Research in Chemical Education: A Reassessment[1]

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1 Introduction

For a chemist turned educationist, though the two labels are fortunately by no means mutually exclusive, the task of preparing a convincing article on research in chemical education for, predominantly, an audience of professional chemists is by no means easy. In the first place little real research has been done, reflecting the feelings of many that we can perhaps manage without it, for we seem to have done so in the past; progress in chemistry and its applications continues. Secondly, educational research has apparently been seen by many to have been tried in other areas, for example in intelligence and school organization, and to have failed because of a lack of established and undisputable methodology. Finally, educational activities are often viewed by practitioners in the élite disciplines, of which chemistry is one, as being inevitably bound up with intuition, passion, and a succession of ephemeral bandwagons rather than with disciplined reason based upon a developed system of concepts. It is the intention of this review to point to and admit the poverty of many ideas and experiments in chemical education research, to provide a map of the field and outline some current British work, and to chart possible routes by which existing deficiencies and barriers to progress might be overcome.

But first, at least for the purposes of this article, the area of concern must be further clarified by the specific *exclusion* of two cognate aspects:

(i) the *administration* of chemical education, by which is to be understood the institutional structure within which chemical education takes place (schools, universities, technical colleges, industry *etc.*), and the elementary hard and software of buildings, services, and apparatus required for the various courses of instruction; and

(ii) *development* in chemical education by which one means the production of new courses and other less extensive innovations, together with their related aids and apparatus; developments may of course include a 'research' element but most, for example the Nuffield courses,[2] have hitherto depended almost solely upon the relatively informal pooling of experience through which some consensus of 'good' practice has emerged.

[1] This paper has arisen in a considerably extended and modified form from the author's contributions to the symposium on 'Research and Innovation in Chemical Education' during the joint Annual Meeting of the Chemical Society and the Royal Institute of Chemistry, University of Sussex, April 1971.

[2] Here there is no intended criticism of the Nuffield developments; few research findings exist as a base for constructing secondary school courses in chemistry; the distillation of experience has been the only viable means for obtaining revised courses.

Research into chemical education implies the detailed, dispassionate enquiry into any aspect of the teaching and learning of chemistry at any stage in education. Some of this enquiry, perhaps more than we realize, can be done by disciplined 'armchair' methods, but much can only be performed by some kind of deliberate, imaginative, yet controlled empirical investigation; implied is much more than mere fact-finding or opinion-gathering surveys.

Although developments in, and the administration of chemical education have been with us in the formal education system for over a century, with a significant increase in, respectively, the pace and complexity of these undertakings particularly over the past decade, research into the field is a relative newcomer, and the need for this research has been intensified by the contemporary myriad of changes and developments in all our institutions of science education. Development leading to research in this field, rather than the reverse, is in contrast to much of scientific enquiry and its subsequent application in technology. But, as in many other spheres, we must see R and D as complementary partners.

2 What Educational Research Can and Cannot Provide

The professional research chemist has little difficulty in understanding the potential contribution of his research to the theory and practice of chemistry. In the laboratory he discovers new ways of transforming materials, the physical and chemical properties of these materials, and an understanding of aspects of the processes of change. All this adds up to an ever-growing corpus of empirically gathered data which is systematized using the conceptual and theoretical tools which the discipline has evolved, chiefly over the past 200 years. The aim is an understanding leading to a control of natural phenomena using an 'if–then' causal attack. Theory and empirical findings march together in a spiral approach to the chemical heights, and a well-defined framework of concepts and methodologies exists both for classifying new discoveries and for publicly testing their validity.

Would that the educational researcher were in such a fortunate position! In the educational 'sciences' we are perhaps 150 years behind the natural sciences in terms of both concepts, criteria and methodology. Only in this century have educational problems been considered worthy of disciplined investigation, and even today, many of those so engaged continue to do battle against conservatism within the established disciplines and all the hoary problems of a 'poor relation'. While the methodological problems of serious research into chemical education, or indeed into many other aspects of education, are immense (see further below) a good deal of popular misunderstanding, let alone misguided research, arises from a lack of clarity about what research in this sphere can, and cannot, provide. And it should be noted that chemical education research is necessarily a branch of *educational*, as opposed to chemical research; it requires a practice of the relevant educational disciplines—particularly I would suggest philosophy and psychology—in an attack on the problems of chemistry in its educational setting, and it is characterized by strengths and weaknesses similar to those which characterize the broad field of educational research.

It must be understood that educational research cannot provide detailed solutions to many specific and important 'in the field' problems—for example whether comprehensive schools are more effective than grammar schools, or what should be the timetable in school X, or whether 'Nuffield' chemistry is more effective than 'traditional' chemistry, or whether it is better to buy an overhead rather than a film-loop projector, or whether undergraduates should have a research element in their degree courses. The diversity of valuations, objectives, and other variables within education is altogether too vast to permit valid *direct* transfer of many research or survey findings. Given an agreed framework of objectives, research may provide generalizable data about certain particular instructional problems, for example those of content sequencing and concept formation, but the area over which such transfer is applicable is probably far smaller than many might hope. What research can supply however, is a set of concepts, principles, and classifications which teachers and others can use in their own, often unique, situation in order to make wiser decisions; it can provide a basis for understanding the topology of the educational process and for designing educational programmes. We should expect to apply the emerging *theory and principles,* not the *particular results:* here there is some, if limited, similarity with the work of the research chemist.

We need therefore to ask the right kinds of questions in research, and too rigid a view of research as the 'systematic study in which major generalizations and the bases on which they are made are publicly reported in such a way as to permit independent verification',[3] pressed by many psychologists too anxious to adopt the physical science model, cannot but lead to disappointment, at least at this stage of our understanding. The generalization of all our findings to cases other than those which were the subject of study, is a worthy but premature objective, since in quests for this transfer we are driven to limit our experiments to the manipulation of a single variable at a time, and this often leads to a highly artificial situation and naive concluding statements (*e.g.* coloured children have a lower I.Q. than white children) which teachers not surprisingly find difficult to translate into practical action. A single pupil or teacher is after all far more complex than a single gram of even vitamin B_{12}; we cannot generalize about them as readily as we can about molecules. Educational research, in so far as it involves persons and their diverse valuations, should neither aspire to, nor be required to settle disputes in the neat and tidy manner which we now tend to expect in the physical sciences.

3 Criteria for Research

What criteria can we therefore begin to tease out for sound research in chemical education out of which we can derive a much needed structure of criticism? The *pertinence* of the research must be a fundamental consideration, and to

[3] R. W. Tyler, *Journal of Research in Science Teaching*, 1967, **5**, 54.

test any investigation in this respect we require a comprehensive yet cogent map of the terrain; an outline is suggested later in this review. Certainly research focused on the realities in which teachers are actually engaged stands the chance of influencing practice; research which does not help to *explain* some aspect of the educational process is worthless.

Pertinence alone is however an insufficient criterion; to this we must add an adequate *conceptualization* of the phenomenon under investigation and appropriate *methodological* techniques. Illustrations will here serve to clarify the first of these two further criteria.

Research on *teaching methods* is clearly of great importance but many of our concepts here have been unproductive. Typical classifications of methods as traditional/modern, didactic/discovery, or linear-syllabus/topic-project tend to be gross oversimplifications of any teacher's classroom technique. Direct comparison of methods so described can be futile, particularly since the underpinning objectives which particular methods are intended to achieve may be different. A more fruitful conceptualization may be to view teaching methods as the teacher's flexible way of manipulating and controlling the variables under his command[4]—for example the content sequence, aids in its presentation, form of pupil grouping, and rules of conduct—the flexibility being incorporated in order to emphasize variations in teachers' actions which are dependent upon the particular pupils being taught. Unhelpful, or even naive, conceptualizations and stereotypes in *learner research* are the axes of able/less able, culturally deprived/fortunate, middle class/working class, convergent/divergent, and scientist/non-scientist; these seem no more useful to educators than the notions of well nourished/malnourished are to the modern nutritionist. More useful descriptions might be concerned with the acquisition of particular skills and abilities and the extent to which these are fostered in particular children by particular manipulations of teaching method variables. What we require are more refined concepts to guide practical action, just as the nutritionist now has at his disposal the ideas of carbohydrate, fat, protein, vitamin, mineral *etc.* in diet prescription. Studies concerned with the *prediction of student success* as undergraduates usually compare A-level performance with degree class. A-level is usually 'shown' to be a poor predictor, but in this crude three-component conceptualization university experience is treated as a constant and the degree class as a wholly dependent variable. Manifestly, other more helpful and appropriate conceptions are possible, and potential variables such as the students' affiliations with his peers, the university teachers with whom he comes into contact, the mode of degree class assessment, the appropriateness of the students' place of residence for study, and the kind of study support which the secondary school provided may be highly significant, affecting both the research conclusions and any possible action to be taken (*e.g.* ignore A-level scores and depend upon interview for student selection). In this example however, even if investigations are more appropriately

[4] A. J. Bishop and L. B. Levy, *Education for Teaching*, Summer 1968, 61—65.

conceived, accurate prediction depends upon a static situation—one which will rarely pertain.

Methodological criteria in experimentally-based work tend to hinge around population and time-sampling techniques, the technical quality and range of the test instruments employed, and the statistical treatment of data. Each of these aspects involves at times complex administrative and technical considerations which it is inappropriate to describe in any detail here (but see bibliography). Investigations of a more philosophical kind are chiefly concerned with mapping and analysing values and concepts; here there are well-charted methodological guidelines and forms in which arguments can be expressed. However it should be stressed that no research methodology, however elaborate and rigorous, can compensate for paucity on the pertinence and conceptual fronts. Many sophisticated research models continue to manipulate irrelevant variables and inconsequential events.

4 A Perspective on Chemical Education

Before we can evaluate existing findings and plan adequately for future research, it is essential for us to map what appears to be the anatomy of chemical education. This can be achieved by a model in which the dynamic inter-relations between key concepts and ideas are charted; such a model forms an outline theory which is required in order to understand and plan the process of chemical education. The lack of a map can lead only to isolated studies, short-term projects and opportunistic investigations which make little contribution towards solving the basic problems and crises before us. The chart shown here (Figure) is by no means prescriptive, but it is offered as an analytic aid for focusing our plans; its further testing and elaboration will be achieved through future researches which can potentially be carried out under almost all the headings shown.

Central in this map are our aims and objectives in chemical education. The difficult task of identifying and clarifying these must be the logical starting point at any level, and in this respect the tertiary sector has much to learn from recent work in the schools. The description of the new undergraduate chemistry scheme at the University of Sussex[5] for example devotes little space to a thorough-going consideration of objectives. A defined and argued philosophy which is the basis of teaching aims is a necessity, not a luxury, for every teacher and course designer. Whether we like it or not, all our teaching is based upon 'theory'; responsible practice requires us to make this explicit, for ease of communication and for the provision of criteria for both course content selection and assessment schemes.

5 Current Research and Pertinent Growth Points

Much of the published research in science teaching has its origin in the United States and papers of the post-sputnik era (1957 being a watershed in U.S.

[5] C. Eaborn, *Chemistry in Britain*, 1970, **6**, 330.

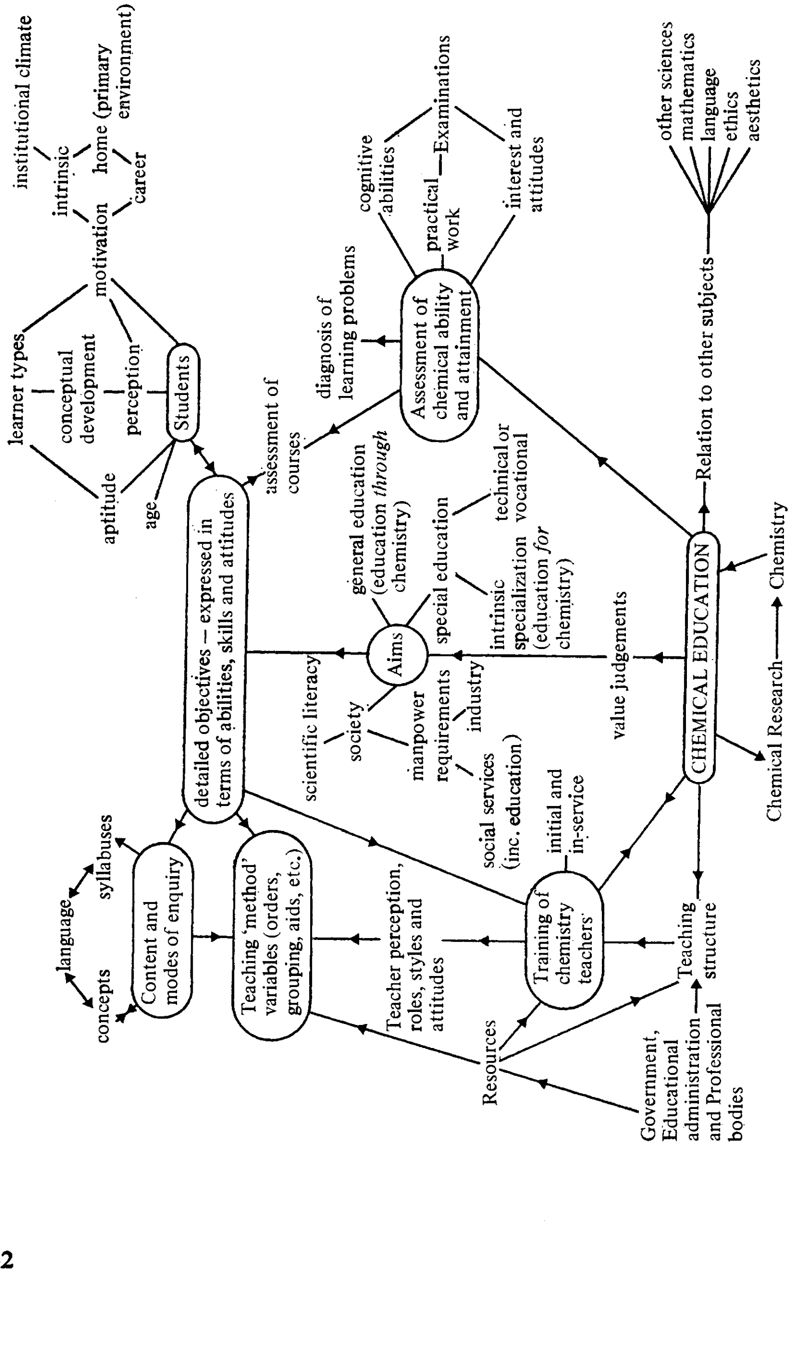


Figure ***The anatomy of chemical education.***

science education) have been recently reviewed.[6] One respected critic of such work found[3] that not more than 10% of recent studies met reasonable technical criteria. The major areas of concern of U.S. investigations, which appeared mainly as postgraduate theses, divided approximately as:

fact finding surveys	25%
collections of opinions	20%
comparative studies of courses and teaching methods	30+%

Few of the reported researches were concerned with the objectives of science, and fewer still with learning theories compatible with different science teaching objectives. None of the investigations conducted empirical tests of different learning sequences in any of the natural sciences—an alarming fact, bearing in mind the highly structured nature of science itself. A single, yet meaningless, experiment concerned with the highly important 'external relations' of chemistry (see later) reported that when chemistry and mathematics were taught in the same course, students scored as well on tests in each subject as when the courses were taught separately. The majority of studies employed gross variables of students and teachers—such as I.Q., personality test scores, years of experience, and degree class—which as we have implied are of dubious value. The critic concludes[3] 'that the potential value of research for improving science teaching is not being realized'.

In Britain, where resources of finance and manpower for science education research have been comparatively meagre, there are a few pockets of activity which could hold out some promise if given adequate support. A cautious beginning can have its advantages since it gives those involved the opportunity to reflect before rushing into inadequately conceptualized empirical work—and an experiment in educational research cannot be halted or modified anything like so easily as an experiment in chemistry.

Having drawn attention to the centrality of aims in the chemical education enterprise, which ultimately reduce to issues of value in relation to the various 'pressures' on chemical education from society, our idea of the person[7] derived from ethics and psychology, and the discipline of chemistry itself (see chart), a brief account will now be given of significant recent British thinking and empirical study. This is described under some of the major headings of the anatomical map.

[6] G. A. Ramsey and R. W. Howe, *Science Teacher*, 1969, **36**, 62.

[7] The possible aspect of student pressure on our aims has here been deliberately omitted. There are substantial philosophical arguments which suggest that it is educational nonsense for teachers to allow those uninitiated into a discipline to influence the *aims*, as opposed to method variables, in its teaching. Here, briefly, a telling quotation on the logical nature of education will have to suffice: Education is . . . 'the transaction between generations in which newcomers to the scene are initiated into the world in which they are to inhabit. This is a world of understandings, imaginings, meanings, moral and religious beliefs, relationships, practices—states of mind in which the human condition is to be discerned as recognitions of and responses to the ordeal of consciousness. These states of mind can be entered into only by being themselves understood, and they can be understood only by learning to do so. To be initiated into this world is learning to become human; and to move within it freely is being human, which is an historic, not a natural condition'. (M. Oakeshott, *Proceedings of the Philosophy of Education Society of Great Britain*, 1971, **5**, 73.)

A. The Assessment of Chemical Ability—This has recently been the most popular area for research in the U.K. and we are moving, at least in the school sector, to a more adequate and comprehensive characterization of chemical ability. There has been widespread recognition of the inadequacies of traditional tests and examinations, particularly in the high weightings given, often unconsciously, by examiners at all levels to the ability to remember. Curriculum developers have recognized that new courses must carry new complementary examinations if their underlying objectives are to be achieved. Work led, initially under the Nuffield development umbrella, by Mathews has made an outstanding contribution to chemical education and has set a fine example in techniques of assessment to many other curriculum subjects. Much of this unique work has been described elsewhere,[8] and studies continue under Mathews at the University of Lancaster.

Hitchman, Yeoman, and Brown of Nottingham University recently completed an interesting and thorough investigation[9] into the oral examining of chemistry at C.S.E. level in which five abilities were tested in the context of practical work. It proved possible to construct valid and reliable tests, and while the authors appreciate the complex logistics involved in widespread examining of this kind, they suggest that oral tests might form an effective moderating instrument for internal assessments at any level.

The objective assessment of abilities fostered through practical work in science is also being carried out under the auspices of the International Association for the Evaluation of Educational Achievement (I.E.A.).[10] The English national science committee for this project pleaded for the measurement of practical outcomes in addition to the cognitive and affective measures, and we became responsible with our Scottish friends for the development of test items in each major science to measure three abilities which were condensed from a larger and more detailed 'Taxonomy of Practical Abilities':[11]

(i) The ability to use simple apparatus and implement simple procedures.
(ii) The ability to observe changes/differences in structures or systems under investigation and to record such changes/differences in ways which yield the maximum relevant information.
(iii) The ability to select appropriate apparatus and/or procedures for a novel experimental problem.

Although results of this vast survey of science achievement in some 20 different countries will not be published until 1973, it is disappointing that the optional prctical tests have been taken in very few countries; this is a reflection of the somewhat unique British approach to science teaching in which individual

[8] See for example: J. C. Mathews, *Educ. in Chem.*, 1967, **4**, 2; 1969, **6**, 205; also IUPAC Report, *Pure Appl. Chem.*, 1965, **11**, 587, and 'Evaluation in Chemistry', IUPAC/UNESCO, 1969.
[9] Schools Council, Examinations Bulletin No. 21, Evans/Methuen, London, 1971.
[10] I.E.A. Box 6701, S—113 85 Stockholm, Sweden (co-ordinating director: T. N. Postlethwaite); document IEA/SCI/27, April 1971, by J. F. Eggleston describes the origin of the national option practical tests in science.
[11] J. F. Eggleston and R. C. Whitfield, unpublished work; for a version with chemical examples see R. C. Whitfield, 'The role of practical work in school chemistry', UNESCO, Guidebook on the Teaching of Chemistry, to be published.

practical work and sensory experience is, be it noted *in faith*, valued highly as a means for attaining our objectives.

B. Assessment of Courses.—The assessment of chemical abilities is closely related to the appraisal of courses designed to promote these abilities—this latter field being that of 'curriculum evaluation'.[12] The I.E.A. studies referred to above are essentially comparisons of gross national school science curricula at four different age levels, but do not attempt a rigorous division of national populations into sub-groups—*e.g.* in England, 'Nuffield' and 'others'. The utilizable feedback from these studies as far as specific curriculum improvement is concerned may be minimal. What we require perhaps more urgently are more sensitive national studies on particular courses and sections of courses. But such studies are far from easy to design; the common question about the relative effectiveness of different courses has no simple answer. In course comparison we are not simply placing on trial two brands of something like washing powder, designed to do the same job. Revised curricula at any level often represent far more than an up-dating of content; they also frequently embody a marked shift in both the objectives being sought and the underpinning learning-theory upon which course materials are constructed. Comparing course A with course B at the student performance level, as opposed to the objectives level, can therefore often be a meaningless exercise since the underlying aims of the two courses may be different.

Empirically it is usually far more helpful to look at individual courses or course units using both formative (on-going) and summative (terminal) evaluation[13] techniques. The Nuffield chemistry courses have been compiled using informal formative feedback from trial school teachers, but uncertainties about practicable methodology and restricted resources have prevented any more elaborate assessments at the compilation and revision stages. Nevertheless, since the intended pupil outcomes from these courses have been framed with a commendable precision, which should be the envy of many other curriculum developers, interesting objective feedback of a summative kind from the examinations referred to earlier should be possible. However, important long-term aims which cannot be assessed in this way—for example that 'pupils should gain an understanding that lasts throughout their lives of what it means to approach a problem scientifically'[14]—should not be forgotten. Long-term researches on the persistence of independent learning and the external transfer of abilities acquired in the formal educational settings are urgently required.

It is perhaps relevant to mention here that tests for use in curriculum evaluation differ from graded examinations in one important respect. Examiners must needs be concerned about the operational discrimination of questions included in

[12] For a readable introduction to this complex field see D. A. Pidgeon and S. Wiseman, 'Curriculum Evaluation,' 1970, National Foundation for Educational Research.
[13] M. Scriven, 'The Methodology of Evaluation', in AERA monographs on curriculum evaluation, No. 1, Rand McNally, Chicago, 1967.
[14] H. F. Halliwell, *RIC Reviews*, 1968, **1**, 211.

their papers; that is they plan, or ought to plan where grades are publicly required, for the identification of individual differences in the population under test. Questions which are likely either to be very easy or very difficult for the population as a whole are consequently often rejected. In the appraisal of a curriculum on the other hand we are more concerned about the performance in each target ability of the whole group being taught, rather than the grades of individuals. Hence, ideally, tests for curriculum evaluation ought to be constructed upon modified examining principles; fortunately the diminished need for discrimination eases some of the test-construction problems. Nevertheless we are a long way from having at our disposal valid and reliable tests for the spectrum of chemical education objectives which our courses seek to attain, especially in the areas of practical work and attitudes.

The interpretation of group test scores remains a professional value judgement. For some of our objectives, such as the acquisition of certain practical skills or perhaps knowledge of the structure of the Periodic Table, we aim for 'mastery' learning; in others, such as the ability to apply previous understanding of reaction rates and mechanisms to new problems, we may, depending upon the level of study, be satisfied with a good deal less before drastically revising our courses. The sole ultimate purpose of gathering data of a statistical nature on the effects of teaching is to provide information for wiser professional valuations and decisions.

As has been indicated, incursions into curriculum evaluation[15] in providing information about the effectiveness of course materials shed light upon the feasibility of our objectives and diagnose learning problems and learning strengths of student groups. Johnstone[16] is presently engaged at the University of Glasgow on important follow-up work and problem diagnosis arising from the introduction of the Alternative Chemistry Syllabus in Scottish schools in the early 1960's. Topics rated as 'difficult' by about 1000 'successful school chemists' now studying at the Universities of Glasgow and Strathclyde fall into two basic groups: (*a*) work based on a facility in the use and interpretation of formulae and equations, and (*b*) formal organic chemistry. Although this finding may be in accord with the everyday experience of many chemistry teachers, proper diagnosis must precede causative speculation and rectification. One of our tasks in research is to gather hard data before hastily prescribing for intuitive diagnoses.

Apart from the evaluation of programmes of national significance, it is possible to train the practising classroom teacher to be more sensitive in the day-to-day appraisal of his work. Evaluation is in any case an unavoidable element of teaching, and provided teachers are able to state their intentions at the right

[15] See for example R. C. Whitfield, 'Assessing Outcomes of a New Approach to Organic Chemistry', in 'Studies in Assessment', ed. J. F. Kerr and J. F. Eggleston, English Universities Press, London, 1969. Some problems which emerged during this study are discussed by J. F. Kerr and R. C. Whitfield in *Teachers College Record*, Columbia University, New York, 1970, 72, (2), 268.

[16] A. H. Johnstone, *Scottish Education Department Science Newsletter*, **11**, 27.

level of generality, some relatively simple assessment techniques are available to enable them to gather more objective data on their classroom performance as mirrored by student gains.

C. Content Analysis.—Philosophical analysis of the nature of chemistry and chemical enquiry is an essential prerequisite for the construction of sound courses. This relatively neglected area would map the key concepts of our discipline, the ways in which they are and can be used, and the incorporated criteria for chemical truth; the criteria we apply to the concepts we use in discussions of bonding for example are of a different kind to those used in establishing the rate of a particular chemical reaction. Content/conceptual analysis is likely to give us insight into teaching orders which might logically be most likely to succeed; any adequate 'psychological' theory of learning must build upon philosophical analysis of the logic of material to be communicated; such analyses could save much fruitless experimental investigation.

Some possible hierarchical structures among concepts—which might be termed 'concept runs'—are now given (see Table).

Table *Some possible structures among concepts*

	Prerequisite experience	*Primary concept*	*Secondary concept*	*Tertiary concept*
1.	Vision	Red, blue, *etc.*	Colour	Salmon-pink *etc.*
2.	Handling things	Weight, volume	Density	Expansion
3.	Warmth, cold	Temperature	Heat	Specific heat
4.	Dissolving	Solvent, solute	Particles	Solution
5.	Uniformity within stuffs	Pure substance, mixture	Chemical change	Formulae, equations
6.	Visible changes in things	Conservation of weight	Combining weights, proportions	Formulae, equations
7.	Walls, bricks, sand, *etc.*	Composites, simples, relative simples	Atoms, molecules	Elements, compounds
8.	Brownian motion, *etc.*	Atom, molecule	Element, gram atom, molecule	Compound, mixture, chemical change
9.	Electrolysis	Ion	Gram ion	Structure, models
10.	See-saw, mixing different coloured balls, *etc.*	Steady state	Dynamic Equilibrium	Effect of constraints on steady state systems

It should however be noted that little serious philosophical analysis has been done to chart these concepts accurately either vertically, horizontally, or diagonally; the ground in more complex areas such as quantum mechanics and thermodynamics, which degree students often find difficult, is even more uncharted, and our present orders of presentation of chemical experience are little more than guesswork. In any future work we will need to distinguish between a pupil's implicit (assumed) and explicit (articulated and verbalized) possession of a concept. The Nuffield O-Level Sample Scheme for example assumes an implicit understanding of the ideas 'pure chemical substance', 'compound', 'mixture', and 'chemical change' by the time pupils reach topic A5 on 'chemical elements'; but an explicit understanding of all these notions may be contingent upon an understanding of the idea of an *atom* which is not encountered until topic 11 (see runs 7 and 8 above). Certainly little sense can be attached to the idea of a 'chemical element' beyond that of a 'pure chemical substance' unless there is some concept of different kinds of atoms.

D. Method Variables.—Some of the problems of research into teaching methods have already been mentioned, and it was implied that since activity in any classroom is highly complex, we might view 'methods' as a series of variables, perhaps not yet all definable, which are potentially under the teachers' control. Here the analogy is perhaps more one of teaching as a craft rather than as an 'art' or a 'science'. When an investigator enters a classroom he requires a conceptualization of what to look for other than the purely 'physical' aspects of the environment—teacher, children, apparatus, furniture *etc.* What gives meaning to the complex exchanges involved are the structures, relationships, and processes perceived by the skilled observer. Here a formal 'model' is essential in order to provide some means for viewing the diverse phenomena in orderly and meaningful patterns and to give a basis for 'method' recommendations.

The Schools Council project on the evaluation of science teaching methods[17] has since 1970 been engaged upon an important investigation to determine if pupils who are taught by contrasting teaching methods exhibit significant differences in both their attainment and attitudes towards science. Early work centres around the complex task of identifying and classifying the predominant 'teaching styles' of a representative sample of science teachers. In this connection an observation schedule has been developed as the major instrument for recording and analysing teacher behaviour. Carefully trained observers are now using this schedule to record accurately a selection of the intellectual transactions which take place between pupils and teachers in science lessons, the product being an estimate of the probability that a teacher may make a particular kind of statement, give a certain type of direction, ask a specific sort of question, and so on; estimation of the probability that pupils will engage in certain kinds of activity (*e.g.* seeking guidance when solving problems) is also incorporated in the schedule. It is therefore hoped that each teacher in the sample can be placed at some point upon an enquiry/didactic continuum by the time their pupils' changing in thinking and attitudes over one year are measured.

[17] Co-ordinating director J. F. Eggleston, School of Education, 21 University Road, Leicester, LE1 7RF.

We must however remember that many of our apparent problems in relation to teaching methods may be removed by a closer scrutiny of our objectives in which are incorporated important notions of *desirability*. If for example we do not expect our undergraduate chemistry students to be walking encyclopaedias of 'in' facts, albeit in abridged versions, then we will not trouble to lay on lecture series which consist of solo recitals of 'in' facts. If we believe that a sound chemical education consists of a broad coverage of key concepts in the context of a wide variety of elements and compounds, then we will view project or topic-centred work with some suspicion. If we believe that deep personal contact with practising chemists is very important for motivating students and endowing them with favourable attitudes towards the practice of chemistry, we may be disinclined to use programmed instruction for large sections of our courses.

On the other hand, we must be cautious about action based upon unsubstantiated beliefs about desirability. We may assert for example that there can be no substitute for individual practical work by students *i.e.* that it is desirable for all students of chemistry to be individually engaged at the bench. Curiously however it has yet to be shown that individual-pupil, or even group, practical work, as opposed to *e.g.* class assisted demonstrations, confers distinctive skills, abilities, and attitudes on students. This is a question of the greatest practical importance, for we invest massive resources of time and capital at all levels on this untested article of faith; there are after all many ways of providing a practical context. Or do we incorporate individual practical work so extensively in our courses for motivational reasons, while failing to appreciate that the motivations of 12 year-olds and undergraduates are likely to be significantly different? We may however be certain that much time and effort is wasted in teaching laboratories at all levels because we have failed to analyse practical work objectives[11] with sufficient precision, both as a basis for experiment selection and for putting our hypotheses to the test; and so often we justify practices for all students in terms of the professional requirements of the small minority who reach or who want to reach the research level.

E. Student's Perception.—The anatomical map presented earlier placed the concept of perception central in certain considerations about students as learners, particularly in relation to their conceptual development and motivation. This factor is being increasingly drawn to our attention by social psychologists. How we react to any situation is largely governed by the way in which we 'see' the situation and the associations we can draw upon from our past experience. Classical experiments in psychology using visual stimuli show that several people looking at the same object 'see' different things. The same is true for 11-year-old secondary school pupils, freshman chemists, or new employees for example, who will perceive different objectives for themselves, tutor and employer intentions, and so on, and these perceptions, whether 'correct' or not, form the basis for much of their later action. Present evidence indicates, rather agonizingly, that our perceptions of persons, objects, and events form during our early contact with them and remain relatively stable despite later attempts to modify the inadequacies of the early perception. Practical work in chemistry, yet again, is an example in which student perceptions are likely to be vitally important for both motivation and effective learning; work has recently begun in Cambridge to investigate this area with lower-secondary-school children. One canon for practice which seems clear despite our ignorance of this field is that teachers are more likely to convey 'desired perceptions' particularly in the area of the *purposes* of learning tasks if they are able to dispassionately communicate and justify to students the objectives of the tasks in educational and professional terms.

F. Chemistry and other Subjects: 'External' Relations.—Halliwell has remarked[18] that chemical education still has many of the characteristics of a cottage industry —a somewhat parochial attitude. While this is probably the case, there is no evidence to prove that chemists are any more inward-looking than specialists in other disciplines. Neverthless there are vital 'external' questions which all subject specialists must consider for the sake of both the health of the community and, perhaps paradoxically, the disciplines themselves.

Considerations of chemistry's logical and practical relationships with other subjects are particularly important for planning the whole curriculum of our schools[19] where our main concern is education *through* chemistry. Schemes for the integration of the major sciences for teaching purposes at any level require a closer consideration of the relations between concepts in the three subjects than we have hitherto achieved for effective planning. Although in epistemological and psychological terms, integration of the empirical sciences is logically permissible (there are similar concepts, methodologies, truth criteria and abilities developed), we have a long way to go before we have effectively 'bridged the gaps' or 'removed the barriers' between physics, chemistry, and modern biology. A move towards more 'integrated science' in schools seems imminent, and may enable us for the first time to provide all children with a balanced programme in science.

Relations of chemistry with non-scientific subjects are however equally important and some current questions of interest are:

(i) Which concepts and methods within *mathematics* constitute essential tools for modern chemistry at C.S.E., O, A, and University level? How can we plan jointly with mathematicians and other scientists both for the development of mathematics *qua* mathematics and mathematics as a tool?

(ii) To what extent is the development of scientific concepts and favourable attitudes towards learning contingent upon a sensitive use of *language?* The need for detailed investigations into the structure and function of language in chemistry teaching, particularly during the pupil's earliest

[18] See ref. 14, p. 205.

[19] For a seminal work in relation to questions about the whole curriculum for general education see R. C. Whitfield (ed.), 'Disciplines of the Curriculum', 1971, McGraw Hill, Maidenhead, 1971. Parts of Chapter 17, and an essay by E. H. Coulson on the contribution of chemistry to the curriculum are particularly pertinent.

chemistry lessons, has been highlighted by Barnes' revealing preliminary explorations[20] into language exchange in secondary schools.

(iii) How might we make more effective use of chemical knowledge and understanding in *ethical and moral* issues? Can and should chemical educators avoid being moral educators? How may we help to promote moral awareness and sensitivity in our pupils and students through chemistry?

(iv) What contribution does chemistry make to *aesthetic* experience? Has chemistry any relevance in the teaching of art, craft and creative design?

G. The Training of Chemistry Teachers.—Rapid changes in curricula, our increasing understanding of the processes of education, when compounded with our British tradition of giving teachers a large measure of professional responsibility for their teaching programmes, now place teacher training at a focal point for the fulfilment of many of our aspirations. While the present structures within which the initial and in-service training of science teachers takes place have many shortcomings (felt not least by those of us endeavouring to work within them), there has been no shortage of new ideas and practices in training in the recent past in which chemists have played a full part. The Association of University Chemical Education Tutors (AUCET), the corporate body of chemistry method tutors in university departments and schools of education, has for several years acted as an informal forum for the exchange of ideas and the development of practice. More recently, after initial clarification of training objectives[21] and the pooling of sample resource material, the association acted as a springboard for the Science Teacher Education Project (STEP) which has been sponsored since its inception in early 1970 by the Nuffield Foundation under the general direction of two chemistry method tutors.[22] This project has accumulated some exciting materials in a dozen topic areas for its main trials with student teachers in the academic year 1971—72. These trial units demonstrate quite clearly that we are a long way past the naive and narrow conception of teacher training as instructing people *how* to teach. While it remains our duty to do all we can to provide new entrants to the teaching profession with a 'survival kit', our aim is more fundamentally to provide young teachers with the elements of a conceptual framework upon which they can modify their initial and build their future professional actions. STEP has therefore sought to incorporate aspects of educational philosophy, psychology and sociology, together with systems management, alongside material of a specifically scientific

[20] D. Barnes, 'Language, the Learner and the School', Penguin, London, 1969.

[21] See for example, R. C. Whitfield, *Chem. in Britain*, 1969, **5**, 362. The training of chemistry teachers has its own sub-set of objectives, methods, content, student and assessment considerations, *etc.* which are not shown in the Figure.

[22] Drs. C. R. Sutton (Leicester) and J. T. Haysom (Reading); further information about the project, whose materials will be published in 1973 by McGraw Hill, can be obtained from S.T.E.P. School of Education, University of Reading, 24, London Road, Reading, RG1 5AQ; see also C. R. Sutton, *Education for Teaching*, 1970, Summer, 13, and C. R. Sutton and J. T. Haysom, *School Science Review*, 1970, **52** (178), 7.

nature. Some of the project's units are likely to be put to good use in courses of in-service training.

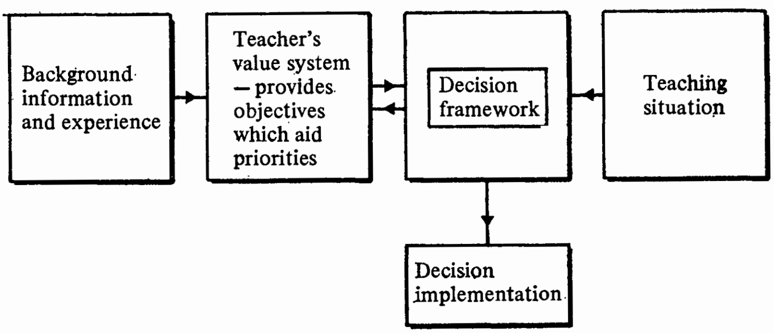
In Cambridge we are endeavouring to make a more adequate characterization of that elusive creature the 'good' or 'effective' teacher by placing emphasis upon the teacher's unavoidable role as decision-maker. We suggest[23] that the effective teacher is one who possesses:

(*a*) an awareness of the variables under his control (these variables acting as a source for generating options from which teaching decisions are selected);

(*b*) an awareness of the likely effects of manipulating these variables in different environments; and

(*c*) an ability to manipulate variables in order to achieve his objectives, this last attribute being the realization of the potential mapped out by (*a*) and (*b*).

In our work we make a distinction between 'planned' and 'on-the-spot' decisions. The former have traditionally received significant attention in courses of teacher preparation by way of lesson planning exercises and so on. The more complex but crucial area of decisions which have to be made 'on-the-spot'—whether in classroom, common room, corridor, or playground—has received relatively little attention. Our investigations are centred in this area through analyses of actual teaching situations, some of which are chemical in origin, though we must remember that the chemistry teacher has many decisions to make that are superficially not concerned with chemistry. We are interested not solely in *what* effective teachers do, but more fundamentally *how* they decide what to do in any given situation. We suggest that the teacher's decision framework is central in any consideration of 'good' or 'effective' teaching:



This decision framework is undoubtedly complex, but we believe that among its key components are (*i*) a system for classifying teaching situations, and (*ii*)

[23] A. J. Bishop and R. C. Whitfield, in introduction to 'Situations in Teaching', McGraw Hill, Maidenhead, 1972.

a system for appraising decisions taken. Analysis of over 200 situations in science and mathematics teaching together with some general school situations has led us to suggest[23] the following potential components of a classification system:

A. Learning.	A1	Cognition
	A2	Attitude
B. Relationships.	B1	Pupil–pupil
	B2	Pupil–teacher
	B3	Teacher–adult
	B4	Pupil–other adult
C. Environment.	C1	Physical—apparatus, aids etc.
	C2	Organization and administration.

Every teaching decision involves a consideration of one or more of these elements, and in a practically-based subject like chemistry class C decisions seem fairly frequent. Take for example the following laboratory situation: a class of 15 year-old pupils is engaged on a volumetric analysis practical and the supply of standardized 0.1M-HCl becomes exhausted because some pupils have used too much of this solution for rinsing purposes. In this context a teacher could take a number of courses of action. The potential chief elements involved (with classification categories shown) seem to be:

(i) a lack of understanding of volumetric analysis technique (A1)
(ii) a careless and casual approach to laboratory work (A2)
(iii) a defiance of the teacher's specific instructions (B2)
(iv) a problem of a deficiency of a laboratory material (C1), and
(v) a consideration of the time required to make up some more solution and its effects on the organization of the lesson (C2).

The effective teacher will *rapidly* assess these considerations and make an on-the-spot decision; the 'experienced' teacher, *i.e.* one with a well-developed decision framework, may have a 'standard way' of dealing with this kind of situation and may not generate more than one line of action from which to choose. The 'inexperienced' teacher may only generate one frequently ineffective option—such as leaving the class while he himself goes to the preparation room to prepare some more solution! Possible more effective lines of action might be:

(*a*) gather the class round the front bench, re-explain technique and give controlled questioning to test understanding; repeat experiment next lesson.
(*b*) Admonish the class and do the experiment as a class-assisted teacher demonstration.
(*c*) Send a pupil to ask the laboratory assistant if he can manage to prepare some more solution while leaving 30 minutes to the end of the lesson; demonstrate technique again in time gap and then carry on as planned if more solution is now available . . . and so on.

The purpose of this simple illustration is to show not only the complexity of teaching—for any single day brings to the class teacher a myriad of such 'critical incidents' (how much easier it is to give a lecture!)—but also to indicate the inadequacy of the concept of the single '*right*' decision in the context of teaching. Hence our belief in the importance of developing during training the teacher's own professional decision framework. We postulate that practice in on-the-spot decision-making by student teachers using written and videotaped situations accelerates the development of this framework which we see as central for effective teaching. We are concerned not merely to enable student-teachers to respond in particular ways to particular situations but more basically to increase both their likelihood and their capability of responding in effective ways in their future careers. The analogy with the flight simulator for training airline pilots is appropriate in at least some of its aspects, though the 'right' decision concept tends to be one employed during their kind of training. In addition we believe that such simulated practice will act as a bridge between 'advice about' teaching and the 'deep end' of teaching practice.

We have however yet to test our postulates in any rigorous way, and before this can be done we need to investigate in much more detail the means by which teachers whose professional competence is widely respected actually make on-the-spot decisions. Methods of teacher training, like any other methods, can only be put to the test when we have an adequate theoretical basis for them. We therefore plan to gather introspective data on the on-the-spot decision-making process from a sample of effective teachers to refine our theories. We are encouraged by recent comment[24] which suggests that introspection as opposed to the observation of overt behaviour has received in recent years all too little attention in educational research. Introspective data have for example given insight into the processes of mathematical problem solving and chess playing. Many studies of teachers have investigated *personality* types and a knowledge of these does little directly to improve classroom performance. All too few studies seem to have troubled to examine in detail the *work* of effective teachers, so that when one dies it still remains too much akin to a light going out.

The perceptions of learners have been mentioned as a pertinent area for research; the perceptions of teachers are no less important. Many of those concerned with the diffusion and uptake of new curriculum ideas are familiar with and often alarmed by the wide variation in what is taking place under apparently new banners. We therefore require studies of teachers' perceptions of the objectives and methods of various courses and the roles which they are taking in relation to them, for there can sometimes be a significant difference between a teacher's understanding and his overt teaching performance.

6 Gaps in our Understanding and Barriers to Effective Research

Having indicated some areas of current thinking and thereby the potential growth points for the immediate future, it will be all too apparent that there are many gaps in our understanding, and for some time yet we must in many areas proceed almost entirely by hunch. There is much to report about innovation but

[24] See for example L. S. Shulman, *Review of Educational Research*, 1970, **40** (3), 371.

relatively little about research. A recent review[25] of research of a psychological nature into science education notes the dearth of work concerned with post-primary pupils—the stage at which serious science teaching begins! Apart from a trickle of M.Ed. theses, mostly done on a part-time basis by practising teachers (a U.K. doctorate in science education is a rarity), the output of research aimed at enlightening some of our practices is meagre. Yet we continue our vast investments of manpower and capital at the practical level. There are of course reasons for this state of affairs, not all of which are commendable, and some of the major barriers impeding progress will now be outlined.

Firstly there are the general difficulties associated with research into any human endeavour. There seem to be so many problems that it is difficult to focus upon priorities and to get them adequately conceptualized; the numerous variables make empirical investigations far from easy and these are in addition beset by many practical difficulties such as co-operation between many persons in the field and pupil absences. The chemistry research laboratory becomes a relatively certain environment in which to work! These general difficulties are often exacerbated by the attitude of many social scientists anxious to make researches in this field 'respectable'. Many would for example argue that attacks on 'whole' or 'macro' problems in natural settings—exemplified in this paper by, for example, the general area of curriculum evaluation and the introspective investigation of effective teachers—are by their nature 'unscientific'. But have 'micro' investigations of individually inconsequential events in over-controlled environments been all that productive for those in the front line of the educational process? Have not many of those engaged in educational research been labouring with a kind of reductionism in which it is very difficult, if not impossible, to put the pieces together again? How can we carry out controlled reality testing? Herein lies our dilemma, and heeding Shulman's wisdom,[26] which has no cant for national inadequacies, could carry us far:

> 'On the one hand, in order to maximize the internal validity of our measurements, we must develop carefully controlled settings within which we can govern our research. This has long been recognized as a necessity, but it is likely that the experimental tradition in America overemphasized the importance of reliability and control at the expense of the characteristics affecting that other factor of equal importance in the development of experimental settings, external validity. . . . [We] must . . . attempt to maximize the similarity between the conditions in which we study behaviour and those other conditions, whatever they may be, to which we may ultimately wish to make inferences.'

Secondly, there is a self-perpetuating dearth of suitably trained personnel for research into chemical education, for we require competent chemists with an understanding of either philosophy or one or more of the social sciences. Would it be heresy here to suggest that we might divert some potential chemistry

[25] Schools Council, Curriculum Bulletin No. 3, Evans/Methuen, London, 1970.
[26] See ref. 24, p. 377.

Ph.Ds. into the field of chemical education research after suitable preparative training? If we are concerned about the future careers of our Ph.D. students let alone the educational problems themselves, perhaps we should. In addition, more effective means must be found which will enable practising schoolteachers to engage in research of an educational kind. Secondments and day release from school are by no means the norm, and teachers can often assist in defining problems for investigation. Associated with this problem of personnel is, of course, finance for research student grants, secondments, research officer salaries, supporting soft- and hard-ware, and so on. Most of the British work reviewed in this paper has and is being carried out under conditions of manpower and finance which no research chemist would tolerate. Our requirements are of course of a different nature, and even scale, but they are nevertheless real, and expertise is already going untapped; some two thirds of a sample of AUCET members for example stated in a questionnaire that they would like to be more involved in research if circumstances permitted. On some projects which meet the criteria described earlier, progress is either so slow or in some cases non-existent because of inadequate institutional and external support that unconstructive frustration results. One of the problems here is that chemical education is a 'middle-ground' area, and the buck of responsibility can be passed between several potential supportive institutions. Might not the chemical education division of the new Chemical Society help here?

A third significant barrier to effective chemical education research is the highly diversified literature. The educational disciplines are a long way behind the sciences in the organization of journals, and there is almost no abstracting or retrieval service. Relevant papers tend to be published haphazardly, and even the conscientious student can easily miss a significant contribution—indeed the author may have missed several for this article! Allied to this problem of dissemination is of course the uptake of research findings at the practical level—our papers, one is sure, often only preach to the converted.

Finally there is still a certain complacency, subconsciously expressed in the feeling that research is a low priority in our educational concerns and that new horses for new courses, or at least new courses for old horses, is all that we need. This attitude is, however, irresponsible, yet it is to be found at times even in University Departments and Schools of Education where the limited view of education as 'handing on advice from my years of experience' often suffices. *It is surely the professional duty of every chemist involved in education to seek to apply such similar high standards to educational decisions as he applies so meticulously to chemical decisions;* in the University world in particular, the proceedings of many faculties are characterized by an ambivalent approach to 'professional' and 'educational' concerns, which today no longer goes unnoticed. There is an urgent need for those involved in shaping science and education policy to devote more resources to research if we are to gather intelligence for more informed action. Would that this plea came from someone eminent *outside* the field! But let support be unblinkered; any increasing commitment to chemical education research carries a concomitant commitment for us all to act upon its findings.

I am grateful to my colleague Dr. A. J. Bishop for many discussions which have helped to clarify some of the ideas here presented.

Further Reading

The following are useful introductions to the methodology of educational research:

N. L. Gage (ed.), 'Handbook of Research on Teaching,' Rand McNally, Chicago, 1963.

F. N. Kerlinger, 'Foundations of Behavioural Research,' Holt, Rinehart, and Winston, New York, 1964.

D. G. Lewis, 'Experimental Design in Education,' University of London Press, 1968.

K. Lovell and K. S. Lawson, 'Understanding Research in Education,' University of London Press, 1970.

J. D. Nisbet and N. J. Entwistle, 'Educational Research Methods,' University of London Press, 1970.