuffield Continuation Group provided suggestions for programmes, but these were not binding[40]. Plans for the Leicester chemistry course are still available and provide an example of the type of course offered. Rather than trying to skim through the whole scheme, the course organizers decided to cover certain topics in as much depth as time permitted. Topics were chosen because they constituted some new use for well-established ideas, such as part of 'getting stuff from the world around us', or because they were a major break with established tradition, such as g-atoms and equations. Books for the first four years of the scheme were sent to participants at the end of November, well in advance of the course[41].

At the course as much time as possible was spent on experimental work in the laboratories, members working in pairs, as pupils would be expected to do. Five course tutors worked with three or four groups of two pairs each, so that maximum use was made of laboratory time, in an effort to ensure that future tutors really did get the 'feel' of the approach. Other periods were set aside for discussion with the group as a whole. At some of these, tutors formed a panel; at others they were not present. Group reports were made and used both as an immediate catalyst for discussions, and for the record and, therefore, future use. The course was visited by experienced trials teachers, who spoke on various aspects of the work, and answered questions. At the end of the course most tutors felt ready to help on future Local Authority courses[42].

In the meantime the Schools Council had, at the request of local groups, organized summer courses. They formed thirty-three local groupings, containing most of the 215 tutors trained in January. (Two future tutors in each of the thirty-three local groups had attended the January course.) The plan was to have ninety-nine courses, one in each subject for each local group, though in the event only seventy were held, since all three subject courses were not held in each locality. Each course averaged thirty-six teachers, and courses varied in length from three days

to a week, following the pattern that was by now established.

From this point on, provision of inservice courses in local areas depended upon local initiative, and there was considerable variation from substantial provision to relatively little. Again, all three subjects were not uniformly covered, provision probably reflecting local interest, initiative and expertise[43].

Recognition of the fact that curriculum development of any sort should occur in a state of dynamic interaction with classroom practice and that this requires an informed and critical teaching force was nothing new. But growing curriculum activity in Britain and elsewhere increased the need for such a teaching force and therefore for suitable inservice training, and at the same time it appears to have heightened feelings of concern in a number of other quarters. With publication set for the early summer of 1966, 1965 saw a marked rise in preoccupation with the problem. A conference in that year sponsored by the Royal Society discussed such difficulties as persuading teachers to attend courses; past Local Authority unwillingness to meet teachers' expenses or to provide incentives or help in the form of substitute teachers; the types of course needed (single day, regular evening courses, or full-time, extended 'high level courses' to train those who might play a key role at local development centres); the establishment of closer links between university science and mathematics departments and institutes of education; the communication of information about course opportunities; widening teachers' contacts with scientists and with industry; the role of media in teacher training, and the urgent need for the coordination and rationalization of inservice provision[44].

Professional bodies, especially the Royal Institute of Chemistry, were extremely active, and although their concern lay very largely with sixth form work they were undoubtedly highly significant as seedbeds for enthusiasm, interest and reorientation[45]. The Department of Education and Science organized a range of courses in the years after 1966, although their courses covered various new trends, of which the Nuffield materials were only a part. After initial high attendance figures, however, there was a considerable fall-off in numbers and in demand and several courses had to be cancelled for lack of support. By 1967 a senior HMI reported to the British Committee on Chemical Education that all the available evidence suggested that current efforts to increase the demand for courses among teachers were having no effect. Longer, full-time courses, such as the 'wing colleges' courses, had been as under-subscribed as short courses. They had never achieved take-up of more than half the available places, and it had sometimes been as low as one quarter. Only one course had recruited a good number of teachers, he continued, and that was a weekly evening course in autumn and spring terms, run by a London polytechnic — and it had to be remembered that the number of chemistry teachers in London was relatively large. Possible reasons for the lack of demand were, he suggested, general apathy, resistance due to some teachers' belief that they were already competent, family ties and other interests, and financial deterrents (since very few Local Authorities paid the full cost of such courses). At the same time, he noted that science teachers had shown themselves far more reluctant to attend the courses than their colleagues in mathematics. Positive action was needed if a climate was to be established and maintained that gave normative support to courses, and all these barriers needed to be overcome.

This lack of response to courses was very disappointing and completely unexpected[46]. The explanations put forward were supported by a study of inservice attendance, but subsequent findings suggest that all such reasons were, in part at least, a rationalization of a far more fundamental issue, namely, that the centrally developed projects, with their 'course rather than resource' image, might be offering a solution to problems that teachers did not really feel to be *their* problems or, at least, their most immediate problems. These more individually immediate problems were, at the same period, being considerably exacerbated by the complexities of secondary school reorganization, by the approaching raising of the school leaving age, and by the moves to mixed ability teaching in comprehensive schools. This subject will be taken up again in the last chapter.

There was considerable concern over this lack of response to the courses offered, and a few weeks after the meeting of the British Committee on Chemical Education a deputation led by Professor H.L. Thompson, Vice-President of the Royal Society, went to the Secretary of State for Education and Science, Anthony Crosland. But they obtained little more than assurances of concern[47].

We have already seen that there was a belief that responsibility for the provision of courses should pass to the Local Authorities after 1966. Although few records remain, the Curriculum Diffusion Research Project[48] was able to establish that there was considerable variation in local response and

that it depended very considerably upon individual initiative and enthusiasm. There is little evidence of the nature of the courses offered, however; yet two very important factors are crucially linked with it: the image of Nuffield chemistry transmitted, and teachers' take-away perceptions of this image. Seminars, lectures and practical work all played a part and, to some extent, the Chemistry Team tried to build in safeguards to ensure that practical sessions really provided experience of the approach and did not become mere obstacle races. The use of trials teachers to run courses had several distinct advantages: they knew the materials well; they were committed and enthusiastic (if not, they would be unlikely to give up time to run courses); and many had participated in tutor training and in the summer courses of 1966. On the other hand, there were also inherent dangers. They had helped to develop the *Sample Scheme* and might unintentionally transmit a feeling that it was the 'one right way', with a missionary fervour that might arouse resentment, hostility or cynicism; or their enthusiasm could be so infectious that, for some course participants, subsequent uptake would be relatively uncritical. Such an orientation would also consolidate the 'package' image. Trials teachers' ability or inclination to implement the approach advocated had, all along, been taken very much for granted, and they were now passing on the approach as they saw it. The extent to which it actually reflected the intentions of the Team or, at least, communicated them clearly enough to newcomer teachers, remains a moot point, for it was never tested. It is quite possible that, with each step away from the centre, more distortion entered, especially distortions due to teaching style, and to inadequate perceptions. Herron's work in America was published at this period, and it indicated the risks of assuming too much about the communication of new ideas to established practitioners[49], but little notice seems to have been taken of it by those responsible for the courses, for no attempt appears to have been made to probe take-away perceptions or subsequent actions.

A factor that may have been very significant in reducing this risk was the production and use of films showing the approach in real classrooms. Shortly before the work of the Chemistry Project ended, the film 'Exploring Chemistry' was planned and produced with the help of Unilever. Starting with the development of learning in children through the urge to explore, the film went on to show children in a comprehensive school at work in a chemistry practical class under an experienced Nuffield teacher.

Sequences were spontaneous and unrehearsed. The film had its premiere on 1 December 1966 at the Film and Art Theatre, Hanover Square, London, and was subsequently awarded the British Film Academy's 1966 award for the Best Specialist Film of the Year, as well as a number of international prizes. A second film, 'Chemistry by Investigation', also showed an unscripted and unrehearsed Nuffield lesson in a school laboratory. Both films have been extensively used ever since in teacher training programmes[50].

In 1966 the idea of a television series on the Chemistry Project was put forward. Five programmes on 'Teaching Nuffield Chemistry' were transmitted during February, and again in October 1968. These covered a third form chemistry practical lesson in session, with additional commentary on the problems posed by the new approach given by the teacher concerned, sequences from 'Exploring Chemistry', a film on the use of gas syringes, a programme on examinations and, finally, contributions from Coulson, Nyholm and Keohane on the issues facing teachers taking up the scheme, and some early news of the Nuffield A level Chemistry Project[51].

Two other communication channels became available in the late sixties. The need for local dissemination centres was stressed in Schools Council *Working Paper No. 10*, published in 1967. The suggestion was based on two principles: first, that the motive power for curriculum development should come primarily from local groups of teachers accessible to one another; and second, that there should be effective and close collaboration between teachers and 'all those who are able to offer cooperation'[52]. This need should be met as soon as possible through the provision of special teachers' centres. Local Authorities took the initiative but, clearly, the creation of a new centre is not a guarantee that teachers will come together, especially specialist groups of teachers with strong affiliations elsewhere. Local Authority Teacher Centres have proved to be of greatest value and use to primary school teachers, whilst science teachers have tended to use 'professional' science teacher centres. These have usually been set up in teacher education establishments such as schools or institutes of education or in polytechnics, in association with the major professional institutions. Whilst any centre that brings teachers together to pool ideas and discuss problems is valuable, science teacher centres of this kind must reinforce specialist allegiances[53].

The first published materials appeared in June 1966 (two

months later than intended), heralded by a press conference on the 27th. From that time on, decisions about uptake were heavily dependent upon the 'message' that was transmitted by these publications about Nuffield O level chemistry, the extent to which this was perceived by teachers as matching the avowed intentions of the Nuffield Foundation Science Teaching Project to produce a flexible set of resource materials, the extent to which it met the actual as well as the perceived needs of individual teachers, and its feasibility in individual schools and classrooms. Nevertheless, courses, conferences and articles remained significant in so far as they ensured that the fundamental orientation of each section of the Nuffield Project was explicitly transmitted, and that a high level of interest was maintained. The role of significant persons in this connection, and the post-Project movement and activities of Project Team members, is probably highly important; this is an area which would repay research effort, particularly in later projects, where records are more complete.

Reception

Shortly before publication of the materials in 1966, *Education in Science*, successor to the Association for Science Education's *Bulletin*, printed a leading article entitled, 'Some thoughts about Nuffield and the approach of the publication date of the O level texts'[54]. This reaffirmed the Association's independent position and its right to 'ask any questions which it wishes'; it advised members to come to no decisions until texts had been thoroughly examined, the experiences of those teaching the courses had been described, and problems of finance, laboratories, available time, discipline and pupil progress had been examined and, it was to be hoped, solved.

A few days after publication, *New Scientist* welcomed the materials as a 'radical but restrained swing to modernity', adding that first impressions suggested that teachers and pupils must benefit from this 'uncluttered presentation' of science. It warned, however, that it might be a full decade before it was clear just how substantial the advance had been[55]. The review in *Nature* in October 1966 expected that most chemists would agree with the central theme that chemistry at O level should be a means of training pupils in scientific habits of thought, and that the approach most likely to succeed was investigational. The materials would 'undoubtedly' stimulate the reform of class teaching. But, while many would welcome new content such as the early emphasis on structure, the prominence given to energy changes and the idea of free energy, fewer might agree with the dropping of traditional topics like equivalent weights, historical approaches to atomic and molecular theory, and the preparation and properties of a range of chemicals[56].

Someone has said that changing the curriculum is like moving an old graveyard, because it is filled with sacred bones: inevitably, most of the criticism was directed against content, especially in relation to the omission of 'eternal truths' (such as those listed in *Nature*). Criticism stemmed principally from a very few, well-established and dedicated teachers of chemistry, with personal preferences and beliefs that clashed with those of the Project[57]. In a rejoinder in 1968 Halliwell pointed out that the soundest approach would be to test which of various suggestions were more effective; in other words, to proceed in the teaching of chemistry as one would normally in handling a problem in chemistry itself[58].

The *Introduction and Guide* emphasized that the Team had no wish to replace the old orthodoxy with a new and more rigid scheme, and that the *Sample Scheme* was intended only to illustrate, by detailed examples, how their ideas might be applied in practice[59]. Whatever the intention, however, publication of a detailed *Sample Scheme* consolidated any tendency to view the materials as a course, even *the* course. Several things followed. In the first place, they then became an obvious Aunt Sally for others with possibly equally valid sample schemes. In the second, this could affect teachers' perception and use of the materials in a number of ways. Finally, it could affect such attempts as were made at post-Project evaluation. Yet flexibility was a major aim of the Chemistry Project's plans, and it was hoped that teachers would choose any reasonable coverage of content that would fit into the framework produced or, in continuing innovation, into any other that could be defended on educational, philosophical or pedagogical grounds. This had been stressed in the materials themselves, and it was stressed again in the official series of articles put out in 1966: 'Nothing would please those who have been concerned with the Nuffield Chemistry Project more than that teachers should develop their own schemes'[60]. Nevertheless the *Sample Scheme* could, in an examination-centred system, very easily be viewed as a 'minimum of teaching material on which presumably the examination will be set'[61]. The introduction of an examination in which

35-40 per cent of the paper would be based, intentionally, on recall (in essence that part intended to safeguard less able, but hard-working pupils) would also consolidate the belief that if the special Nuffield examination was being used then the materials would need to be treated as a package, a 'course', to ensure coverage. Many teachers might well remain apprehensive about stepping beyond the content of the *Sample Scheme*. Further evidence to support the relation between the examination and the 'package' view comes from Ingle's finding that schools taking the Nuffield examination tended not to use the additional experiments at all. For them, he reported, Stages I and II had become 'the course', and were used with little modification. He found far more flexibility with Stage I, and suggested that providing two alternative schemes here, and then only one each for Stages II and III (with very few suggestions for alternatives) might well be consolidating the 'course' view of these parts of the scheme[62].

Other factors may have reinforced this 'course' image still further. In the first place, curriculum projects involve turning ideas into 'things', and it is highly likely that professionally produced sets of materials give an impression of completeness in themselves, and do not invite teachers to adopt, extend and criticize them[63]. In the second place, there was the chicken and egg situation of the frequently used label 'the course', a situation exacerbated by early attempts at evaluation and possibly some inservice courses. Finally, the sheer investment of money necessary to equip a school for uptake might easily dissuade teachers from moving very far away, subsequently, from their content, although this factor carries rather less weight in projects which do not provide a pupils' textbook. (It can be a very significant factor where no fewer than five pupils' books cover the five year 'course'.)

The Project had run into the problem of pupils' conceptual difficulties in some topic areas, even with the selective group of pupils for which it was designed, but, as we have seen, trials teachers ascribed these difficulties largely to pupils' mathematical deficiencies and to attempts to do too much too quickly. However, in spite of their assurances that an increase in time allocation would almost certainly alleviate the situation, there were continuing complaints that some of the work was too difficult for all but the most able pupils. Certainly, Ingle found this view to be quite widely held among chemistry teachers in 1971[64]. This does not necessarily mean that this factor is the only, or even the major one, for the roots of conceptual difficulty are integrally related to previous and current experiences and, without classroom evidence, no firm judgements are possible.

Early comment and criticism showed such preoccupation with content that in 1967 a correspondent in *Education in Chemistry* warned that this focus on content could well divert attention away from the 'all-important philosophy' behind the Nuffield projects[65]. It may be that changing the framework within which teachers could plan their schemes, that suggesting the inclusion of a number of (at this level) controversial topics, that omitting many of the 'eternal truths' of traditional chemistry courses, and that providing the detailed *Sample Scheme* all served to do just this.

Teachers' perceptions were explored by Harding as part of the Curriculum Diffusion Research Project. Using a case study approach, she interviewed teachers and encouraged them to talk freely and to elaborate upon a number of issues, a checklist of questions providing the essential structure. They discussed the appropriateness of the 'course' for their pupils, differences between Nuffield and traditional courses, the advantages and disadvantages of 'going Nuffield', content and approach, and the cost of adoption. All the teachers saw the projects as 'external objects', facts of life, a 'new pressure acting on them that could not be ignored, but demanded a response, even if only of rejection'. Comments ranged from complaints about the level of difficulty of certain concepts and abstract ideas, about pupils' inability to handle data, about the need for more facts (especially facts about specific chemicals) and for notes, and for less time spent on practical work, to others that showed a considerable measure of enthusiasm:

> I knew advanced chemistry was organized around structure, kinetics and energetics, but the exciting thing was to realize that school chemistry could be, too.
> The perception that it's only for the brightest is not valid. Here, numbers have gone up since 1966, and percentage rate has improved.
> Pupils can think deeply and intuitively in a way that surprises me.[66]

Perceptions of the advocated approach, however, remain unclear, for, while there appears to have been much talk by teachers about the 'investigational approach', 'inquiry' and

'discovery' and while they stressed that the 'Nuffield approach' constitutes the major difference between Nuffield and traditional courses, their actual interpretation of these terms was not probed.

A questionnaire used by the Curriculum Diffusion Research Project to survey teachers' perceptions showed that they saw as the main features of the Chemistry Project the development of experimental skills, the ability to investigate open-ended problems, and an understanding of and ability to use 'the scientific method' (whatever that may be). Teachers agreed that these aims are important, but for them, as for most other science teachers in the sample, by far the most important aim of science education was given as 'knowledge of the basic facts of science'[67].

West attempted a 'multi-model approach to evaluation' of O level chemistry in the early 1970s, and although he did not probe teachers' perceptions or their classroom behaviour, he found that his questions about workloads, aims and choice of practical work elicited such ambiguous responses that he was forced to conclude that many teachers simply had not 'thought through the full implications of changes in philosophy and method presented by the Project team'[68]. Again, it is impossible to determine the relation between teachers' perception and Project 'message'. This may or may not matter, but, since a fundamental assumption of most science curriculum projects is that children will learn how and when to 'be scientific', one might wish that teachers' perceptions of these terms were clearer. Certainly, without evidence of greater understanding, few claims for 'diffusion' are possible.

This, in turn, underlines the importance of inservice courses and of other communication channels. In the case of the texts, the message may or may not be clear, but diffusion depends as much upon the client population's having read and reflected upon the appropriate sections before making it a part of their conscious planning procedures, as upon clarity of exposition. Wherever the roots of what appears to be a failure in communication lie, the fact remains that few attempts were made at any time, during or after the projects, to ascertain teachers' perceptions of the all-important approach.

Nevertheless, it seems clear that the materials have been widely welcomed and adopted. More than half the grammar schools in the national sample studied by the Curriculum Diffusion Research Project used them, and this is their target population[69]. Fewer comprehensives do so, but this is to be expected, especially with the move to mixed ability teaching. West, for instance, found that Nuffield Chemistry was used only with the most able pupils in his sample of eleven comprehensive schools, and that some of these had implemented special chemistry courses in Year I for these pupils. He argues that this finding reinforces assumptions about teacher perception of the conceptual difficulty of the Project[70].

Sales figures afford an indicator of use, but they are confidential. It is known, however, that the materials have been very widely bought by schools. Harding reports that sales of Nuffield O level chemistry materials peaked in 1967 for Stage I and, as was to be expected, two years later for Stage II. This time, however, the peak was much reduced[71]. It is not clear, however, just what the fall-off indicates, for a number of extraneous factors such as school reorganization were affecting school courses at this time. The outright bestseller among the resources intended for teachers is, significantly, the *Sample Scheme*, which has achieved twice the sales figures of other teacher materials[72].

There has been a steady growth in entries for Nuffield O level chemistry. By 1972, 15.2 per cent of all O level chemistry entries were for the special examination and the figure was still rising[73]. At the same time, it must be remembered that a substantial percentage of schools who would designate themselves 'Nuffield Science' schools are not included in these figures. Figures for actual 'use' are very difficult to obtain, for it is hard to define what constitutes 'use' of a set of resources, especially where approach is specified as well as content and, moreover, where considerable flexibility is advocated on the matter of content detail. It is hardly surprising that the two major studies of uptake give very different figures, the Department of Education and Science study[74] finding two and a half times as great a 'use' as the Curriculum Diffusion Research Project[75]. The Schools Council's 1968 survey[76] and Thorpe's study in the South West ran into similar difficulties. All were, in fact, trying to quantity the unquantifiable (which they no doubt realized) as the last chapter will show.

Adoption and adaptation has not been confined to Britain. In fact, far more adaptation has taken place outside Britain than in. So many requests for help with problems relating to curriculum development in overseas countries were received by 1966 that the Nuffield Foundation, in collaboration with the Ministry of Overseas Development, set up the Council for Curriculum

Renewal and Educational Development Overseas (CREDO). The Nuffield Foundation made available £100,000 over three years, and the Ministry £50,000 over the same period, together with an undertaking to provide technical assistance programmes using British experts and training facilities and working through the Centre. The Centre was designed to take account of curriculum developments in Britain and elsewhere, to help with their adaptation and modification to suit local conditions overseas, to send teams to help such work, to bring those engaged in projects elsewhere to Britain to work with British teams, and, in general, to co-ordinate all the resulting activities[77].

Even before publication, many foreign countries were anxious to obtain translation rights to the Nuffield Chemistry Project, sometimes with the additional right to modify materials to suit local needs. This has resulted in extensive programmes of development in many parts of the world, with a pay-off in terms of world travel for Team members and for experienced 'Nuffield' teachers, as well as in new communication links. Nuffield chemistry has been translated into many foreign languages and is in use in a considerable number of foreign countries, with or without significant modification. This too, is surely a measure of its success. Nevertheless, Halliwell has some reservations about the process:

> I believe that in the present day context of diversified mass-education the answer to the problems we have in mind will be different in different countries ... [and] that no scheme is likely to have universal application — therefore each community, while learning from the efforts of others, must base its proposals clearly on its own needs and in its own perspectives ... [78]

8

Changing the curriculum

The Nuffield Survey for the O level chemistry revision

During development, attention centred largely upon improvement of the materials and upon examination papers and questions that would test for the attainment of a wider range of cognitive objectives than in the past. Dr R.B. Ingle's research for the revision began in 1970/1 and its focus, too, was on the further improvement of the set of resources, although one of its primary aims was to re-emphasize the flexibility of the proposals, a flexibility which appeared to have suffered much attenuation as a result of the 'package' image. The study was restricted to those schools pursuing the 'complete course' and which entered candidates for the 1970 examination (just over 200 schools). Approximately twenty of these were visited, generally for the best part of a day, during which lessons were observed and informal discussions held with teachers and pupils. A detailed questionnaire was also sent out to teachers in these schools, and then half of them received a second one asking for even more detailed information on individual experiments, film loops and Background Books. An inservice course was attended (only one, because so few were still available for O level projects), and four meetings were convened in different parts of the country to discuss the revision. Talks were also held with Science

advisers, inspectors, members of the original Team, some Area Leaders, the chief examiners as well as staff at the National Foundation for Educational Research, and other interested parties. Ingle also used analyses of the materials, carried out from different points of view, and of pupils' level of performance in the examination[1].

Two major sources of difficulty had revealed themselves during the trials and they re-emerged now — pressure on time, and the conceptual level of some topics. Many teachers told Ingle that they had difficulty in completing 'the course', even where they had the recommended time allowance on the timetable. This left too little time for the 'Options', and for material that was not going to be examined, which was therefore neglected. Yet other schools appeared to cope easily, sometimes on less than the recommended time.

Research into the mathematical demands of the course revealed that, no matter whether schools used traditional or 'new mathematics', pupils' poor performance was a serious stumbling block in chemistry. Many pupils were unable to cope with elementary computation, with proportion and ratio, with indices and small numbers, with graphs, logarithms and slide rules. Meanwhile, teachers' ratings of the difficulty of each topic for the top and bottom quarters of GCE pupils provided a scale of perceived difficulty for each group. These perceptions were matched with pupils' level of performance in examinations and with an analysis of the conceptual demands of the course carried out by Shayer[2]. Although there were some obvious and quite substantial differences, findings were reasonably congruent, and so they afforded a basis for revision, modification or replacement by alternatives, of the areas of greatest difficulty.

It is clear that this congruence indicates weakness somewhere in the scheme, but all three elements — teacher perceptions, pupils' achievement and Shayer's analysis — are open to criticism on the grounds that too many interrelated elements may be being neglected, and that no firm conclusions can be drawn from them at this stage. Without detailed study of the intervening component of classroom interaction, and without control of other important variables such as the teaching methods used in other subjects in the sample schools, and pupils' previous experiences, no direct causal relationships can be established between achievement or non-achievement of desired pupils' outcomes and the materials. Shayer's work on curriculum analysis has an element of circularity in that it is based upon a particular developmental model of learning which it then uses as a framework for analysis, and it can be criticized for apparently ignoring previous experience both inside and outside schools when classifying pupils.

Nevertheless, Ingle's research showed that, even with the most able pupils, some topics or sub-topics were associated with a lower level of performance than most others, and were therefore particularly difficult; that even with the benefit of experienced teachers, many pupils were finding particular topics very difficult; and that there was a 'quantum leap' in difficulty between Stage I and II. In Piagetian terms, pupils who were unable to go beyond concrete operations were, rather suddenly, being expected to work at a level of formal operations.

The tendency to view materials as 'the course' has already been described. This conception is also indicated by teachers' feelings about the need for a text book. When questions were asked about the range of resource materials provided, Ingle found that the major change being asked for was the addition of a pupil's text, primarily for Stage II. Teachers and pupils had apparently felt insecure as a result of its omission, and head teachers and parents had expressed surprise at the lack of a book that a pupil might 'call his own'. This suggests a lack of appreciation of a view of O level chemistry as a flexible framework within which each teacher might develop his own course. A series of six Foreground Books had, indeed, been produced by one of the original Team members, and Ingle found that these had been widely taken up by Nuffield schools.

The lack of a pupils' book seems to have affected the view taken of the Background Books, too, for Ingle found that many teachers were critical of their lack of factual and explanatory material, especially at Stage II, and of their focus on topics that would not be examined, even though they appreciated having such material to hand. In contrast to Halliwell's original intention, Background Books were relatively costly and this virtually precluded their purchase by pupils, and limited the number of sets (and even the range within a set) bought by schools. Inevitably, there was little opportunity for pupils to see and handle them, let alone read them, out of class time. The amount of reading done by pupils varied considerably between schools, but Ingle found that informal discussions with pupils about the books were often frustrated by the fact that they had not read them. Those who had, however, had enjoyed them, and welcomed them as something different from the usual reading

matter available to them. In general, there was little interest in historical material, although this was clearly dependent upon the attitude and interest of both science and history teachers in a school. Pupils liked pictures of great scientists at work in the laboratories, but not portraits of 'old men with beards'.

Teachers' opinions on the pupils' laboratory instruction sheets varied considerably, almost half seeing them as valuable. Half of the remainder wanted yet more detail; the rest thought them unnecessary or even 'harmful'. Some teachers, in fact, saw them as a threat to their professional judgement in that they told them 'what to do'. The idea of pupils' files, with laboratory sheets interleaved with pupils' own notes, had been taken up by most teachers at first, but by 1970 many teachers argued that treating the sheets as expendables in this way was far too expensive, and there had been a strong move towards the use of hard-cover notebooks and only laboratory sets of the sheets. Some teachers reported that very few pupils were capable of keeping good files in the recommended manner, most of them ending up with muddle. Some had stopped using the sheets altogether, especially at Stage I.

The *Data Book*, they argued, contained far more information than was needed for the 'course', and the examining boards' refusal to allow pupils to use the book in examinations had clearly militated against its widespread use. Teachers believed that while much of the information was fascinating, it was too complicated for all but the most able pupils at this stage, and the situation had possibly not been helped by the fact that the *Sample Scheme* provided few detailed suggestions to indicate how it might be used as a 'major teaching aid'. Many schools, again, were simply doing without it.

The teachers' books were all seen as valuable, apart from the *Collected Experiments*. Teachers felt that they did not need to refer to it at all, since Stages II and III represented 'the course', upon which pupils would be examined. Ingle's sample schools were all taking the special Nuffield examination, using the materials as a 'package', and it is possible that non-Nuffield teachers, or those using the materials as resources only, would find this book more useful.

The *Sample Scheme* was by far the most influential of all the books intended for the teacher, especially the *Basic Course*. Use of individual *Options* varied widely, ranging from use by 120 schools in the case of *Option 1* ('Water') to eight schools for *Option 9* ('Historical Topics'). Interestingly, teacher assessed options were clustered at the bottom end of the list with all but two of the examination assessed options well above them. This may have been partly accounted for by the fact that so far schools had only been able to try out two or three of the options, but Ingle also found that many teachers in the sample expressed serious reservations about teacher assessment, some of them, in fact, being strongly opposed to the idea. Pupils had little say with regard to the choice of options, teachers generally making the selection, and the whole class studying the same topics.

Teachers' reactions to the film loops were equally varied. About one fifth accepted them without reservation; for another two fifths, by far the greatest value lay in those using animation to illustrate a principle or an industrial process, and least value in loops illustrating a laboratory technique. The remaining two fifths regarded even the best of the loops as of limited value. The mechanical unreliability and inadequate screen brilliance of film loop projectors in general was a source of considerable dissatisfaction.

With centralized development the degree to which the underlying ideas are made clear and transmitted to teachers without seeming necessarily to be embodied only in the project materials will be an important factor in determining teacher perception and use as well as implementation, and flexibility. The major communication channels for making clear the approach being suggested were the materials themselves, inservice courses and, indirectly, examinations. The Team had been at pains to spell out the approach advocated, and means for achieving it effectively, in the *Introduction and Guide* and the *Handbook for Teachers,* whilst the detailing of the *Sample Scheme* showed how the approach might be used with one particular selection of content. Ingle's findings are, therefore, particularly significant here. The *Handbook for Teachers* was *'widely praised by those teachers who have had time to read it'* (my italics), so that, for many teachers, the *Sample Scheme* was, in effect, the handbook. Again, emphasis appeared to be on particular content, and following a detailed course does not necessarily entail thinking through its rationale, or even that the approach is followed in any recognizable way. Ingle recorded that practising teachers did not often have occasion to turn to the *Introduction and Guide*, and he pointed out that this meant that those parts of the book which required study over a longer period of time will tend, as a result, to be neglected. Clearly, it could also mean that some chemistry teachers 'doing' Nuffield had not read the appropriate passages thoroughly, if at all[3].

The overwhelming impression that emerges from this research

is that many of this particular sample of teachers wanted a detailed course, a package that would somehow transform their lessons and solve their problems, rather than a flexible set of resources. They therefore welcomed more and more spelling out, even of alternative course work, and every further step towards the achievement of the ready-made course. This does not, of course, mean that teachers are unprofessional, incompetent or downright lazy. It probably reflects feelings of considerable insecurity about their ability to meet what may have come to be, for many, a massive demand, amounting to an imperative in the prevailing climate of opinion. The curriculum development projects have been accused of trying to civilize the outposts, to convey light to the natives; but this is not quite fair, for the projects and their package image reflect a concern to provide what the outposts seemed, in fact, to want. On the other hand, more secure teachers might easily resent this steady move from resources to a course, with its implied criticism of their professional capacity and judgement.

More widely based curriculum evaluation activity

For some time after publication, such evaluation research as was carried out remained focused upon the congruence or otherwise of pupil outcomes and planners' objectives, an approach which was clearly influenced by the 'objectives' ideology of the period. The first post-Project study was carried out in 1966, using trials pupils. Although it did not commission his research, the Nuffield Foundation provided a grant for Meyer's study of the reactions of pupils to O level trials materials in that year. Meyer recognized that the Hawthorne effect was likely to operate with these pupils, and he tried to allow for it in his control group. Nevertheless, he found a number of significant differences between his Nuffield and non-Nuffield samples in relation to both attitudes towards science and levels of scientific thinking. Nuffield pupils were certainly not always 'superior', but his analysis showed that Nuffield chemistry was particularly effective in promoting positive attitudes to school science teaching and interest in science[4].

Kempa and Dubé in 1971 appear to have been interested, initially, in whether these differences of Meyer's would remain significant once it could be assumed that some diffusion of Nuffield ideas had occurred in schools following more 'traditional' courses. They therefore built their research upon Meyer's.

But their findings were somewhat unexpected, for the 'non-Nuffield' group was found to have the more positive interest/attitude change, especially in areas most readily related to the curriculum offered. The authors therefore suggested that this was due to the 'better balance' between problem-centred and fact-centred content in the non-Nuffield courses, as compared with Nuffield courses. However the number of schools and teachers is really too small to allow too much weight to be placed on these findings, especially since there does not seem to have been any analysis of what Nuffield and non-Nuffield teachers actually *did* in their lessons, even in the broadest terms, and whether there were clear and uniform distinctions between the two groups, so that the conclusions remain a matter of opinion and value judgement only[5]. Similar considerations apply to West's study of outcomes in his 'performance evaluation'[6] (although he recognizes and acknowledges this limitation) and to the Stage I evaluations of Oliver and Roberts[7] and of Flynn and Monro[8] (which had the advantage of pre- and post-tests).

Laughton and Wilkinson[9], West [10] and Eggleston *et al.*[11] have all found evidence of a fall-off in positive attitudes in the final year of the O level course, but it has not been possible to draw any conclusions relating this to the Nuffield course itself, for other factors may have been operating. Duckworth and Ormerod[12] found that Nuffield teachers did not seem to have changed their teaching style significantly, and this would be a factor of some importance, too, in fostering positive attitudes. For O level chemistry this last finding is perhaps somewhat tempered by the findings of Eggleston *et al.*, but there are still too many unknown variables at work for comfort.

By the early 1970s Eggleston and his colleagues were arguing that the classroom and its activities had so far remained a 'black box' in evaluation research related to the science projects, and that it was time to 'lift the lid' to search for patterns of interaction that might have significance for curriculum innovation. Merely to focus on preconceived notions of 'process' would, they believed, entail far too many inferential elements, and so their first step was an attempt to focus on the observed behaviour of teachers and pupils in a search for patterns of similarity in behaviour profiles. In this way they hoped to reduce the number of variables to manageable proportions. Early work concentrated on the development of the Science Teacher Observation Schedule (STOS), and it was not long before its application indicated that at least three main categories of 'teaching style' could be quite readily distinguished. *Style I* is characterized by teacher direction, but is one in which science is treated as a problem solving activity, the teacher challenging pupils with a comprehensive array of questions which require observation, speculation and problem solving in both theoretical and practical contexts. Pupils are, therefore, actively engaged in hypothesis-making, predicting and testing at all times. *Style II* is largely theoretical in bias, is teacher dominated and closely tied to facts. Teachers using it tend to provide a relatively high number of statements of fact, to ask few questions other than those requiring factual recall or application of facts or principles to problem solving, and to direct pupils to sources of information on facts. *Style III* is more pupil-centred, and involves a fair amount of practical work, and a high level of 'intellectual engagement'.

Interestingly, they found that pupils following Nuffield O level chemistry were three times as likely to be taught by Style I as by either II or III, and that this applied right across the ability range for both sexes. Style III was more common with girls than boys and especially with lower ability girls, but here the girls found chemistry 'more fun', and were more vocationally orientated towards the subject than their sisters in other types of classroom. Style II was relatively little used by chemistry teachers. Where it was found, it was generally in use with high ability boys, and the authors suggest that this is, perhaps, because teachers feel that such pupils do not need much concrete experience (it may also be a response to the 'getting through the syllabus' syndrome that often afflicts such classes). Eggleston suggests that these findings may indicate, too, that chemistry teachers are selecting a teaching style suited to particular groups of pupil, even though their preferred style is, in general, Style I. Overall, though, there was considerable consistency of style in individual teachers, adaptation to classes of pupils of differing ability usually producing little more than an alteration of pace.

The tendency of Nuffield chemistry teachers to use Style I is interesting, because the relation to the approach advocated by the Team is clear, and because it raises questions about possible differences in the transmission of the 'message' by different projects, and relative success in implementation in chemistry as compared with, for example, biology, where Style II is overwhelmingly common. It is equally important to remember, however, that there were both chemistry and physics teachers who never asked questions about what pupils observed during practical sessions and who never encouraged hypothesis-making, predicting and testing. One might speculate on the possibility that (and the extent to which) the emphasis in projects on resources, and hence on the teacher as essential stimulus, accounts for the less frequent use of pupil-centred Style III[13]. Overall, Eggleston *et al.* suggest that a 'considerable dissonance exists between the aims of curriculum developers and related classroom practice'[14]. An attempt was also made to match teaching styles with a restricted range of attitudinal and cognitive achievements by pupils. Teaching Style I emerged, in fact, as a significant factor in relation to nine attainment and eleven attitude changes, and this was seen as a clear vindication of their initial argument that teacher-pupil interaction is a crucial variable in evaluation. This is undoubtedly true, but it remains to be seen whether it is justifiable to assume that certain aspects of classroom interaction can be isolated and then related to outcomes in this way, for 'good teaching' is rather more than 'teacher effectiveness'.

No one style proved more effective in producing desired outcomes across the range investigated and across all three subjects, although Style I 'showed up well', and Style II appears to have 'little to recommend it'. A rather disappointing finding was that Style I produced an especially marked fall-off in favourable attitudes to chemistry in the penultimate year to O level. It may be that a focus on teacher effectiveness (at least in rather clearly specified and limited terms) is achieved at a cost, drawing attention away from broader issues of classroom context. This may, in fact, be true, though to a lesser extent, of all chemistry teaching, Nuffield and non-Nuffield, for the development of negative attitudes towards the end of the O level course has been a consistent finding. Again, the consistency of use of teaching style is of value to the researcher, but for pupils it could well mean that certain skills are unlikely to be developed, and therefore that more flexibility of approach is desirable.

Rightly or wrongly, the O level projects took a particular path which in a highly uncertain situation seemed to be that which was most likely to be effective — the production of tested materials for use by teachers, with or without modification. During development the focus was on getting the materials 'right', and feedback was evaluated and acted upon within this context. Once they went on offer to teachers, however, evaluation of their effectiveness as a means to change would, with hindsight at least, seem to be a pressing need, before more projects of the same general type were allowed under way. The

scale of financial and manpower investment in each project was considerable, yet such was the euphoria that no official attempt was made to look for significant changes, either in the nature of classroom interaction or in the range of pupil outcomes — that is, therefore, for the achievement of their original purpose. The Nuffield Foundation did not view summative evaluation as part of its pump-priming function; the Schools Council's only essay at this point was a very limited survey of 'uptake'[15]. This meant that early evaluation was confined very largely to a few individual studies, small scale and of variable quality, with no coherent overall policy or planning.

It can, of course, be argued that a lapse of time was necessary after publication, and that a concern to spread the benefits of curriculum development more widely among pupils and teachers and schools was so overriding a consideration that it could not wait, even for evaluation of the crudest variety, and that these more pressing demands upon available finance and personnel demanded project-proliferation, based on the newly established model. It raises equally important considerations, however, about ideological blinkering in relation to the most fundamental underlying assumptions.

The changes being sought fall into three main categories: the achievement of widespread diffusion and implementation of a 'modern approach to chemistry'; a more effective use of science (in this case, chemistry) teaching in order to achieve a wider range of pupil outcomes; and the initiation of continuing innovation in classrooms. Choice of the *means* to change — centrally developed curriculum projects, reorientation programmes for teachers, and modification of the examination system — was made on the basis of value judgements, a very little knowledge, a great many assumptions and considerable practical experience. In such a situation it would seem extremely important to follow up at least some of the major areas of uncertainty. Yet there has been very little attempt to evaluate teacher-pupil interaction as means to the attainment of educational ends such as creative thinking or critical judgement, no consideration until very recently of classroom activities in relation to the underlying ethos of 'inquiry', even in very broad terms, let alone in terms of the 'discipline'. Above all, there has been an extraordinary failure to follow up three fundamental and major assumptions. The first is the belief that the teaching of process and product in science can and does make possible the development of particular skills and states of mind and the interrelationships between them that constitute the scientist's 'way of knowing', and which contribute uniquely to the development of mind, of rational autonomy. The second is that 'desirable' change can and should take place in this context, or is even feasible with teachers with different personalities and teaching styles and children with quite different experiential backgrounds[16]. Both are, surely, areas of the utmost importance, and both are fundamentally related to studies of classroom interaction as well as to the evaluation of outcomes across a wide range. This may seem to be a quite unrealistic demand, yet without it few claims can be made for improvement as a result of a project. And what constitutes 'improvement'? The whole area is one of considerable complexity, and within it, knowledge about the teaching and learning of intellectual skills, attitudes and interests and of the contexts within which they occur, remains minimal. Yet unless the underlying assumptions are treated as problematic, progress will be limited, for pupils' failure to evidence the hoped-for achievements will continue to be ascribed to their intellectual deficiencies, or to the unsuitability of the materials.

The third fundamental assumption that has been taken for granted is that merely to place materials on offer to teachers is to make them viable in the classroom. Successful realization in the classroom of the approach and content advocated by a project constitutes 'implementation'. This, in turn, implies the existence of both commitment and understanding, as well as the ability to put the proposals into practice in the classroom. Widespread implementation implies the successful 'diffusion' of the 'message', that is, of real understanding, via communication networks and decision making processes. To talk of the 'diffusion of a project' must surely be to imply that no distortion has taken place during transmission from developers to target population. If distortion has occurred or if what happens in a classroom would be virtually unrecognizable to the developers, then the advocated change has neither diffused nor been implemented, and it is preferable to use the term 'adoption'. Whilst 'adoption' implies a commitment that guides practice, this practice may not reflect any understanding of the project's most fundamenal intentions[17]. It is clear that this term should also be used where there is no direct knowledge of what teachers are actually doing with the project's materials in the classroom.

The distinction between 'implementation' and 'adoption' is an important one, and not mere pedantry. This is particularly the case where the 'success' or otherwise of a project is in question. At the heart of the Chemistry Project was a framework of 'process and product', with an integral teaching approach, but with considerable flexibility on the matter of content detail. Thus adaptations which put into operation the basic framework and approach constitute successful diffusion and implementation, because they also involve understanding. But there can be no claims of implementation unless it is known what teachers are *doing* in concrete situations. It is not enough to take what they say, rather than what they do, as sufficient evidence of diffusion and implementation. This applies particularly to teachers who have been on courses and who may therefore believe, quite sincerely, that they are Nuffield-orientated. They may be able to talk in the language of the teachers' manuals, and yet they may fail to evidence, in any way, the appropriate behaviour in classroom or laboratory. They may, in short, have acquired little more than a new vocabulary.

It is arguable that because the situation is so much more complex than the intentions of curriculum projects imply, any real understanding of means-end relationships in classrooms is likely to remain little more than a pious hope, and that evaluation of project diffusion and implementation is doomed to failure simply because the expectations were so impossibly great. At the same time, however, studies of adoption can never provide an alternative measure of this means to change, and diffusion studies that rely upon 'adoption' rather than implementation may fail to reveal weaknesses in the communication network and sources of distortion that arise during both communication and decision making, and which may have very important implications for the spread of change (for example, where a key individual is transmitting a distorted or inadequate 'message').

It is clear that making claims for change, except in very broad terms, is very risky. In the same way, trying to establish causal relationships between projects and, for instance, examinations and textbooks, is equally open to error. These might all three be expected to show related changes since, in a particular socio-historical climate, all will be affected by similar pressures for change, whatever other issues of cause and effect may be operating.

Harding concludes from a 'somewhat cursory' (because not central to her study) study of textbooks that publishers and authors have been 'heavily influenced', although she admits that they may have been more aware, perhaps, of the advantage to sales of declaring an association with the projects or their objectives. Nevertheless, there is strong evidence of a general climate of approval. She points out that few chemistry textbooks were published between 1966 and 1972, although one of the Project's Team members produced a series of Foreground Books (pupils' texts) after 1966. Of two comprehensive texts published in 1970 and 1972, both sets of authors acknowledge their 'great debt' to the Nuffield O level Chemistry Project[18].

O level projects used examinations as an instrument of change, and in doing so produced new-type examinations which tried to test for the achievement of a somewhat larger range of intellectual skills as well as of recall. Nevertheless, some examining boards, such as the Northern Universities Joint Matriculation Boards, were already questioning techniques and syllabuses[19].

In some ways, examinations appear to have been remarkably little affected by change. At the time of the development of the O level projects it was anticipated that all boards would move in the same direction with regard to the range of skills demanded and that ultimately, therefore, all would be exerting the same pressures upon teachers. This did not happen, however. In 1973, Giddings[20] analysed O level papers in chemistry and found that, while the special Nuffield papers had shown consistency in demanding relatively stable proportions of recall, synthesis, graphical interpretation, calculations and data interpretation, there had been rather little movement elsewhere. Three of the biggest boards had actually increased recall items in the period. While no valid generalizations can be made from a comparison which uses figures for only two years, there seems to be little doubt that recall still features far more heavily in most papers than in the Nuffield examination and it is clear that examining boards, whose papers require only recall for more than two thirds of their questions, demand fairly close adherence to their syllabus and that, therefore, consistent use of Nuffield materials or resources will depend heavily upon the closeness of content-match. And it will tend to focus attention, once again, on content-transmission.

Curriculum projects and the art of the possible

Educational change involves a vast complex of interrelationships with the social environment. It is complicated still further by the diffuseness of educational goals, the complexity of its communication patterns, and the weight of tradition, of vested interest and of other factors in society which constrain or facilitate the activities of those seeking to bring about change. The multiplicity of variables and the repeated obtrusion of new phenomena greatly limit the usefulness of models of curriculum change, for the liability to error is inevitably great and, in addition, unless power relationships and communication networks can be made both explicit and accurate, a model has limited descriptive use only, and cannot be used for the purposes of generalization and prediction.

Because of its complexity, educational change is very slow. Mort, for example, found that 'between insights into a need and the introduction of ways of meeting those needs that is destined for general acceptance, there was in the past typically a lapse of half a century, while another half century was required for the diffusion of the adoption[21].' His research was carried out in the late 1930s, but even if educational change has been speeded up and made more efficient since then, the rate of societal change has also increased. A more recent study by Voege of the diffusion, between 1936 and 1970, of one of the major perspectives on economics in the twentieth century (Keynsian macro-economics), showed that the time needed for the entry of a leading idea into the school curriculum may be as much as twenty-five years[22]. Many features of our modern society demand rapid curricular response; many others hamper it. Two major constraining factors are, first, the politics of educational knowledge, by whose means the content of education remains an instrument of social control, tending to perpetuate a particular hierarchical structuring of knowledge and differential availability to different groups of pupils, and a relatively stable curriculum over many years — in short, a maintenance of the *status quo*; and second, stabilizing tendencies in both central government and in individual classrooms as a result of conservatism, institutional structures and inertia.

In a rapidly changing society in which the place of science was becoming more and more central, attempts by a major pressure group (the Science Masters' Association) to get change in the direction of more up-to-date knowledge and approach had developed, over some thirty years, an established procedure: the provision of new syllabus proposals and teaching notes, along with suggestions for the teacher on laboratory organization and management and other problems. In the late 1950s, as in the past, the science teachers wanted to bring about change of a piecemeal sort, change in the conception of science education within the stable context of the educational *status quo*. Inevitably, then, their *Policy Statement,* which was to provide the framework for their suggestions for getting this change, was very largely in agreement with the general educational value system and, consequently, with the accumulation of assumptions, beliefs and practices that constitute educational tradition. Among these was a major assumption — that teaching should be discipline-orientated.

The tenets of the *Policy Statement* provided a basis for action. In accordance with long-established practice, the Science Masters' Association sent copies to all those with an interest in matters of the science curriculum and then set about the task of devising, once again, an appropriate syllabus. Earlier exercises of this sort had demonstrated that pruning a syllabus and replacing excisions with more 'modern' material could be a matter for conflict. This was not the major problem, however. That lay in the fact that, because of its focus on 'process' as well as content, the new ideal depended quite fundamentally upon the teaching approach used. It was their attempt to meet the resulting need for teacher guidance that led to the steady escalation from teaching scheme with notes to curriculum development project, for it required full-scale action — and money — to provide what was now believed to be necessary. The climate was extremely favourable. Science was in a position of strength, and its advocates were very vocal in their efforts to persuade government and public that, because of its crucial importance to the economy and to the 'standard of life of the whole community', science education at all levels was a matter for considerable national concern. The country, they argued, needed a scientific and technological manpower which it could not hope to achieve unless immediate action were taken. At the same time the 'Two Cultures' controversy, similarly linked with the social matrix, produced other, more 'educationally' orientated pressures, as did the curriculum development movement then in full swing in the United States.

The formidable problem that faced the science teachers was that there was not, as yet, any official agency with responsibility for the curriculum. Action in this area — the proposal to form the Curriculum Study Group — was, in fact, under discussion at the Ministry of Education, but it was meeting with some opposition from the Inspectorate, who seem to have anticipated

the extreme political sensitivity of any such move[23]. Any approach to government, then, for finance and help was unlikely to succeed, although this could not have been known to the Science Masters' Association. It was the purely fortuitous conjunction of time, place, circumstance and persons that the man whose advice they asked was not only the chairman of the Advisory Council on Scientific Policy, which had just pointed out the need for reform in school science, but a Nuffield Trustee, and that this led, finally, to the establishment of the Nuffield Foundation Science Teaching Project. It may be that the Science Masters' Association's action at this juncture served simply to catalyse a process already latent in the situation, a process that manifested itself in the establishment of the Schools Council in 1964. Yet this is in no way a denial of its significance, for the setting up and financing of curriculum development was, in itself, a major educational innovation in Britain in that it led to the establishment of the idea that the use of special agencies to effect curriculum change was, at least, feasible. In addition, the Nuffield O level projects demonstrated for the future both the problems and the possibilities involved. The extent to which such demonstration was recognized and acted upon, however, is uncertain, for many crucial questions remain not merely unanswered, but largely unasked, certainly at official level, and possibly more widely.

Since men act as they do for a variety of reasons, some covert, some overt, the question of motives inevitably presents itself, and it becomes necessary to consider the possible use of ideas as political weapons rather than just as social levers. One may, for instance, focus on the conscious or unconscious self-interest of the advocates of science in their concern to emphasize and to maintain their newly dominant position in the economy, and so in society and in education. On this view, their fostering of anxiety about manpower by the 'manipulation of statistics'[24], which eventually produced action at educational levels, was clearly political and self-interested. Similarly, it is possible to question, as M.F.D. Young[25] and others have done in the 1970s, the motives of the science teachers, and of the Nuffield Foundation, in starting curricular reform within an accepted organizational framework, for an élite group of pupils, defined as such by virtue of their possession or manifestation of a very limited range of pupil characteristics, called 'ability'. While one must be aware of the possible existence of covert and less altruistic motives in the activities of a pressure group, in this case the Science Masters' Association (and Association of Women Science Teachers), it is both constricting and presumptuous to treat their ideological base simply as the product of the distorting effect of a loss of objectivity, occasioned by vested interest. Ideologies have a broader, gnomic function: they impart meaning, creating thereby a frame of reference for collective action. The motives underlying that action may, indeed, be cynical and manipulative. On the other hand, they may equally well be, in large measure at least, the product of a sincerely held belief in the therapeutic qualities of the ideas involved. This, in turn, may produce a sense of deep commitment and involvement, and dedicated and indefatigable work for the attainment of the ideal which may dwarf and transcend whatever vested interests may be present.

While the vested interest of the so-called 'science lobby' is clear, that of the science teachers' associations is less so, except, possibly, in the sense of 'prestige' and 'status' considerations. Clearly, the relative mix of motives will differ from individual to individual, but certainly, personal advancement could not have been a major factor in pre-Project days, when work for school science was not a noticeably effective path to promotion. After 1965 post-Project careers were undoubtedly affected and enhanced, especially with the help of the rapid university expansion of the period. But it is important to remember that Team members of the early projects were *invited* to participate (only one member of any O level team actually applied for, and obtained, a post and this was not in chemistry) and that, in the case of the Chemistry Team nucleus, all had been on the SMA Chemistry Panel. Career motivation was, however, very much more likely after the O level projects.

After the end of the Second World War the active core of the Science Masters' Association had devoted much time to secondary modern school science. The fact that what was produced has been described as 'watered-down' academic science may reflect their inexperience with this group of pupils, although elements of 'prestige'[26] may also have been involved, not least in terms of what was likely to be acceptable to secondary modern schools and secondary modern teachers of science, who were largely non-graduates. Thus it can be ascribed to a wish to extend their 'property' to a wider population, although the goods on offer were, for various reasons, of questionable value to their recipients, and although they were altered in the process of adaptation. In the meantime, the teachers' own examination-determined

and examination-dominated curricula were in great need of reform. They therefore turned their attention to their immediate needs and started from the given situation — the education in and through science of able children, within a selective system, and with strong economic pressures for specialization, made more cogent by contemporary university entrance demands. Their proposals for reform were, as the meaning of the word itself suggests, proposals for the modification of an already existing tradition. In the climate of concern over the supply of future scientists and technologists, a climate which they had helped to create and which they had used to press for change, the arguments of philosophers of education afforded apparent justification for the discipline-orientation (if justification was considered necessary at all). In a decentralized system in which power is so diffuse and in which examining bodies can exact sanctions by failing pupils, it is unrealistic to criticize the action of a small and relatively powerless group for restricting their definition of change, and for not attempting Utopian or paradigm change.

The Chemistry Team was concerned to provide a general education for all pupils in the top 25 per cent (which formed their given client population) and at a time in which this was regarded as synonymous with a 'liberal education' defined in terms of the 'development of mind' through 'initiation' into the disciplines. Thus it must have seemed that the interests of future non-specialist and specialist alike were being catered for in work which was conceived largely in terms of process and product. Nevertheless, the firm intention to set chemistry in its human ad social context was set out in the *Memoranda*. Work done in class on 'being scientific' was to be followed up in some 'options' and in the Background Books with material that would 'bring in the historical, biographical, sociological and industrial backgrounds'.

Young has argued that separation of knowledge from its use turns the applications of chemistry into an appendix, a set of properties, so that 'potentially exciting scientific discoveries, which provide ways of solving real problems and transforming aspects of our environment, become self-justifying and, for many, boring, and difficult and pointless[27].' Such a view could be accentuated where applications are relegated to back-up reading or to 'options' studied at the end of a course. The Background Books did, in fact, contain much historical material and some applications of chemical principles to industry, but they had little on the social context of science. There was little on conservation and even less on science as social process or as 'an expression of man's historical attempt to transform the natural world'[28]. Where applied chemistry appeared, it tended to be 'technologically sweet', stressing the benefits, and ignoring the problems and the questions that such issues should raise about choice and responsibility on the part of scientists, of government, of industrialists and of laymen in the interests of human welfare, rather than of productivity and profit. There was nothing to indicate that science is only one of several ways in which man explores, explains, represents and transforms the natural world (albeit the way that affords him most control of that world — and most power). The germ of all these ideas had been present in the *Memoranda*, but they were not realized in the resources. In mitigation, however, these criticisms should be set in the context of time and place. It is all too easy to use the frame of reference created by subsequent experience to criticize action (although such criticism is crucially important if used for adaptive reform and not merely for trying to belittle what has been done). Two additional factors must be kept in mind: the willingness or otherwise of science teachers to include such work, and of examining bodies to include questions upon it in public examinations. According to Ingle even the special Nuffield examination contained few questions on applied chemistry between 1967 and 1971, and none at all on the social aspects[29]. Some of the teachers in his sample were adamant that the social issues of chemistry were 'not a valid part of science education', and that if they were to be included in the curriculum their place was elsewhere — in English or history say[30]. *Option 9*, 'Historical Topics', had been taken up by very few schools (in fact, fewest of all the options) in Ingle's sample, although this may partly have been because it was to be teacher-assessed — apparently an unpopular factor. On the other hand, many teachers told Ingle that they would like to give some emphasis to the social aspects of chemistry, but expressed some uncertainty about what to choose and how to present it[31].

The means to change that were adopted consisted of (i) the published sets of resources, (ii) the beginnings of a system of reorientation programmes for teachers, (iii) the development of public examinations which would test for the achievement of a wider range of cognitive outcomes, and (iv) the legitimation, authority and credibility afforded by the involvement of status persons in science and in education (and later, by officially

recognized bodies such as the Nuffield Foundation Science Teaching Project and the Schools Council), and by placing development in the hands of experienced teachers and linking it with large-scale trials in schools. This appeared at the time to be a reasonable and workable choice of means and, again, in criticizing it, contemporary context must be kept in mind.

Whatever transformation of intentions and expectations occurred during development as decisions taken in one area affected outcomes in others, as vague ideological generalizations had to be turned into specific suggestions about content and approach, and as pressures from trials teachers were acceded to or disregarded; whatever distortions of meticulously worked out schemes of ideas manifested themselves in individual classrooms; however inadequate, confused or confusing the evaluation, there seems to be little doubt that much change has, in fact, resulted from the projects, even though it may not always have been in the direction anticipated. They provided teachers with a range of resource materials and ideas that were infinitely superior to anything previously available, and this can only have been very valuable. Because the idea of development projects was an innovatory one, the first projects were essential for getting research going in a novel situation, and they initiated a considerable expansion both of funding and of the scope of educational research and experiment. The experience has heightened the awareness of many teachers, teacher trainers and theorists of the complexities of teaching and learning, and of the crucial importance of a sensitive and wide-ranging monitoring by teachers of classroom interaction, in both conventional and innovative situations. The movement has strengthened existing, and created new, communication channels, and it has turned educational publishing into a growth industry.

Projects can provide (with varying degrees of specificity) only the means to change. Paradoxically, perhaps, the more specific and detailed they become, the more likely they are to stifle classroom innovation, as teachers either struggle to 'get it right', within their own particular cluster of classroom pressures and problems; or distort it, even to the point of nullification, in uncritical or uninformed, even if enthusiastic, adaptation; or reject it because alternative approaches are, for them, demonstrably satisfactory. There has been considerable variation between projects in the amount of flexibility offered, both intentionally and in the event. For O level chemistry, at least, the intention was merely to demonstrate the art of the possible, and not to create a new orthodoxy. Having demonstrated it, the

Team was concerned only that others might be given an accurate perception of it, and that from that point on, teachers might use their professional skills and informed judgement to work out their own salvation. If there was failure here, then, it lay not in the resources themselves, for they were meticulously thought out, but in those aspects that obscured their fundamental intention of flexibility. With hindsight, it would seem that chief among these was publication of a detailed *Sample Scheme*. Detailing the scheme in response to feedback from trials teachers was probably necessary in the interests of assessing feasibility where both content and approach were important aspects of what was being proposed, for it gave some control over the enormous array of variables, and it was containable within the administrative organization of the trials. It might then be argued that since trials teachers clearly experienced so much difficulty, it was important to produce a course which non-trials teachers could use as a starting-point and then adapt as their experience, understanding and confidence grew. But it now seems clear that it acted, instead, very much to consolidate the 'package' image, with all of its consequences. Teachers in the past had, as a matter of course, adapted examination syllabuses to their preferred modes of classroom interaction. Could they not have done the same thing using the framework or, at most, the outline *Sample Scheme*? A major source of difficulty lay in the fact that a particular approach formed part of the framework and that it had been assumed that this could be introduced into the context of the classroom without affecting many other variables with which it would inevitably be closely interrelated, and without being affected in turn. Yet the very different conception of trials and of briefing and inservice work that would have been demanded by such an approach might have thrown up this major barrier to change at an early stage.

The idea of curriculum development projects as a means to reform was a major educational innovation in Britain, but it has been too easy to view them as *embodying* innovation, which could then simply be transferred to the classroom. As Hamilton has argued, the true locus of classroom innovation is, and can only be, the classroom[32] (and, of course, the laboratory), because it is what happens there that constitutes change. Yet it is precisely in the area of classroom change and its relation to the projects that so many questions have remained unanswered, and often unasked, because evaluation has been only partial, random and ideologically confined.

As long ago as 1954, Riesman[33] pointed out that the combination of internal and external pressures in schools is a major factor in their conservatism, since it makes it very difficult for teachers to move away from traditional practice. Since then this view has been confirmed by a number of studies[34] which suggest that schools and the teachers within them gradually accommodate themselves to a state of equilibrium (which is possibly unique for each school and for each class and teacher) within the context of a relatively stable body of ideas about how and what to teach. This state of equilibrium minimizes tensions and, in doing so, favours traditional approaches that have shown themselves to be at least minimally satisfactory. So while outside pressures for change may incorporate confident arguments about the error of traditional ways and the advantages of newly advocated ways, far too little is known about what actually constitutes 'successful' teaching and learning, or about methods of achieving them, for such pressures necessarily to seem sufficiently threatening to ensure a change of equilibrium — especially when the proposed change is in any case optional. Thus, for instance, McKinley and Westbury found that in a number of case studies of attempts by outside agencies to promote change, the actual response found in classrooms subsequently was far 'less grand' than had been anticipated.

All innovation involves a shift of equilibrium, which may have upsetting and unexpected consequences. In 1968, concern over the role change expectations of the Nuffield science projects led to the appointment of a Research Fellow at the Centre for Science Education, Chelsea College, London, which was, by then, the nerve-centre for the Nuffield Foundation Science Teaching Project. During the following year he worked his way through all the published materials and then spent considerable amounts of time observing in 'good Nuffield classrooms', and matching his observations with Project intentions. Study of the then state of the art of classroom observation led him to conclude that no adequate technique was yet available, no 'framework of meanings to describe implementation and consequences of innovation and change within the educational process'. It was not enough, he argued, to rely upon descriptions of teacher effectiveness in relation to the handling of a specified 'process' in classroom and laboratory. The wider social and material context must be considered as well, for pedagogy and curriculum were 'adaptations to a particular school structure and a set of educational values implicit in it'[35], and teachers had a coherent personal solution to their educational problems, even though this might not be in line with current definitions of educational solutions. Research should therefore also take into consideration such factors as variation in setting and content, climate and interaction, behaviour of teachers and pupils, actions and activities. But his application to the Social Science Research Council for funds to start coming to grips with this task was rejected, and it is only relatively recently that any researcher has looked closely at the forces at work on the innovating teacher, and the system of interpersonal relationships within which he and his pupils work.

Again, by 1966, there was considerable evidence[36] to show that normative re-education on courses or in seminars is not necessarily sufficient to sustain change once teachers return to their normal social setting, and that mere possession of knowledge does not guarantee its use. Herron's studies[37], based on a follow-up of reorientation programmes by the major National Science Foundation-funded projects in America, confirmed these findings, even for situations in which detailed course materials, incorporating the required approach, were available during and after training courses. Yet no evaluation of teacher reorientation as a result of either materials or inservice courses was undertaken here in Britain; subjective judgements only were made. It seems clear that both materials and courses generated, and often sustained, considerable enthusiasm[38], and that a workshop approach to them may have been particularly successful, but there was no probing of teachers' take-away perceptions, nor any follow-up study of subsequent classroom interaction. Teachers may find an inservice course stimulating, even exciting, but the roots of their satisfaction may lie in any combination of a variety of possible causes: the satisfaction that derives from social interaction with peers; the updating of knowledge; the possibility of introducing more up-to-date conceptions of their specialist subject into schoolwork, with resources ready to hand; encountering a host of new and tested ideas for experimental work and for apparatus; the flexibility of the proposed framework in O level chemistry with the opportunities provided for professional decision making (if this is what the teacher wants); or merely the excitement of bandwagoning. Similar considerations apply to courses aimed at helping teachers to make informed decisions on curriculum matters by having them analyse materials in detail and consider their classroom implications[39]. The potential of such courses for effecting actual change on return to the classroom, however,

remains largely untested, in spite of the gap they leave between abstract analysis and implementation. Yet, in either case, if it is change that is wanted, it is what happens subsequently in classrooms that matters.

The climate of euphoria that accompanied the appearance of the first projects was shortlived. Teachers appeared to be reluctant to attend inservice courses, and there was growing disquiet over reports of 'innovation without change'. In 1970, Wrigley drew attention to the fact that:

> ... the curriculum development movement has not always paid enough attention to the question of how its materials will be used. Good teaching using traditional content will certainly be more effective than poor, unimaginative teaching using materials by either the Nuffield Foundation or the Schools Council ... It is my view that problems can be side-stepped for a while successfully ... but that in the long run fundamentals cannot be ignored. Hence my concern for fundamental research and for better inservice and pre-service training of teachers.[40]

Official reaction, however, was to move in three new directions. Greater provision was made for evaluation studies during development, and a 'new wave' of evaluators emerged who were concerned to explore and examine a range of more subtle reactions to change and of many more consequences of project uptake than simply pupil achievement of (mainly cognitive) objectives. A Dissemination Working Party was established by the Schools Council in 1972 to look into the problems and strategies of dissemination and, in particular, to identify and strengthen communication networks and to determine key points at which decisions about adoption were made. The Curriculum Diffusion Research Project, based at the Centre for Science Education, Chelsea College, London, received support from the Social Science Research Council to explore these and other aspects of dissemination and diffusion, and topics such as 'failure' and 'barriers to success' were explored elsewhere, notably at the Centre for Applied Research in Education at the University of East Anglia[41]. Finally, there was a greater emphasis on local, as against centralized curriculum development, in an effort to ensure greater commitment and more effective implementation. This, clearly, brought a high risk of parochialism and amateurism, and of isolationism. Gradually, therefore, there has been growing support for the view that some combination of central and local development is desirable.

New perspectives like these make demands upon teachers seem intolerable, coming as they do on top of demands for greater accountability and for greater 'effectiveness' in terms of prescribed ends. The whole area is one of controversy and uncertainty. To require teachers to be more closely involved in 'research and development' may sound unrealistic and even pretentious, so the purpose and nature of the demand must be clearly defined. If the purpose is to give teachers readier access to new ideas in a search for solutions to their own problems, along with the means to evaluate success and failure in terms of their own classrooms, then the focus must shift from concern for teachers' acquisition of new knowledge and skills believed by those in authority to constitute 'effective' teaching, to concern to develop existing potential.

What happens in any classroom is infinitely more complex than can be spelled out in attempts to discuss 'teacher effectiveness' or 'being scientific' or 'exhibiting the spirit of inquiry'. 'Good' teaching cannot be specified in a form that can be generalized to other teachers. In any case, attempts to define 'good' teaching embody a range of assumptions and value judgements. Whatever it is, it is intimately related to situational factors, as well as to the personal characteristics of both teachers and pupils, and to the possession of skills and attitudes that make possible a sensitive and wide-ranging monitoring of classroom interaction and more informed decision making. Nor are teachers merely passive recipients of new ideas. What all this implies, then, is the need for curriculum innovation and development within a new conception of inservice work, in which the earlier image of an informed élite bearing gifts, or 'reorientating' teachers in a more 'appropriate direction' is replaced by a situation in which teachers themselves work on their own methods and materials with the help of colleagues and outside researchers[42], drawing where necessary upon centrally produced resource materials — not 'packages'. (Because of the high cost and the range of expertise needed to produce up-to-date resources, some centralization of production would seem to be unavoidable and even highly desirable.) The outside researchers/change-agents could be drawn from those engaged in educational research and teacher education (many are involved in both), and they could bring to this school-based research and development their wider experience and greater theoretical knowledge and their expertise in handling the problems of collecting and interpreting data. They could form an important

link in the communication network and, by working alongside and with teachers in schools and colleges or departments of education, they could themselves learn much about interpersonal interaction, about monitoring and about the development of relevant skills and attitudes. Of course there are enormous problems — of finance, of personnel, of time, of individual initiative, resistance and inertia, and it is clear that this idea does not in any way answer questions about what is to be taught, or who is to determine it. In the past, the key to curriculum content has been in the hands of university-controlled examining bodies, at least for the client population of pupils with whom this case study has been concerned. Teachers have had a measure of say, although many have shown a reluctance to take responsibility into their own hands — a reluctance which is surprising in view of the strong resistance expressed to any proposals smacking of centralized control. But others, too, are claiming the right to have some say on matters of the curriculum, and the issue is, at present, a particularly sensitive one in Britain.

This study has attempted to show just how deeply embedded in an historical and social situation the fundamental conceptions of pressure groups and of decision makers are. Translation of policy into action always involves decision making which is inescapably ideological, and it demands negotiation and compromise all along the line. While the ideological nature of any policy — governmental or of other power group, pressure group or individual — greatly simplified decision making, failure to try to identify the ideological assumptions upon which both tradition and recommendations for change rest can blinker evaluation of achievement, even cripple future progress. It is essential to accept that in all normal social (and therefore educational) decision making the 'degree of complication that we can tackle is governed by the degree of our experience'[43], and so of our knowledge and understanding. Since the limited extent of this knowledge and understanding places considerable limits upon the boldness of innovation in any one increment of change, it is hardly surprising that originality always works within the framework of tradition and that a totally new tradition is 'one of the most improbable of events'[44].

If, however, there is to be continuing progress, reform policy must be something more than *ad hoc* or random response to changing circumstance, existing dissatisfaction and prevailing ideology. It must be essentially serial, with each step tested, with the utmost rigour, against reality. What seems appropriate is a temporary gelling of beliefs to facilitate action. Once action has been taken, however, it is crucially important not to become preoccupied with attempts to justify past decisions and action, or to prove them 'right', for this is counterproductive. Imagination and bold pioneering work are the very foundations of change, but they must be followed by a readiness to look for and to learn from mistakes, for without this there can be little progress.

A view that acknowledges that to support and sustain the necessary action requires, on the one hand, firm convictions — faith, even — despite inadequate knowledge and understanding and, on the other, critical, monitoring, open minds, creates something of an intellectual dilemma in which no really comfortable stance is possible. If such a view is to provide a major dynamic of 'change and changing', then to allow for and to facilitate it requires an intellectual climate which corresponds to that of an 'open' society — a society where social institutions are recognized as man-made and therefore open to question, where 'conscious alteration is discussed in terms of their suitability for the achievement of human aims or purposes'[45], and where power and authority can be shifted to achieve this end.

Appendix

Data collection for the case study

This work was carried out some ten years after the events it describes. In the intervening years, successive 'house moves' and some unfortunate spring-cleaning reduced the records to a fragmentary fraction. It was therefore felt that it would be useful to try to collect and piece together what data remained and to supplement it with the recollections of those most closely involved. The need for such action was sadly underlined by the tragic death of Sir Ronald Nyholm, FRS, in 1973. The Nuffield Foundation approved the undertaking and provided access to relevant files at Nuffield Lodge. Six weeks were spent there in intensive note taking and inquiry, following location and sorting of those documents that were still available at the Centre for Science Education.

It was now possible to piece together a rough outline of the history of the O level Biology and Chemistry Projects. This was supplemented by a study of the Minutes of meetings of the General Committee of the Science Masters' Association and the Association of Women Science Teachers, and, after January 1963, of the Association for Science Education at their headquarters at Hatfield. The Minutes of meetings of the Chemistry Panel were also available. Records were also studied at Shell House, BP Ltd, and the Royal Institute of Chemistry, and other information