CURRICULUM DEVELOPMENT IN POLYMER TECHNOLOGY: TOWARDS A CLARIFICATION OF NEEDS AND INTEGRATION OF EDUCATIONAL OBJECTIVES

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SUMMARY

The desire to carry out this investigation arose as a result of the writer's experience in the teaching of plastics technology.

While the students (most with a predominant chemistry background) were experiencing difficulties with the subject matter related to the properties and processing of plastics, the teacher was becoming increasingly aware of several unanswered questions about the curriculum, e.g. (a) levels and types of terminal competences to be expected, (b) adequacy of the structure of existing courses and (c) validity of separate teaching units for the technology of plastics, rubbers, surface coatings, etc.

With this in mind, the writer has attempted to define the nature of polymer technology, as a unified subject of study, and to identify its place in higher education in the light of current curriculum theory:

By considering the needs of the manufacturing industries, in terms of expertise in polymer technology, and the implications of various curriculum models the writer has put forward three curricular structures for courses leading respectively to technician, graduate and professional qualifications. Through an analysis of the activities of practising polymer technologists a unified set of educational aims and objectives were formulated for the three areas of study deemed to be appropriate for inclusion in the curriculum.

Finally, the writer has analysed the feasibility of integrating the subject matter related to the technology of individual classes of polymeric compositions, namely plastics, surface coatings, rubbers and adhesives, and has identified further common elements for a unified materials technology curriculum.

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This work could not have been carried out without the help of all those who have participated in the surveys described in the text, and to whom the writer wishes to express his deepest gratitude.

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CHAPTER 1

1. ANALYSIS OF THE PROBLEM

1.1 Historical developments in the teaching of polymer technology in tertiary education

The teaching of the technology of polymeric materials originated in regional colleges for the purpose of training technicians for the local industries.

A course on the technology of natural and synthetic compositions was already in existence, apparently (1), at the Northern Polytechnic as far back as 1916 and the first plastics technology examination was held in 1937 (2). To keep abreast with other established professional institutes the two professional bodies, the Institute of the Rubber Industry ; and the Plastics Institute, developed more advanced courses leading to associateship qualifications, which were deemed to be equivalent in standard to university degrees. Although three routes were made available, a chemistry, a physics and an engineering route, to provide a continuation to the well established pattern of part-time education leading to higher national certificates, only the chemistry route attracted a substantial number of students. It was obviously the large research and development programmes of the rapidly expanding polymer producing industry that provided the impetus and, therefore also, the supply of students for these courses.

With the setting up of the Council for National Technological Awards (C.N.T.A.) in the 1950's, responsible for the establishment of degree courses, Dip. Tech.s, outside Universities, many regional colleges developed into national centres for specialized studies (national colleges) and colleges of advanced technology (C.A.T.). The development of the curricular structure for these new courses, which were meant to provide the answer to the criticisms repeatedly voiced by industry on the training of university graduates, was obviously influenced a great deal by the professional institutes. Consequently much of the subject matter of Dip. Tech. courses was similar to that of A.P.I. and A.I.R.I. courses. Lecturers for these courses were recruited directly from industry, often on part-time basis only, in order to expose students to the more advanced and specialized technologies demanded by the level of these courses. The newly recruited lecturers were normally graduates of scientific disciplines, particularly and inevitably chemists, who had acquired the technological know-how through practical experience.

With the changes which occurred only a few years later, that is the C.N.T.A. becoming the Council for National Academic Awards (C.N.A.A.) to broaden its responsibility for degrees other than technological ones, (which also brought about the dropping of the Dip. Tech. designation in favour of the conventional B.Sc.), the C.A.T.s becoming technological universities and many regional colleges acquiring the newly created status of polytechnics, several new courses with a 'polymer' content emerged. Whether caught in the wake of the inevitable strife for academic recognition by traditional universities, which in recent years have become increasingly more involved in research in polymer science, or simply because of the increased conviction that advancements in technology depend on the foundations laid down by the underlying science, it would seem that both existing courses and newly created ones have acquired a larger content of polymer science at the expense of polymer technology contents. The teaching of polymer technology received some criticisms, in fact, on the ground that it lacked adequate depth and did not develop sufficiently the intellectual potential of students (3,4).

By this time the expansion in full-time education and the general swing away from science based courses has resulted in a reduced demand for the Plastics Institute and the Institition of the Rubber Industry courses and, to some extent, also for degree courses specializing in Polymer Science and Technology. Partly to make these courses economically more viable the Plastics Institute introduced a new scheme for the courses leading to the API qualifications, in which the three existing routes became amalgamated, and some universities and polytechnics introduced new courses centred around studies of materials to attract those school leavers not committed to specialization on any particular class of materials. The impetus to introduce the latter courses arose mainly from a decreasing demand for metallurgy courses, which were experiencing similar changes to those in polymer technology, that is, in the strife to gain academic recognition by the more traditional universities, they were abandoning the designation of metallurgy in favour of material science.

1.2 Present curricular structure of degree and professional courses with polymer technology contents.

In order to establish the place of polymer technology, as a subject of study, in the courses discussed in the preceding section, it is worth considering whether the nature of the curricula of these courses may be identified and characterised on the basis of certain available models.

1.2.1 Curriculum models in tertiary education

Dressel (6) suggests that there are eleven basic models of college and university curricula. These are:

Model 1. A "Dewy eyed" Programme

This model starts with the following assumptions:

a) All learning is individual and problem based.

b) Knowledge is worthwhile only if it can be used to solve problems.

c) Education is life and must be a multifacet experience as similar to life as possible.

d) Sequence and integration of subject matter are individual problems and cannot be planned for groups.

The distinction between depth and breadth of subject matter is not significant because the programme assumes a high level of student motivation, which will result in a depth experience over a wide range of knowledge and problems. This programme is suitable when the teachers involved are more concerned with students than with research so that they can supply the motivation for learning.

Model 2. A "Saintly" conception

This model is based on the following assumptions:

a) Significant truth and value have been discovered by the great minds of past ages.

b) Education consists of bringing students into contact with these ideas.

c) "The aim of education is the development of the mind through dialectic and mastery of existing integration of scholars".

d) Education is for an intellectual élite.

The programme is orientated towards the past and rarely considers current problems. This programme is more widely used for classical education and completely avoids proparation for a profession.

Model 3. A "Pedantic" pattern

This model assumes that:

a) The major disciplines represent the best effort of man to date to organize knowledge and systematize the task of seeking new knowledge.

b) Since no one can master all knowledge, one or two disciplines are chosen for intensive study.

c) Only after a "discipline" has been mastered should one consider the practical implications and applications.

d) Since professors are the masters of the discipline they are best equipped to determine college curriculum.

In this model concern for the individual, for problem analysis and for practical experience is not as important as the mastery of an organized body of knowledge. The function of the teacher is to disseminate knowledge; the function of the student is to absorb it. Concern with learning and teaching is apt to be negated by the concept of the discipline as an organized body of knowledge. The programme is orientated towards an academic or professional career in the discipline and therefore tends to be highly specialized and vocational.

Model 4. A "Narrowly" vocational model

This model assumes that:

a) Vocational education should focus on the development of knowledge and skills necessary for specific tasks.

b) The various disciplines in the arts or sciences are relevant only if they provide knowledge and skills that are required in performing vocational responsibilities.

Such a programme encourages the integration of knowledge relevant to a specific vocation, and qualification for a job tends to outweigh all other competences. The narrow emphasis leads to preoccupation with skills and details, and fails to provide the broader knowledge and competence required for adaptability and advancement.

Dressel points out that the above four models are the most widely used in American colleges and finds weaknesses in all of them: they fail to deal adequately with personal development, there is a lack of concern for individual students, and they do not provide coherence and unity of learning experiences.

Model 5. The "outreach" model

This model is based on the assumption that if colleges and universities are to affect life, then the educational experience must encompass "real life" experience and encourage the student to interrelate them.

Practical and theoretical experience are balanced and the students will decide after practical experience whether they need further formal education.

Model 6. The "single module" plan

The major assumption in this model is that education will be more meaningful if students can concentrate for a period of time on one area of study and penetrate deeply rather than flitting from one area to another. The courses are run sequentially in varying lengths.

The principal arguments for the single course module is that students are provided with more academic coherence at any point in time. Four types of courses are offered: the single course, the interdisciplinary course, the extended half-course, and the subject course.

The extended half-course is intended for subjects that are particularly demanding or require considerable time for mastery. The adjunct course may include a foreign language, music, etc.

Model 7. The "Theme" college model.

This assumes that identifying major social issues or problems and using them as themes will achieve relevance, manifest the social responsiveness of education and force both students and faculty to integrate disciplines with each other and with social problems. Selection of the themes involves consultation with leaders, analysis of special reports, and review of daily news to determine the major needs, problems and characteristics of the area. The type of courses using these themes are likely to carry titles such as: Environmental Sciences, Creative and communicative arts, etc. This represents a different approach to liberal education and to designing meaningful programmes to meet the needs of contemporary students and the community in which they study and work. It forces the disciplines to define their roles in respect to the themes and the individual students' interests in variants of those themes. Attention to themes of community concerns injects an element of relevance and practicality into theory.

Model 8. Individual tutorials

It assumes that all learning is individual, and is effectively carried on only when the individual (student or teacher) pursues his own developing interests in whatever way seems most attractive to him. Each professor designs his own course as to content and method of instruction. The student may take any course for which he can qualify, and makes selections according to his own needs and characteristics.

Model 9. The "Integrated" model

This model assumes that learning requires a varied array of experience; that the student requires help in choosing among them, and that the diverse experiences must be highly structured so as to offer distinct alternatives. The student is guided through a sequence of on- and off campus activities and projects that increasingly place the burden of learning on him.

This model places a great emphasis on advisory service by members of the academic staff and the student works with his adviser to establish which programme would best satisfy his needs and aims. The difficulty with such a programme is that it appears to depend too much on prescribed experiences without adequately identifying the expected contributions of these experiences to the long term objectives to be attained by students.

Model 10. The "Elective" model

This model assumes that the mastery of knowledge is the major goal of education, but that students must have the freedom to define both the knowledge they desire and the particular mode by which it is pursued. Courses start with a problem of immediate concern to students, relevant material is developed accordingly, and the student performance is evaluated by continuous assessment.

Model 11. The "Flexibly-Rigid" model

This model assumes that good education results when able and highly motivated students are brought together with a like group of teachers. Independent study is emphasised throughout the course and evaluation is carried out by means of seminars, assigned papers, and the like, as well as by means of independent study reports. The academic programme has stucture (the rigidity element), but within the limits of that structure the individual student is offered a variety of options to meet his own needs.

Discipline is necessary but largely self-imposed, in other words, the student is allowed to cut across standard disciplinary lines.

1.2.2 Matching existing courses against Dressel's curriculum models

In order to characterise these courses in terms of the curriculum models described above, a unified scheme representing the G.P.I., G.I.R.I., B.Sc. and M.Sc. degree courses has been drawn up and illustrated in figs. 1.1, 1.2, 1.3 and 1.4.

Note that in every case: (a) (*) denotes that the unit shown is not always part of the course; (b) "dotted units" show possible changes in the time of introduction of the unit shown.

Fig. 1.1

A generalised scheme of courses with polymer technology content

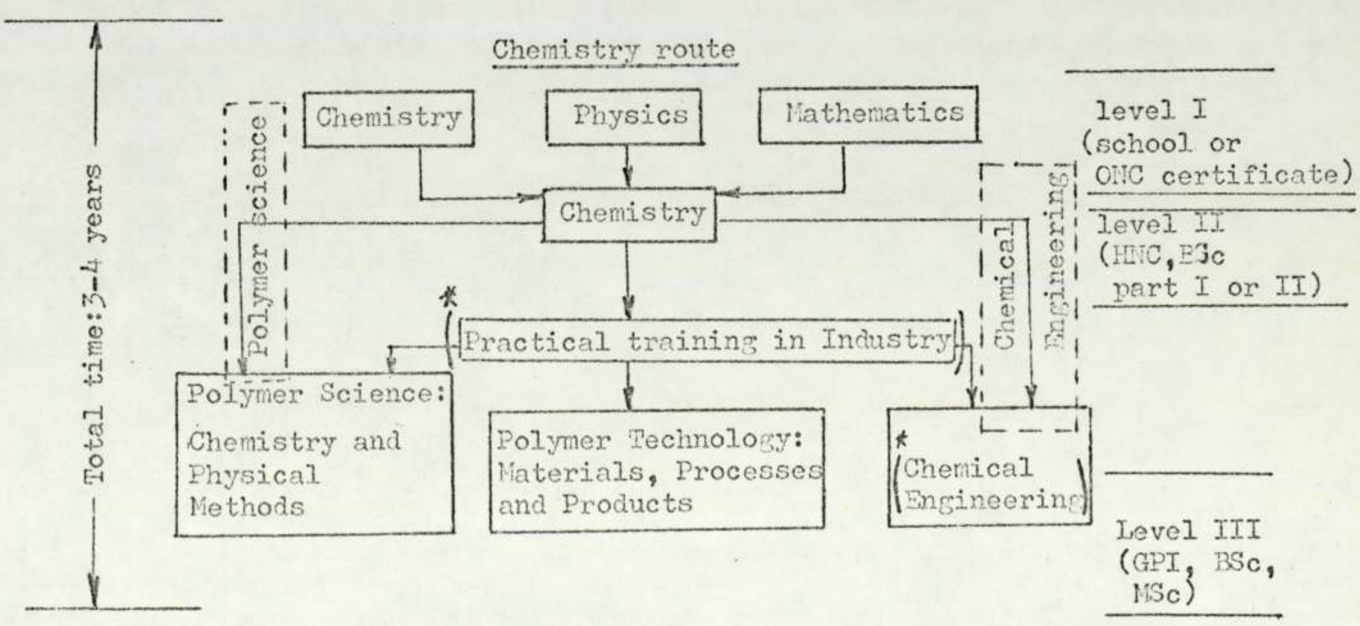


Fig. 1.2

A generalised scheme of courses with polymer technology content:

Physics route

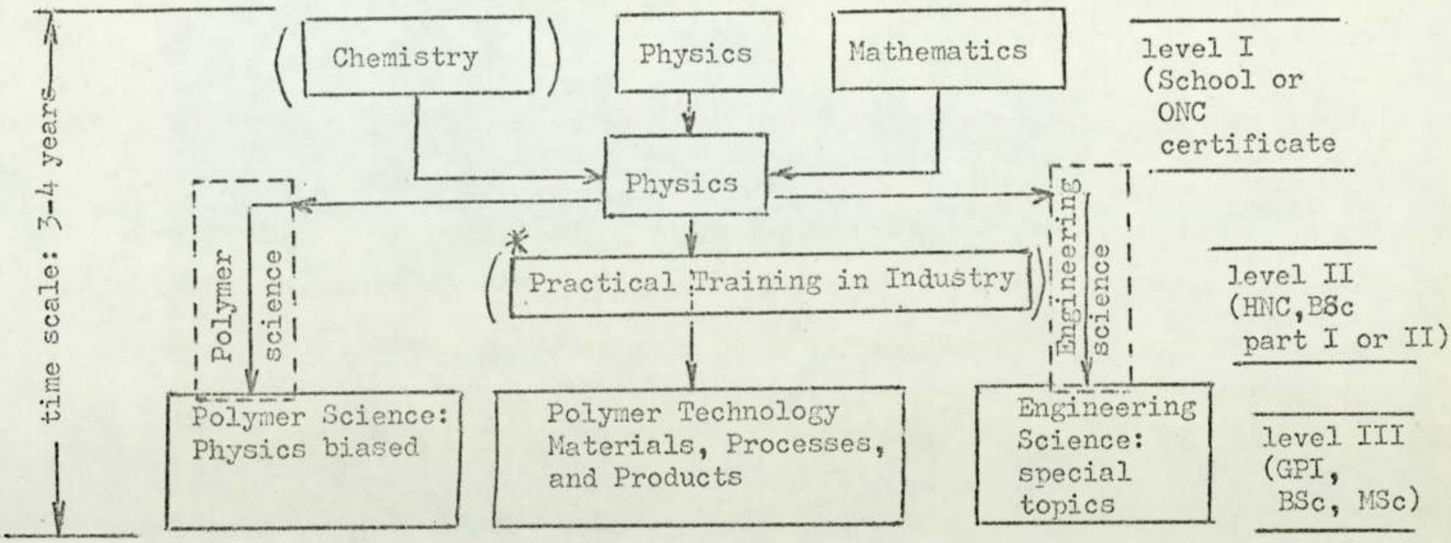


Fig. 1.3

A generalised scheme of courses with polymer technology content:

Engineering route

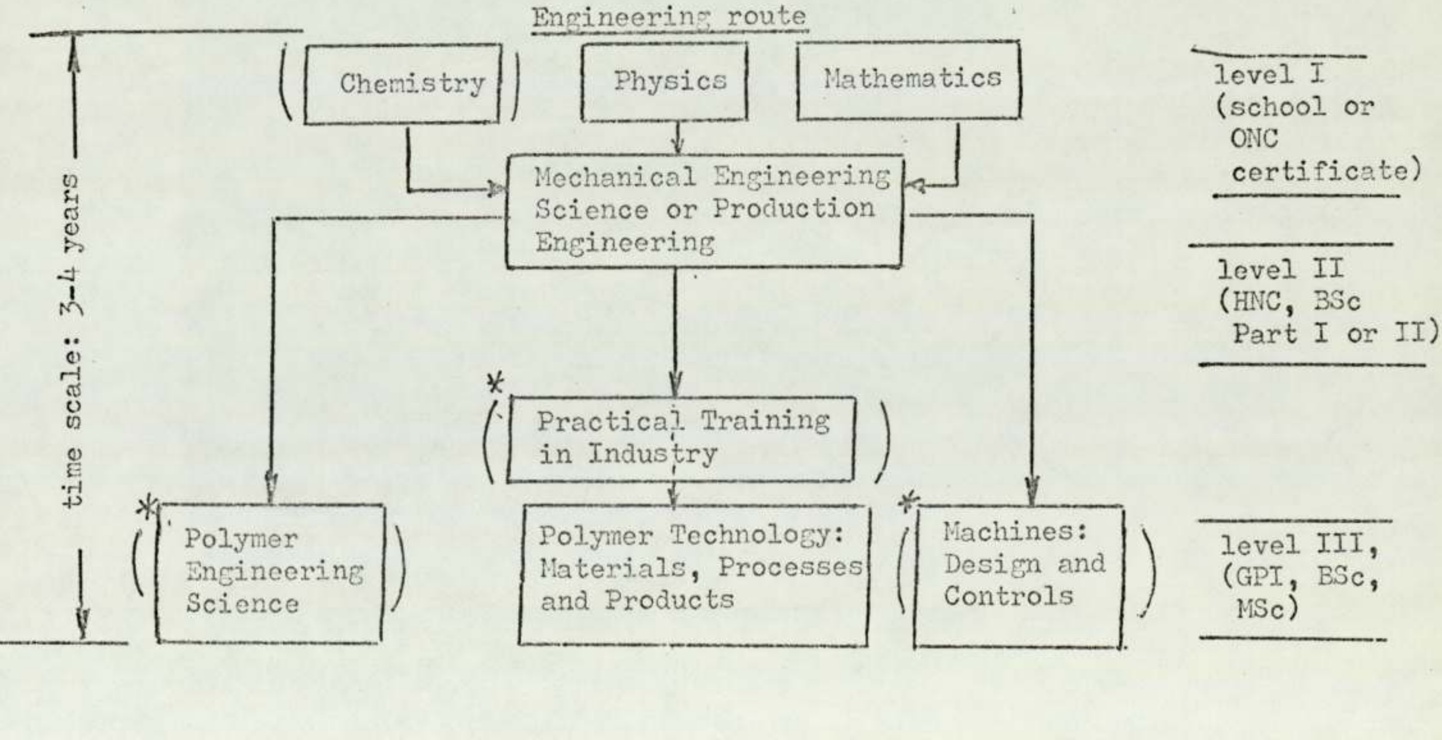
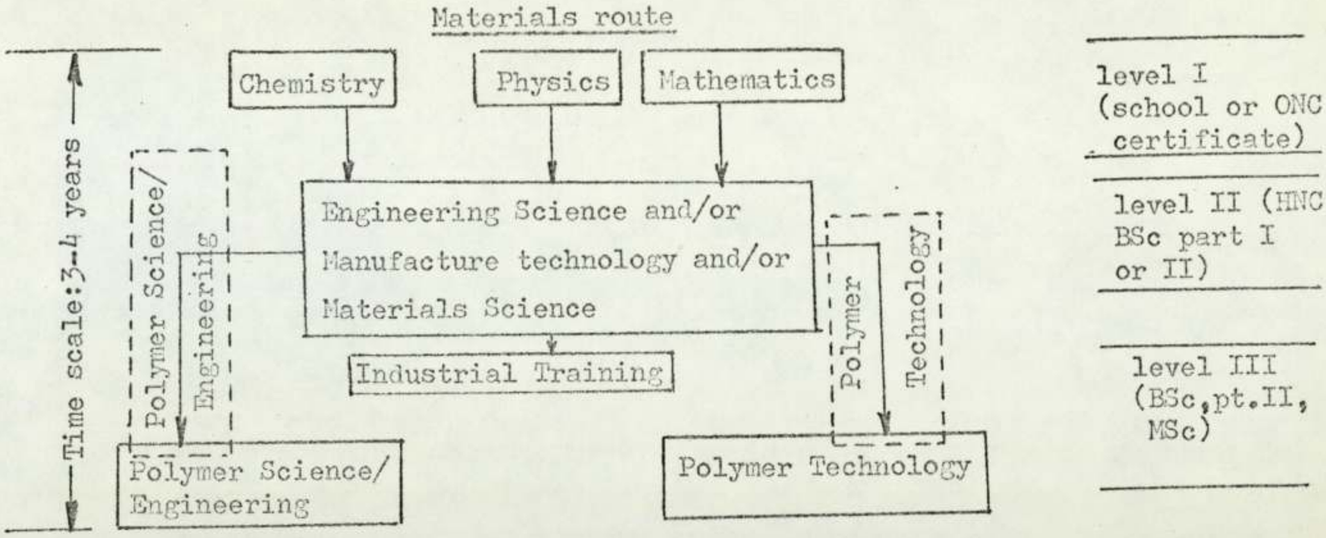


Fig. 1.4

A generalised scheme for courses with polymer technology content:



On examining the broad structure of these courses, figs. 1.1 to 1.4, and judging from the writer's own experience both as a student and teacher of one of these courses, it can be implied that the basic disciplines, e.g. chemistry, physics, mathematics and - to a large extent - engineering science, are treated without any substantial reference to practical problems. Therefore up to level II these curricula may be identified with the 'pedantic' pattern. At level III, on the other hand, it would seem that they assume the characteristics of a 'vocational' model.

The introduction of practical training in industry either between levels II and III or spanning across both levels, as in the case of GPI courses by part-time release studies, may confer also some characteristics of the 'outreach' model. The likeness to the latter model is even greater for the case of the HND/LRIC routes to the GPI qualification.

It is also very unlikely that there are common objectives for all the units in any of these courses, partly because of incompatibility of views on the role of education held by academics. Partly also because there is a general tendency to delay the commitments of any educational programme to more specific objectives, hence the reason for the change in character of the curriculum in most cases from a 'pedantic' pattern to, what we have loosely called, a 'vocational' model towards the later stages of the particular course.

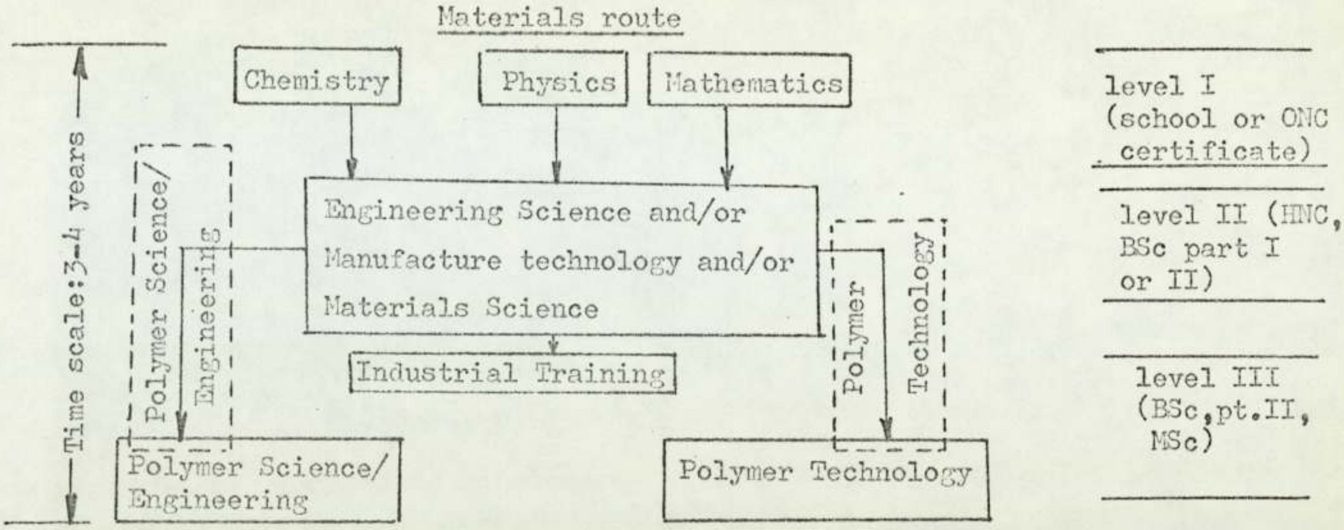
Although the majority of the "materials route" courses, owing to their history, are biased towards metallurgy and, therefore, the contents of polymer technology could be minimal, it would seem that the nature of the curriculum adopted is the same as that described for the chemistry, physics and engineering routes. In every case, however, it is also possible for the students to enter the degree courses via the H.N.D. route after their attainment of a technician certificate in the relevant technologies, e.g. rubbers, plastics, metallurgy etc., instead of "A" levels or "O.N.C." certificates in chemistry, physics and mathematics. In the latter case it would seem that the curricular structure is vocational throughout, with the exception of the basic subjects which are treated much in the same manner as for the "pedantic" stage of the courses described previously.

The majority of these courses have a common curriculum for the basic and applied sciences, e.g. chemistry, physics, polymer chemistry, material science, etc., but each specialise in one material or product technology, e.g. rubbers, plastics, surface coatings, metals etc. Consequently in many cases there is a "double specialization": one based on traditional disciplines and one on product or material type.

It will be noticed that the professional institutes, the Plastics Institute and the Institution of the Rubber Industry, have now become amalgamated and that the two courses, G.P.I. and G.I.R.I. now bear the same title of G.P.R.I. The associateship of the new Institute is granted to graduate members after three years post-graduate experience and after having satisfied the Institute of their professional competences by means of an interview. There is however no formal course work for the A.P.R.I. qualification and the candidates are expected to acquire the necessary competence through private studies and attendance of conferences, meetings etc. and from personal experience by working within the industry or associated institutions.

Fig. 1.4

A generalised scheme for courses with polymer technology content:



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1.3 Effects of existing curricula on students' learning: some personal observations.

The writer has had considerable experience in the teaching of plastics technology at both undergraduate and postgraduate level, i.e. GPI, BSc and MSc courses, in which the student's academic background was essentially chemistry dominated. In each case the plastics technology units were complementary to units dealing with the technology of other polymeric materials and to polymer science units. As far as it could be inferred from the syllabus the BSc and MSc courses differed from each other and from the GPI mainly with respect to the amount of emphasis placed on particular areas of study, particularly rubber technology. In each case the specification of content for various courses seemed to be dictated by two different considerations: firstly the preoccupation with the maintenance of academic standards and secondly the desire to meet industrial needs. It appeared that whereas it was relatively easy to achieve academic respectability in the areas of polymer science owing both to its acceptability in academic research circles and to the availability of well structured textbooks, those subject areas, e.g. plastics technology, which were more committed to deal with industrial relevance, raised many questions, not least the question of how does one define needs and how these may be established. Naturally, the mere statement of content of any course, even when drawn up in collaboration with members of industry, does not necessarily provide an answer to these questions, nor does it help to clarify the level of knowledge required and what abilities are intended to be developed (14). Consequently each teacher has to derive his own objectives and devise an instructional programme for his own subject accordingly. Without searching into educational theories for evidence which could suggest that this situation is harmful to the intellectual development of the student, it was apparent that:

a) the student found it difficult to transfer concepts across the various units of the course and was making little use of the concepts of the basic disciplines studied in earlier units;

b) in the case of BSc and MSc courses, because polymers were dealt with in a very intensive manner (i.e. 4 terms and 2 terms respectively), the student experienced difficulties in dealing with certain areas of technology, especially those concerning the performance of plastics materials in processing and their application.

The writer has also had some experience in the teaching of plastics technology to students with a background in metallurgy and mechanical/production engineering respectively. In the latter cases the writer noticed that by stressing some analogies and differences between plastics and metals the students were able to cope relatively easily with those concepts in which the "chemists" showed weaknesses. It was also quite evident that the metallurgists' background was more adequte than that of chemists to tackle open-ended types of problems. Students in mechanical/production engineering, on the other hand, experienced enormous difficulties in understanding the behaviour or plastics materials and their relationship to both molecular and microstructure. Consequently the treatment of the properties of plastics and the interpretation of their behaviour had to be made on a factual basis, which placed too much burden on their power to memorise and to transfer this factual knowledge to novel problems.

In addition to the above experience, the writer has also acted as an examiner for one of the papers in plastics technology leading to technician's qualifications: judging from the statement of contents in the syllabus and from the type of answers provided by the students, it was often difficult to differentiate them from GPI candidates.

1.4 Questions arising about existing polymer technology curricula

The discussions in the preceding sections raise some fundamental questions about:

(a) The interpretation of polymer technology as a discipline or subject of study, and its relationship to polymer science and engineering.

(b) The validity of the double specialization in existing courses, i.e. based on single disciplines and diverging into detailed studies of specific classes of polymeric materials, and the relationship between polymer technology and the technology of other materials, e.g. metals and ceramics.

(c) The relationship between professional, graduate and technician courses, and the nature of the curriculum adopted in each case.

1.4.1 Polymer technology as a "discipline" and its relationship to polymer science and engineering

There have been many discussions in the past as to the difference between technologists, scientists and engineers and many attempts have been made to identify the boundary of the disciplines in which they work. It is opportune, therefore, to define the term discipline in order to put into perspective questions on the nature of polymer technology as a discipline.

One view is that a discipline develops from the rules of procedure which define its scope and mode of enquiry (7). Each discipline has its own body of facts, concepts and principles, and its own specialized mode of acquiring that knowledge. Hence it is not the structure of knowledge (i.e. the subject) per sè that determines a discipline, but the thought process and rules used in discovering, verifying and applying, knowledge. Schwab (8) poses several problems in identifying and classifying disciplines; namely "how are disciplines organized?", "what are the structures of disciplines?" and "what are the rules and how strictly can they be applied?"

He then concludes that a classification can only be made on the basis of the nature of the product of the disciplines rather than the mode of enquiry and knowledge acquisition, etc, and divides them into:

(1) a theoretical discipline the aim of which is the acquisition of knowledge (natural science, mathematics, social science);

(2) practical disciplines concerned with choice decision, action, etc. (ethics, politics, education);

(3) productive disciplines concerned with making (fine arts, technology, engineering).

Irrespective of how a discipline is defined Schwab (8) affirms:

"Four bases of classification of disciplines have always demanded attention: (1) their subject matter, what they aim to investigate, or work upon; (2) their pratitioners, what competences and habits are required to carry on their work; (3) their methods (syntax) and modes of enquiry by which the enquirer brings himself to bear on the subject matter; (4) their ends, the kinds of knowledge or other outcomes at which they aim".

Green (9), on the other hand, proposes a classification based on human skills:

(1) formal disciplines (clear thinking and accurate use of language), which includes mathematics, logic, semantics and linguistics;

(2) factual disciplines (knowledge about the physical, social and cosmic environment);

(3) normative disciplines (standards of values), which include ethics, politics, religion etc,

(4) synoptic disciplines (integration, development of perspectives), which include history (synoptic in respect to time), geography (synoptic in respect to space), philosophy (synoptic in respect to time, space, causes and values), and religion (the ultimate attempt to relate life and eternity).

Hong (10), finally, provides a classification on the basis of the function of the disciplines to particular areas of studies:

(1) Receptive-focal studies which draw upon other disciplines and relate them to a particular problem area;

(2) Receptive-contributive studies which both draw on and contribute to other disciplines;

(3) Basically contributive studies which contribute to or are employed in other disciplines (e.g. mathematics)

(4) Synoptic studies which embrace the whole of knowledge and reality (e.g. history, philosophy etc.)

The above considerations seem to suggest the corollary that if polymer technology can be identified in terms of its objects, concepts and rules, it will constitute a discipline (Schwab's maxim). On the other hand, if it uses the rules of other disciplines for the solution to particular problems it will constitute an "area of receptive-focal studies" (Hong's suggestion). It would be an over-simplification to assume 'a priori' that the latter is the case only on the basis that it has evolved from the work of those trained in traditional disciplines, such as chemistry, physics, mathematics, engineering, etc, since these workers may have created hybrid rules to the extent that an observer would no longer be able to distinguish one worker from another in the execution of their tasks. Such considerations are also linked to the question of whether polymer technology results, as it is often assumed (see comments in p. 2), from the application of polymer science or whether it is the (complex) product of polymer science and polymer engineering. These seem to be the views held by traditional academics in so far as one notices that there are large science and engineering faculties in universities. This in itself, however, is not a negation that the task of exploiting polymer science and engineering concepts, principles etc. may have to be performed in some distinct manner, as implied previously, which may constitute in effect the essence of polymer technology.

Some supporting evidence for such implication may be found in statements often made about the aims and role of scientists, technologists and engineers.

Science is regarded as a "disciplined" curiosity about the world; an attitude of mind, a mixture of observation, deduction and induction, aimed at developing concepts of logical structure possessing wide-spread applicability (5). Science is, therefore, the process of enquiry aimed at structuring and advancing our knowledge of the universe. The purpose of technology, on the other hand, is to exploit the resources of the universe to improve the quality of life of mankind. Therefore, even when technology is regarded as an applied science, the term applied must not be taken to indicate that the object of technological work is to apply scientific principles to every possible situation, but to seek rational solutions of a practical problem. It is therefore the practical nature of the problem which justifies the use of the term 'applied science' and not necessarily the underlying knowledge used to solve the problem. To differentiate between engineering and technology the 1965 Committee for the Manpower Survey of Engineers, Technologists and Technical Supporting Staff gave the following definitions:

(a) "Engineering, whether civil, mechanical, electrical, chemical or any other brances of engineering, deals with the conception, design, construction and application of new forms of equipment, machines or installations, and with ensuring the most efficient and economic means of achieving defined objectives by such means"..."The engineer is a creator of projects of engineering significance and his responsibility is to bring together all the elements required to attain some prescribed objectives".

(b) "In every technology the ultimate purpose is to exploit existing scientific and other knowledge for productive ends, whether or not all processes involved in the technology are currently capable of scientific explanation"...."The technologist is frequently several steps ahead of the scientist in the breadth of his knowledge and his awareness of the potentialities within the field of enquiry, but he is likely to be less concerned with the full understanding of the underlying scientific relationship".

Of the difference between science and technology, Sir Robert Watson-Watt had to say this (11):

"Science and technology are the 'Gemini' of the (not always heavenly) conceptual constellations of the human mind. They are far from identical twins, and endless confusion may be generated by failure to recognise their sharply differentiated identities. They are, however, like Siamese twins; they share a common blood stream, but are divergent in their outlook on their common world. The divergence of outlook denies them the status of heavenly twins - science may pretend to the adjective, but technology is of the earth, earthy".

Technologists and engineers, on the other hand, seem to be united in their outlook and work more closely in so far as they are both concerned with the same end-product. For the particular case in question, the polymer technologist develops materials and supplies the engineer with data for the design and construction of components and equipment.

This close association between technology and engineering can be also inferred directly from:

(1) The terms of reference of the SRC working party on polymer engineering (91):

"Polymer engineering for this purpose is defined as research relating to

a) the processing of polymeric materials including the design of processing machinery;

b) relationships between processing variables and properties of polymers;

c) properties relevant to the practical utilization of polymers and plastic materials derived from them;

d) design processes and forms of construction in polymers".

(2) The definition given by the American Society of Engineering in respect to Ceramic Engineering (62):

"The branch of engineering concerned with the conception, development, production and understanding of ceramic materials and products".

In the latter definition the concept of engineering is extended and merges completely with that given for technology.

For the purpose of the curriculum, therefore, it would seem necessary to clarify the role of polymer technologists in order to determine more accurately than hitherto the types and levels of competences expected from students on completion of a particular course of studies.

1.4.2 Specialization and integrated studies in courses with polymer technology contents

Industrialists are sometimes sceptical about education dealing with single classes of materials (*) and professional institutes and socities have developed various schemes for curriculum integration. The Society of Plastics Engineers in USA, in fact, has put forward six schemes for polymer studies in which are included topics on all classes of polymeric materials (15), and the Plastics Institute in UK, through a joint examination board with the Institution of the Rubber Industry, has also encouraged substantial cross-fertilization of plastics and rubber technology. Furthermore, the Plastics Institute, as it has already been mentioned, has introduced an 'integrated scheme' for the GPI courses in which the physics, chemistry and engineering routes have common contents for approximately two thirds of the entire curriculum. The PI reached this decision on the basis that many technological tasks in industry are essentially multidisciplinary and, therefore, included introductory courses in chemical aspects of plastics for engineers and physicists and similar courses on engineering subjects, such as heat transfer, for chemists (16).

The reaction of industry to these changes seemed quite favourable (17) bearing in mind for instance that both in Germany and in the United States it is quite common to find a substantial chemical content in plastics engineering courses (18, 19). In other words there seemed to

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* S. Gratch of Ford Motor Com pany USA, made the following comment at the 3rd Buhl International Conference on Materials (1968):
"In the field of coatings, we have some paint chemists who become expert in some specific type of polymer, but lack the fundamental knowledge required to transfer their skills to another field".

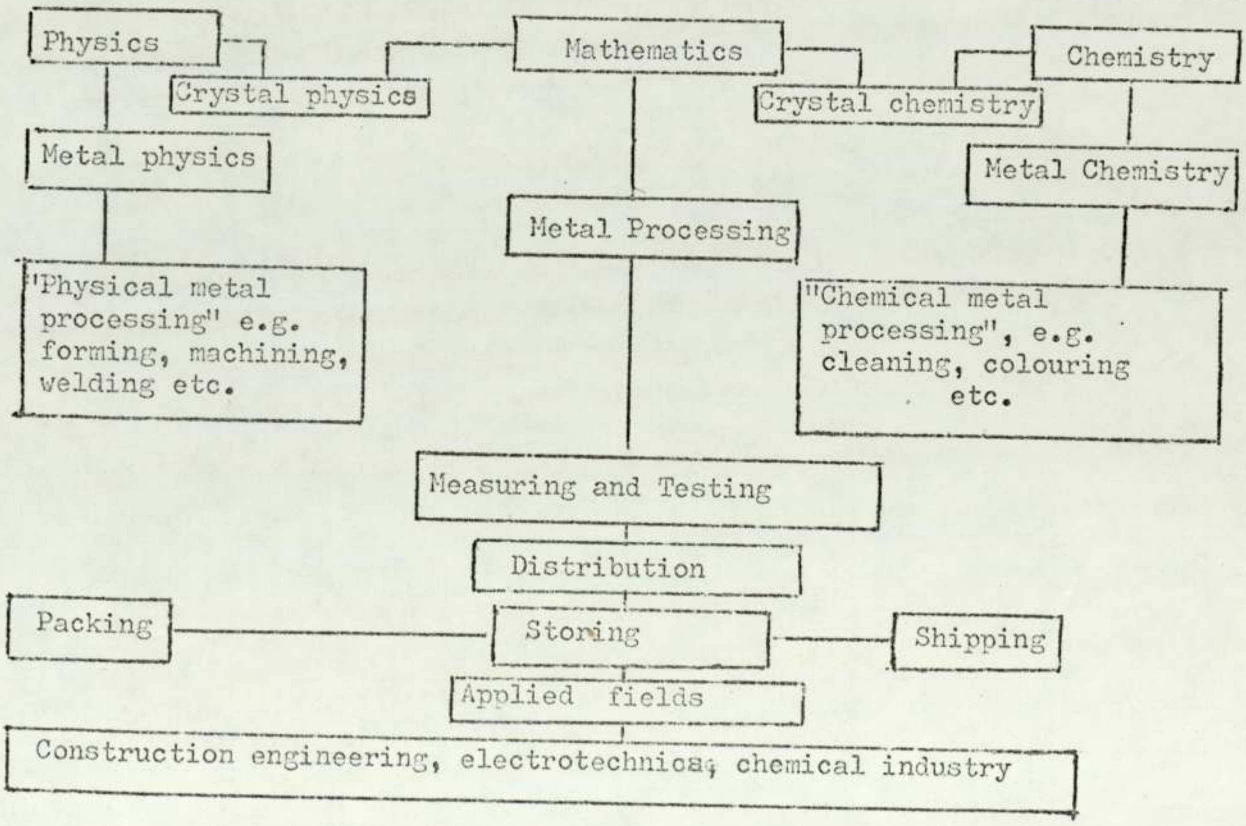
general agreement on the interdisciplinary nature of plastics technology, and that this should be reflected in teaching curricula. Holloway (20) goes as far as to specify that at least 70% of jobs in industry in general require interdisciplinary knowledge. Peterson (21) illustrates this by giving an example of what an aluminium expert should know. (Fig. 1.5.)

The question arising from an examination of this model is "how far, for instance, can one overlap a replica of a similar model, say, for an expert in PVC?" In other words, if the term metal is substituted by polymer, does the model still hold for the kind of competences expected of a polymer technologist?

A positive answer to this question would provide a case for the horizontal integration of polymer technology with other materials technologies.

Fig. 1. 5

What an aluminium expert needs to know and, to a large extent, must know (3)



Holliday (20) gives some guide lines as to how this can be achieved. He proposes manufacturing and product technology, rather than material science, as a basis for integration. It would appear that the MSc course at Imperial College attempts this type of integration but the emphasis is on engineering aspects, e.g. design of processing machinery and mechanical properties: evaluation and manipulation for design. The course on materials at the Open University, on the other hand, appears to do the reverse. The integration here is based on material science with particular emphasis on molecular and morphological structure of polymers.

In either case, however, one can barely accept that polymer technology, as laid out in the syllabus of the GPI, GIRI and other established degree courses, is dealt with at all. There is a failure, for instance, to recognise that polymers are only the base materials for polymeric products and the existence of thermosets is being ignored altogether. The impression is given that the student at the end of the course will not even know which of the thousands of synthesizable polymers are actually used for plastics, rubbers, adhesives etc., let alone being able to tell the difference between them.

From the above considerations, it would seem necessary, therefore, to establish the extent to which polymer technology is to be treated as an interdisciplinary area of study, and whether the existing sub-division of technological studies based on single classes of materials is still valid on the basis of both educational theory and present industrial needs.

1.4.3 The relationship between professional, graduate and technician courses and the expected levels of competences

Unlike the learned professions, such as medicine, law etc., the Institution of the Rubber Industry and the Plastics Institute (as well as the majority of other engineering professional institutes) require only an additional examination in "Industrial Administration" and three years industrial practice for the transfer from graduateship to associateship. In the light of recent events, i.e. (a) the amalgamation of the Plastics Institute with the Institution of the Rubber Industry, (b) the plea of senior members for a more fundamental approach to degree courses and to upgrade the professional status of the APRI qualifications (46, 47), and (c) the increasing proportion of graduates qualifying through some widely differing BSc and MSc courses over those taking the GPRI examinations, one wonders whether it may become necessary to introduce special post-graduate courses leading to the APRI qualifications.

Irrespective, however, of how the transition from graduateship to associateship is conceived, it is of the utmost importance for both curriculum planners and students to know the difference in level of competences expected at each of the two stages.

Furthermore, since there are cases in which students progress to graduateship and associateship from technician courses, one wonders (as already pointed out earlier) whether in this progression the only difference to the curriculum is the introduction of polymer science and of further instruction on basic science, without any substantial additions to the technology areas of study.

If this is true, and it is based on the assumption that the purpose of polymer science and further basic science is to increase the understanding of technological problems, then serious consideration must be given to the achievement of transferibility of knowledge in sequential and/or concomitant instruction units of a course on account of the observations recorded in section 1.3.

Such considerations are also linked to questions about the type of curriculum which should be adopted in such courses and whether it is necessary to change approach in various stages or units of a course. One wonders, in fact, whether the lack of common goals among the teachers of a particular course constitutes a major hindrance to the educational process. There is a trend, for instance, among teachers of basic subjects, e.g. physics, chemistry, mathematics etc. to denigrate 'vocational' curricula and 'technological' subjects on account of the widespread usage of these terms in 'low' level courses and, therefore, assumed to be suitable only for teaching specific and manual skills. Conversely, teachers of technological subjects may be equally at fault to suggest that only a 'vocational' curriculum provides the students with the knowledge and skills useful in their subsequent employment.

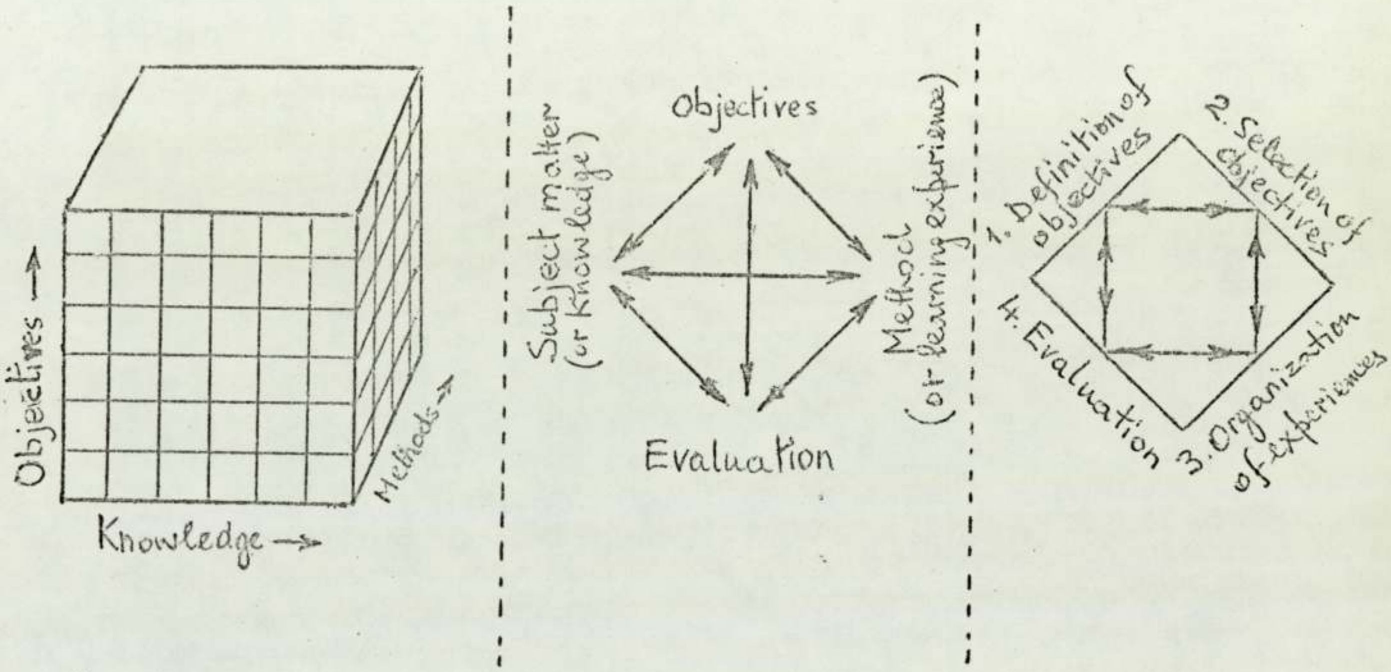
In other words, the question is being raised here, perhaps for the first time, as to whether the teaching of polymer technology may be usefully adopted in non-vocational curricula, such as Dressel's 'theme' and 'outreach' models, as a means of developing competences in matters related to the production and utilization of materials.

CHAPTER 2

THEORETICAL CONSIDERATIONS IN CURRICULUM DEVELOPMENT

2.1 The essential elements of a curriculum

There is little disagreement amongst educationalists as to the essential elements of a curriculum. These are often represented in diagramatic form to indicate their inter-relationships (Fig. 2.1).



(After P.H. Taylor) (ref. 22)

(After J.F. Kerr) (ref. 23)

(After P.L. Dressel) (ref. 24)

Fig. 2.1

The essential elements of a curriculum

Taba and Tyler (25) produced a more elaborate scheme of procedures to be adopted in curriculum design, in which objectives are preceded by a 'diagnosis of needs' and the learning experiences are divided into 'selection' and 'organisation'. The recommended sequence of steps to be taken in curriculum development on the basis of Taba's method (26) are as follows:

Step 1. Diagnosis of needs.

Step 2. Formulation of objectives.

Step 3. Selection of content.

Step 4. Organization of content.

Step 5. Selection of learning experiences.

Step 6. Organization of learning experiences.

Step 7. Evaluation of achievements.

The diagnosis of needs becomes an essential step before educational objectives can be defined and, similarly, a basis for selection of content and learning experiences must be formed before they can be organized in a manner which produces an appropriate sequence and integration in the learning process.

Tyler (25) defines educational objectives as the statements of the changes in student behaviour which it is intended to bring about by learning.

On the question of evaluation Bloom (38.) emphasises that, although it appears as the last step, it must not be regarded as the final test to grade or classify students' performance at the end of a course or an instruction unit, but must be used as a means of improving teaching and learning (38.). The process of evaluation would encompass, therefore, the following:

1) Evaluation as a method of acquiring and processing the evidence needed to improve the student's learning and the teaching.

2) Evaluation as an aid to classify the significant goals and objectives of education, and as a process for determining the extent to which students are developing the desired behaviours.

3) Evaluation as a system of quality control in which it may be determined, at each step in the teaching-learning process, whether the process is running efficiently and whether changes must be introduced to bring about any desirable improvements.

Philosophies of education are rarely used as a source of educational objectives as they are too vague to be translated directly into teaching material (27, 28).

An example of curriculum development based on educational philosophy is given by Dressel et al. (29). The difficulties suggested above are clearly elucidated in the three approaches suggested:

a) The traditional educationalist approach. This programme is orientated to the past, believing that all significant truth and value has been isolated and presented by great minds of the past. Education consists, then, of bringing the student in contact with these ideas as presented in a curriculum made up of a number of subjects.

Evaluation in such educational programmes is highly subjective and emphasises oral and written procedures. If traditional educational practice does not directly supply an answer to a problem, rational analysis and discourse by those well versed in traditions will yield the right answer. For the traditionalist, issues and courses of actions are seen in black and white. Shades of grey suggest compromise and expediency not to be tolerated by free men who know the truth.

b) The eclectic educationalist approach. This programme is orientated to the present for, recognising that our society is pluralistic and that many disciplines and professions are currently taking shape, the eclectic educationalist receives from the past nothing so definite as does the traditionalist. Education consists then of bringing the student into brief contact with a wide range of courses to provide some breadth, and into extended contact with a particular body of subject matter to provide depth. The curriculum is composed partially of requirements (both specific and general) and partially of electives. Since no agreement is possible on a general body of knowledge, emphasis is often on the specific fact, discrete items of information and those concepts and principles which differentiate one discipline from another.

Evaluation in such a programme of education tends to focus on mastery of a body of factual knowledge and less certainly, but possibly, on the intellectual skills needed to deal with it.

Although "intangible" values may be hypothesised as accompanying the student's contact with the scholar, there is no interest in making them explicit.

c) The relativist approach. This programme is orientated to the future, not because it ignores the present or discounts the lessons of the past, but because the relativist educator believes that each individual and society must seek its own truth and values, which are always relative to the times and conditions. Furthermore, he views education more definitely as an instrument for progress and improvement.

In the curriculum, knowledge is by no means discounted, but the emphasis is on experiences which develop habits of thinking in each individual and encourage him to seek new and more meaningful relationships from his experience. Programmes and persons holding these views are empirically orientated and the approach is to emphasise any matters which develop maturity.

Dressel (30) recommends the following sources as the most useful: (a) needs of society, (b) needs of individuals, and (c) consultation with professional organisations.

2.2 Levels of educational objectives and expected students' competences

Educationalists find it convenient to distinguish various levels of educational objectives, and sometimes make a distinction between educational and instructional objectives (31). The difference between these two, however, is mainly with respect to the degree of specificity with which objectives are being stated and, therefore, the term educational objectives can be used to encompass the whole spectrum of objectives which an educational programme seeks to achieve.

TABLE 2.1

An example of increasing specifity of a generally defined objective (34)

abstract — operational

Abstraction ladder	Progression of objective from abstract to specific	Observability and agreement dimension
Abstract goal	(For Learners) To acquire a basic understanding of earth-sun relationships	Possibly observable
Less abstract sub-goal (or objective)	To use the terminology of earth-sun relationships in sentences and paragraphs	Observable by the teacher but without provision for assessment of understanding
More specific objective	To discuss with others the relationships between sun and the earth, using correct terminology	Observable. Some assessment of understanding is possible
Even more specific objective	To use the terms orbit, axis and elliptical in meaningful ways in a paragraph	Observable. Can be compared with other performances
Very specific objective	To differentiate correctly between such terms as 'revolution' and 'rotation' in earth-sun relationships.	Directly observable and comparable. Authorities on the subject would agree on correctness of statements made

Krathwohl suggests that these may be stated at three levels (32) whereas Jenkins and Deno (33) propose a four level model (Fig. 2.4), each level of objectives being characterized by their degree of abstraction or distance from observable data and measurable behaviour. Lysaught and Williams (34) give an example showing how a stated objective can be translated into instruction procedure by subdividing the objective into various sub-groups of different degree of abstraction (table 2.1). Stones and Anderson (35) propose the introduction, at each level, of three types of objectives varying from one another in level of complexity. The relationship between areas of study, levels of objectives and types of objectives is shown in fig. 2.2, and the procedure to be used for the derivation of subordinate objectives is illustrated in fig. 2.3

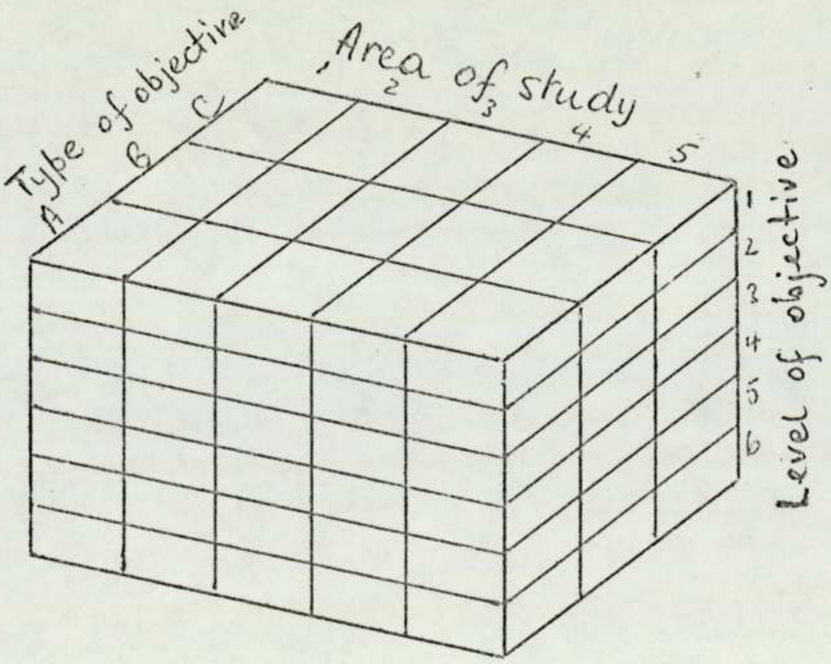


Fig. 2.2

Relationship between type of objectives, levels of objectives and areas of study

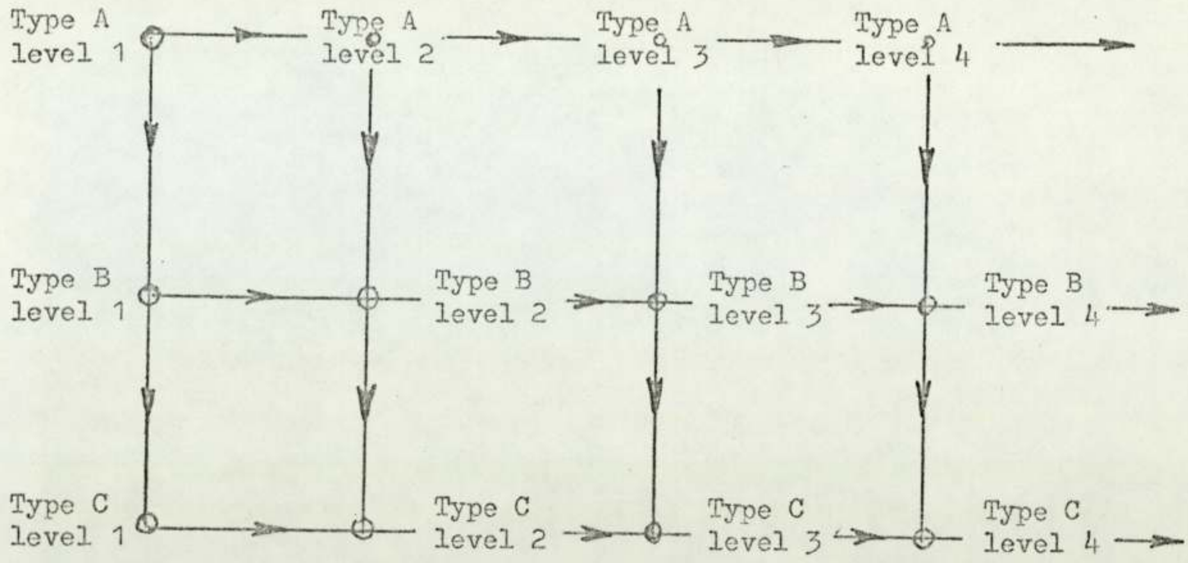


Fig. 2.3
Procedure for the derivation of subordinate objectives.

Horizontal arrows indicate the direction towards increased specificity.

Vertical arrows indicate the direction towards less complex modes of learning.

Type A objectives involve the most complex type of learning, generally at the very highest level of problem solving or creative activity. Type B objectives are still at the problem solving level, but involve less complex behaviours. Type C objectives are least complex and are at the level of principle learning. All level 1 objectives, whatever their type, are very general objectives. However, any type A objective at level 1 depends on prior achievement of the appropriate type B objective at the same level, and type B depends in turn on the achievement of type C at the same level (Fig. 2.3).

Dependency of objectives at various levels is, on the other hand, conceptual: level 1 objectives being conceptually more general than those at lower levels 2, 3 etc. Thus objectives of different types at level 1 subsume objectives of the same types at levels 2, 3 etc. Using this approach Stones and Anderson were able to derive objectives for various areas of study to be included in the Educational Psychology units of teacher training courses. The overall number of objectives were obtained from a survey of lecturers and students in 92 Colleges of Education in Great Britain.

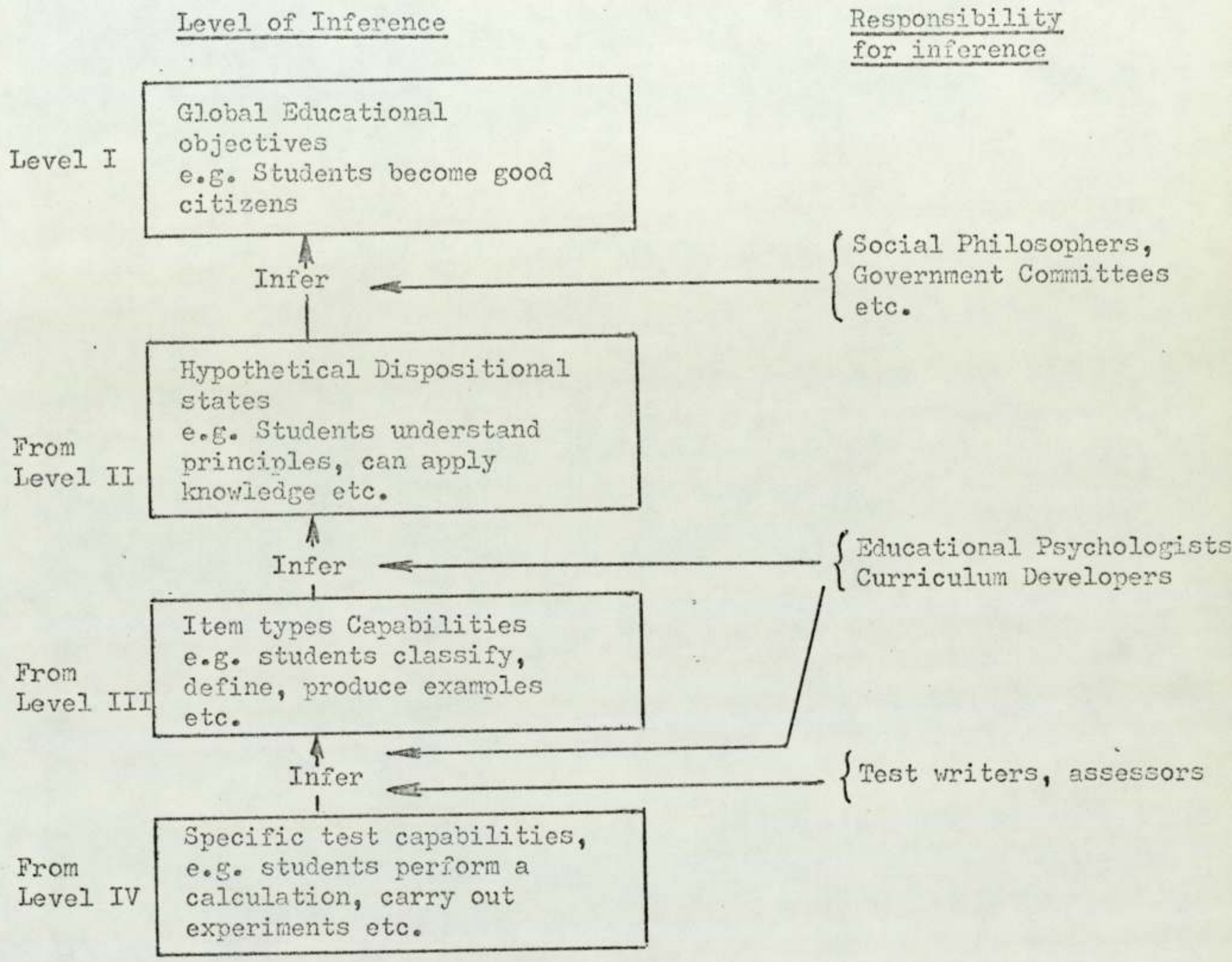


Fig. 2.4

Instructional objectives

(Based on model proposed by Jenkins and Deno (33))

At the first level these authors agree that objectives are very vague and abstract and may be considered as global goals of an educational programme rather than tangible educational objectives. At this level we have statements such as educating for good citizenship, to prepare students to become well-adjusted members of society, etc., which are more identifiable with philosophies of education than with curriculum objectives, hence they are of little use to teachers and designers of instruction units. At the second level we have behavioural objectives, but stated in general terms so that they are applicable to any situation irrespective of curriculum content. The most famous example of objectives at this level is that suggested by Bloom in his classic text on 'Taxonomy of Educational Objectives'. A brief summary of these objectives is shown in table 2.2. Taba describes several behavioural objectives whereas Dressel specifies six competences, (table 2.3 and 2.4 respectively).

At the third level, the most concrete in terms of selecting content of a course and devising instruction procedures, are specific behaviours, e.g. learning a foreign language, etc. Jenkins and Deno recognise a fourth level of objectives which contains objectives stated even more specifically than the above, e.g. translating a technical text from one language into another.

There can be virtually no disagreement among observers as to the occurrence of events specified at this level, nor can there be any doubt in the instructor as to the objectives to be achieved, except in the breadth and level of competence required.

The distinction between objectives at level II and those at level III and IV can also be illustrated by reference to the number of interpretations which are possible for a given stated objective (36), e.g.

Objectives at level II	Objectives at level III or IV
(Terms open to many interpretations)	(Terms open to fewer interpretations)
1. To know	1. To write
2. To understand	2. To recite
3. To 'really' understand	3. To identify
4. To appreciate	4. To differentiate
5. To 'fully' appreciate	5. To solve
6. To grasp the significance of	6. To construct

In curriculum development, therefore, one must make adequate distinction between knowledge and abilities, and non-cognitive elements, such as attitudes, enthusiasm, values etc. which must be included in the statement of objectives. The importance of cognitive and affective objectives in curriculum development is that they can be related to the qualities expected of graduates in their subsequent employment. Humble (37) and other researchers in the U.S.A. were able to relate abilities derived through task analysis to Bloom's taxonomy; an example of this is given in table 2.5.

TABLE 2.2

Bloom's Taxonomy of educational objectives (38)

Cognitive domains	Affective domains
1.0 KNOWLEDGE	1.0 RECEIVING
e.g. 1.1 knowledge of specifics	e.g. 1.1 Awareness
1.2 knowledge of how to deal with specifics	1.2 Willingness to receive
1.3 knowledge of principles and generalizations	1.3 Controlled or selected attention
2.0 COMPREHENSION	2.0 RESPONDING
e.g. 2.1 Translation	e.g. 2.1 Acquiescence in responding
2.2 Interpretation	2.2 Willingness to respond
2.3 Extrapolation	2.3 Satisfaction in responding
3.0 APPLICATION	3.0 VALUING
e.g. 3.1 Direct application	e.g. 3.1 Acceptance of a value
3.2 Application by reasoning	3.2 Preference for a value
	3.3 Committment
4.0 ANALYSIS	4.0 ORGANIZATION
e.g. 4.1 Analysis of elements	e.g. 4.1 Conceptualization of a value
4.2 Analysis of relationships	4.2 Organization of a value system
4.3 Analysis of organizational principles	
5.0 SYNTHESIS	5.0 CHARACTERIZATION BY A VALUE OR VALUE COMPLEX
e.g. 5.1 Production of unique communication	e.g. 5.1 Generalised set
5.2 Production of a set of operations	5.2 Characterization
5.3 Derivation of a set of abstract relations	
6.0 EVALUATION	
e.g. 6.1 Judgement in terms of internal evidence	
6.2 Judgement in terms of external evidence	

TABLE 2.3

Taba's classification of behavioural objectives (39)

1.0 KNOWLEDGE

e.g. 1.1 Knowledge of facts
1.2 Knowledge of ideas and principles
1.3 Knowledge of concepts

2.0 REFLECTIVE THINKING

e.g. 2.1 Interpretation of data
2.2 Application of facts and principles
2.3 Logical reasoning

3.0 VALUES AND ATTITUDES

4.0 SENSITIVITIES AND FEELINGS

e.g. 4.1 Capacity to respond to social and human situations

5.0 SKILLS

e.g. 5.1 Ability to define problems
5.2 Ability to plan a method of enquiry
5.3 Ability to assess appropriateness and limitations of data, etc.

TABLE 2.4

Dressel's 'Six competences' (40)

1. The student should know how to acquire knowledge and how to use it.
2. The student should have a high level of mastery of the skills of communication.
3. The student should be aware of his own values and value commitments.
4. The student should be able to cooperate and collaborate with others in studying, analysing and formulating solutions to problems, and in taking action on them.
5. The student should have an awareness of, concern for, and sense of responsibility about contemporary events, issues and problems.
6. The student should be able to relate his development of competences into a coherent, cumulative and unified college experience.

TABLE 2.5

Example of interpretation of objectives on the basis of Bloom's taxonomy (abstracted from ref. 37)

Skills required by a theoretical unit manager in a steel plant

One of the Objectives: / Abilities	Ability to check performances against standards and schedules and taking action to correct deficiencies
COGNITIVE BEHAVIOUR	
1. Knowledge	1. Criteria standards schedules
2. Comprehension	2. Ability to interpret standard schedules
3. Application	3. -
4. Analysis	4. Identifying causes of non-achievements
5. Synthesis	5. Take corrective action
6. Evaluation	6. -
AFFECTIVE BEHAVIOUR	(Writer's comment:)
Valuing	Recognized to be important, but no interpretation reported

2.3 Continuity, sequence and integration of learning experiences

The concepts of continuity, sequence and integration of learning experiences are to curriculum development what process optimization is to production technology, that is they increase the efficiency of achievement of educational objectives. Taba, in fact, calls the process of curriculum planning "a kind of educational engineering"(41) by which the logic of the subject matter is combined with the psychology of learning. She illustrates this by reference to the study of Latin American countries. The logical organization of contents is represented by two sets of items to be learned: i.e.

Countries to study	Aspects to be studied
Argentina	Economic development
Bolivia	Geographic conditions
Brazil	Patterns of government
Chile	Types of people
Colombia	Social institutions and customs
Mexico	Resources
etc.	Education
	etc.

Either set of items can be selected as a basis for the organization of content, as illustrated in fig. 2.5 and 2.6 below.

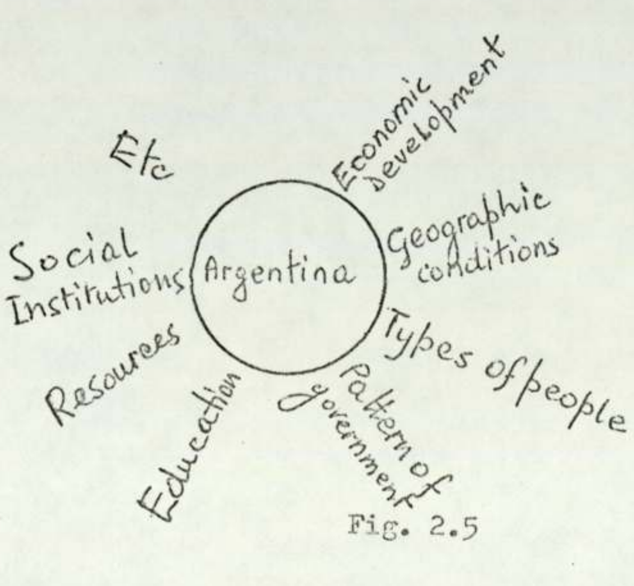


Fig. 2.5

Fig. 2.6

The pattern which is normally chosen depends on:

a) the relative difficulty of learning the underlying concepts when not supported by a pattern of organizations, e.g. names, terminology etc. ;

b) the relationships which provide more significant learning and therefore requiring support of organization of contents, e.g. contrasts in the way of life and the environmental conditions which create such contrasts;

c) the type of pattern which gives the greater depth of understanding about Latin America;

d) the method of organization which better promotes the understanding of general concepts, such as the role of economic resources in economic life, the relationship between pattern of government to historic background etc.

Continuity of learning experiences implies that terms, ideas and skills introduced early in the programme should continue to be used and reinforced to provide cumulative learning which is necessary to develop a progressively more demanding performance.

Sequence implies that learning experiences should be related to preceding and succeeding experiences. Continuity and sequence are therefore closely related and complementary to each other in the learning process.

Several sequencing procedures have been suggested for the organization of learning experiences depending on subject matter and educational objectives to be achieved.

Smith, Stanley and Shore (42) describe four such typical sequences of exposition.

The first is that which proceeds from the simple to the complex. The simple is defined as that which contains few elements or subordinate parts.

The second is an expository order based upon prerequisite learnings. This principle is followed particularly in subjects consisting largely of laws and principles.

The third form of exposition is that which proceeds from the whole to the part.

The fourth kind of exposition is chronological, where facts and ideas are arranged in a time sequence so that presentation of later events is preceded by discussion of earlier ones. This procedure is invariably followed in history courses but is not necessarily the only suitable one. One can, in fact, achieve the same objectives and perhaps even more efficiently by starting with the present, whose events and problems are more familiar to the student, and tracing the development of the present situation backward.

Whatever method is being used, it is necessary to have the right thread or theme on which to base sequence and continuity of learning and it must be chosen in such a manner to enable the grafting of new concepts on the main theme to achieve both breadth of treatment and better transfer of learning.

The provision of continuity and sequence in a curriculum is sometimes referred to as curriculum integration. The concept of integration can assume, however, more precise dimensions. One widely accepted view of integration is that which establishes a horizontal relationship between various areas of study. (43)

The concept of integration must be seen therefore as a process by which the student organizes experiences which may seem unrelated and, as for the case of continuity and sequence, it is necessary to have appropriate threads to produce effectively integrated learning experiences. Bloom (43) defines an integrative thread as any idea, problem, method or device by which two or more separated learning experiences are related.

The most effective integrative threads are, therefore, those which use common principles for the various areas of study and are best achieved by specifying common objectives.

The merits of providing integrative threads can also be inferred by considering the previous example of Latin America as a subject of study. If each country was studied separately and each of the aspects listed was to be covered, this would inevitably a) give rise to repetitions, b) place too much burden on memory, c) some of the contents would most likely be forgotten within a short period of time, and d) the breadth of coverage could obscure the more important concepts.

If, on the other hand, central ideas are selected as a basis of the organization of content, both horizontal integrative threads and vertical continuity and sequencing can be more easily developed which would provide more meaningful and more cumulative learning.

The function of integrated learning in a curriculum is also to prevent compartmentalization of knowledge which impedes transfer to novel situations. These concepts are particularly relevant to the problems of this investigation. Knowledge in the science and technology of polymers, in fact, is advancing very rapidly but its conception and dissemination are carried out through specialized and unlinked routes, hence making it difficult for the new entrants to grasp the overall concepts involved.

CHAPTER 3

SCOPE OF THE INVESTIGATION AND METHODOLOGY

3.1 Aims and objectives of the investigation

The purpose of this investigation is to study the implications of the questions raised in Chapter 1 within the context of the principles illustrated in Chapter 2 with a view to providing suitable guide lines for the planning of polymer technology curricula. More specifically, the study will be concerned with the achievement of the following objectives:

(1) To establish the needs of industry in terms of competences which are required at graduate and professional level.

(2) To identify the areas of study which are related to the activities of practising polymer technologists and, at the same time, are compatible with the structure of the underlying knowledge.

(3) To devise suitable schemes for courses which would enable the students to fulfil their needs according to their educational background, aspirations and aptitudes, and which would also ensure that industry receives a continual supply of suitably qualified manpower.

(4) To develop a set of unified educational aims and objectives, for each area of study, portraying the desirable behaviours of competent practitioners who may be designated as graduates and professionals respectively.

(5) To identify those subjects and topics within the field of polymer technology which may be treated in an integrated manner in order to maximise students' learning, and to examine the possibility of extending such integration into the general field of materials technology.

3.2 A procedure for the diagnosis of needs

The scope for examining the needs in a curriculum analysis is very wide and the procedures adopted are determined largely by the particular situation which is being considered. The general scope is towards the needs of the community in which the student will participate on completion (and during) his studies and the needs of the individual before, while and after he is being educated. Needs may, however, arise from increased knowledge in a particular area of study which may demand restructuring the approach to a subject. The community, in this case, may be identified with the industrial sector and all its subordinate institutions engaged in activities connected with manufacturing, utilizing and providing services on polymeric materials, products, equipment and auxiliaries.

The needs of individuals prior to entering a course are more difficult to assess, but by-and-large these are determined by their aspirations and particular aptitudes. It is particularly difficult, of course, to deal with 'simple' aspirations such as to secure a better "living" and with aptitudes which have been measured solely on the basis of performance in school examinations.

Intermingled with needs are the demands of both individuals and industry and the two are often undifferentiable, and even if they can be distinguished, it is difficult to deal with them separately or to put them into the right perspective.

The 1965 Committee on the "Triennial Manpower Survey of Engineers, Technologists, Scientists and Technical Supporting Staff" made the following distinction between the needs and demands of industry (51). "Demand" was defined with respect to the community's (the employer's) willingness and ability to pay for services. Thus one may speak of a demand for more qualified teachers, meaning that if more were available they would actually be offered teaching jobs.

"Need" was defined in relation to the stated objectives of an organization and community. At any time, the scale and composition of a country's productive activity, the stage of its technological and managerial evolution, and its national economic objectives, give rise to a postulated need for highly qualified skills in order to sustain the economic technological and cultural progress. Thus one may speak of the need for more qualified computer personnel to make a more economic use of computers in industry.

In the evaluation of needs and demands one must bear in mind that the process of technological evolution brings about changes in jobs. Those formerly carried out by crafstmen may well be replaced by others demanding more sophisticated skills, and jobs previously done by technicians may be replaced by higher qualified manpower (e.g. technologists). In addition to changes in the level of education for the new entrants, the technological change may create needs and demands for retraining existing qualified manpower. Therefore it would appear that industrial needs and demands should be reviewed from time to time, and teaching curricula and course organization would have to be revised accordingly. The difficulty of identifying and dealing separately with demands and needs makes it essential to take into account the industrial requests for certain types of qualities in new recruits, and to analyse the type of skills which are deemed to be necessary by the practitioners.

The latter approach, however, will only provide reliable data if the types of behaviours are stated in somewhat specific terms. Otherwise errors may arise from inadequacy of previous training (44), and from a natural antagonism on the part of those, from whom information is to be obtained, towards any changes which they fear may threaten their own position.

The scope of the diagnosis of needs in curriculum development covers also an appraisal of the performance of past-students who have had the opportunity of relating their education to 'real' life (45).

Consequently as a first step it would seem appropriate to consider the following factors:

(1) What proportion of the whole British industry is involved in production, processing, utilization of polymeric materials, and supplying auxiliary chemicals and equipment.

(2) How is the industry structured and how does it merge with other industries., and what changes are likely to take place in future.

(3) What are the tasks of practitioners dealing with polymeric materials and what areas of study are relevant to their job.

(4) What are the opinions of practitioners and past-students whose academic background is known to the writer.

(5) What type of manpower industry seeks to fill new posts.

An outline of the possible sources of information and methods proposed to obtain the data is shown in Fig. 3.1 below.

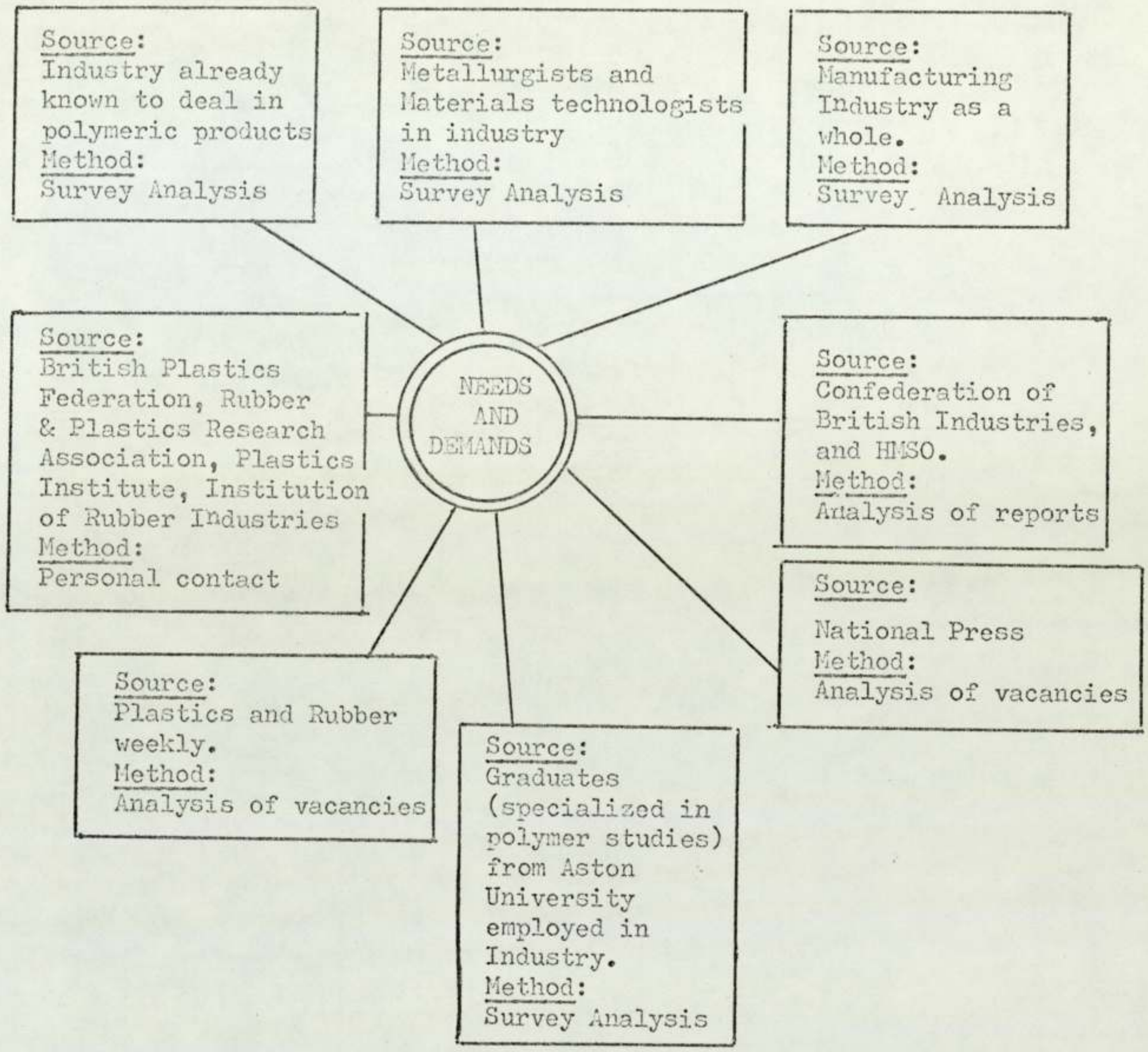


Fig. 3.1

Possible sources of information to establish needs and demands of industry for qualified manpower possessing expertise in polymer technology.

3.3 A procedure to establish curricular structure and aims of courses containing polymer technology units

The curricular structure of courses containing polymer technology units, obviously, has to be determined by the aims inferred from the analysis of needs.

The problem of choice of curriculum models hinges around some of the questions put forward in Chapter 1, such as:

a) Are the aims of the courses concerned to produce professional technologists, either polymer specialists or general materials technologists?

b) Is polymer technology to be included in a course to provide problem-solving examples concerning the production and/or utilization of materials?

c) What are the student's competences and aspirations at the entry and intermediate stages of a course?

In terms of philosophy of education it would seem that the first choice may be compatible with the philosophy of an 'eclectic' educator, the second may bear some relationship to the philosophy of a 'relativist' and the third is probably in line with the doctrines of a 'traditionalist'. Considerations of the philosophies of education will not be taken further owing to the conviction held by curriculum development experts that they are not amenable to derivation of tangible educational objectives. Consequently Dressel's models, which have already been used in the analysis of existing courses, p. 3 will be used for the selection of suitable curricular structures and aims of courses. Considerations will be restricted, however, to those models which are applicable to the British educational framework. The so called 'elective model' and the 'individual tutorial' scheme will therefore be discarded a priori because they are not capable of implementation.

The 'dewy-eyed', the 'outreach' and the 'theme' models will be grouped into a single one owing to the similarity of educational rationale which they convey. Similarly the 'pedantic pattern' and the 'saintly conception' will be considered as one single model.

The 'flexibly-rigid' and the 'integrated' models appear to be more concerned with administrative and evaluation procedures, which fall outside the scope of this investigation.

Although various investigations have been put forward as to the meaning of a vocational education (12, 13), for the purpose of this investigation a vocational curriculum in polymer technology is taken to indicate that it commits the student to employment in those sectors of industry and allied organizations dealing with the development, production and utilization of polymeric compositions and auxiliary materials, equipment and components.

The interpretation of Oakshott (13)

"What is being studied in a vocational education is a literature or a text rather than a language"

is taken, on the other hand, only as a warning against teaching details of techniques in a narrow and specialized manner ("the text") and not as a denigration of the concept of preparing students for a range of closely related occupations.

The structure of a course will be characterized vertically in terms of grades (or levels) of achievement and horizontally by its units or areas of study. The grades will be determined on the basis of the position that the prospective holders would occupy in industry and the types of tasks which they are likely to perform. The course structure will be devised also in such a manner which allows a student to progress through various stages or to terminate his studies on achievement of a grade. Three levels of achievement are envisaged:

a) Technician, b) Graduate and c) Professional technologist. The horizontal organization of a course structure will be divided into main, subordinate and optional units.

The main units form the backbone of the course structure and convey the basic concepts, ideas and learning experiences necessary for the achievement of major objectives. The function of the subordinate units is to provide the student with the necessary skills to advance knowledge on specific aspects of the main areas of study. The purpose of optional units, finally, is to provide a broad education, and for re-orientation of studies towards other professions or qualifications should the student's aspirations and needs change. The specifications of levels of competences for the subordinate and optional units is considered, however, to be outside the scope of the present investigation and will not, therefore, be subjected to further consideration.

3.4 A procedure for the formulation of educational aims and objectives

Some criticisms have been voiced against the practice of specifying behavioural objectives (55). Atkin (56), for instance, wrote:

"The fundamental problem as I see it, lies in the easy assumption that we either know or can readily identify the educational objectives for which we strive, and thereafter the educational outcomes that result from our programs".

These criticisms lose validity immediately when they are compared with some of the convincing arguments, such as the one by Krathwohl (57):

"We cannot predict all situations the student will encounter or all the situations to which he should be able to transfer the behaviours, but we can specify a currently known sample".

Popham (58) has analysed most criticisms expressed in opposition to objectives stated in terms of measurable learning behaviours and has demonstrated their invalidity by means of practical examples.

The writer is convinced, therefore, that the many arguments put forward in favour of stating educational objectives by far outweigh those fewer against. Although one recognises that there are problems in clearly identifying objectives, no reason can be found which would suggest that by means of some suitable procedures one should not, at least, add some clarification to the present curricula containing polymer technology units. Furthermore the writer has observed that the majority of students analyse past examination papers to predict likely examination questions, which must point to the deficiency of the existing practice of not stating clearly to the student what is to be learned. An ad hoc experiment carried out with the students in the MSc course in "the chemistry and technology of polymers" at the University of Aston revealed that the students are in favour of receiving a list of educational objectives, since this would spare them wasting time, and obviating uncertainties, in trying to anticipate the examiner's expectancies.

From consideration of the Jenkins-Deno model for categorizing objectives, it is clear that what is needed is to devise a procedure by which objectives can be established at different levels of abstraction. One can state these objectives at first level of abstraction simply by elaborating global objectives, i.e.

> "To prepare students for their subsequent life in the community which is most likely to be the industrial sector".

This implies that whilst it is not expected that education should prepare a student specifically to work in industry, it is essential that it should develop his full potential for a career in a technology controlled society. There is no reason therefore why education should not use real-life examples to achieve this aim (48).

Obviously these objectives are at the highest level of abstraction in the context of a polymer technology curriculum, and are to be considered as the ultimate goals. Any type of abilities specified at this level is also very abstract, as for instance (49):

(1) Ability to carry any task to an acceptable conclusion within a time constraint.

(2) Ability to draw information from many sources and to select what is useful.

(3) Ability to make good decisions even on insufficient data.

In order to progress to the second level of objectives, and only here is it possible to begin to formulate verifiable hypotheses, it is required to know (a) what types of industry one is dealing with (procedure outlined in section 3.2) and (b) what types of tasks, stated in general terms, graduates are likely to perform in indubtry. Objectives at this level must be sufficiently specific to enable the identification of responsibilities to be clearly made, but at the same time the level of abstraction must be such that they would apply equally well to graduates in a completely different type of industry.

In other words, any type of abilities developed at this level could be classified as 'general abilities' in so far as they transcend the possession of specific knowledge. Other research workers (50) have used a questionnaire method circulated to engineers in industry. From a check list containing a very large number of 'likely' abilities they were able to identify and group together those deemed to be the most important.

Because of the fairly high abstraction of objectives at this level, however, the questinnnaire method may not provide sufficiently accurate data (51). In other words the respondents may just tick off items in a hurry, without due reflection on the implications of the question they are being asked, and therefore the results may consist of a random collection of data which may add confusion rather than elucidation.

The procedure which has been suggested in order to determine objectives at this level consists of a 'brain storm' session with colleagues (44, 51) experiencing similar difficulties, and discussions with selected groups, mostly experienced practitioners. A further source is, of course, the literature since objectives at this level must be applicable to other occupations or other types of industrial employment.

To establish objectives of greater specificity, various research workers (44, 52, 53, 54) have adopted a questionnaire procedure in which the practitioners were asked to make judgements, by 'forced-choice technique' over a wide range of potential performances expected in the occupation specified, or to tick-off those subject topics which are most widely used in their job.

This procedure is often known as the "Magerian Method" (36).

Some of these workers (52, 53) developed a course structure in which the amount of time devoted to a particular subject (corrected by means of a weighting factor) was proportional to the degree of importance assigned to it by the practitioners. These workers, however, did not make use of the principles of curriculum development in their approach, and consequently were only able to specify subject titles for the particular courses rather than terminal behaviours which are expected to result from studies of the subjects specified.

The Magerian method appears to be the most accurate procedure for establishing desirable behaviours at fairly specific levels and therefore it is proposed for use in this investigation to determine objectives at levels III and IV of the Jenkins-Deno model.

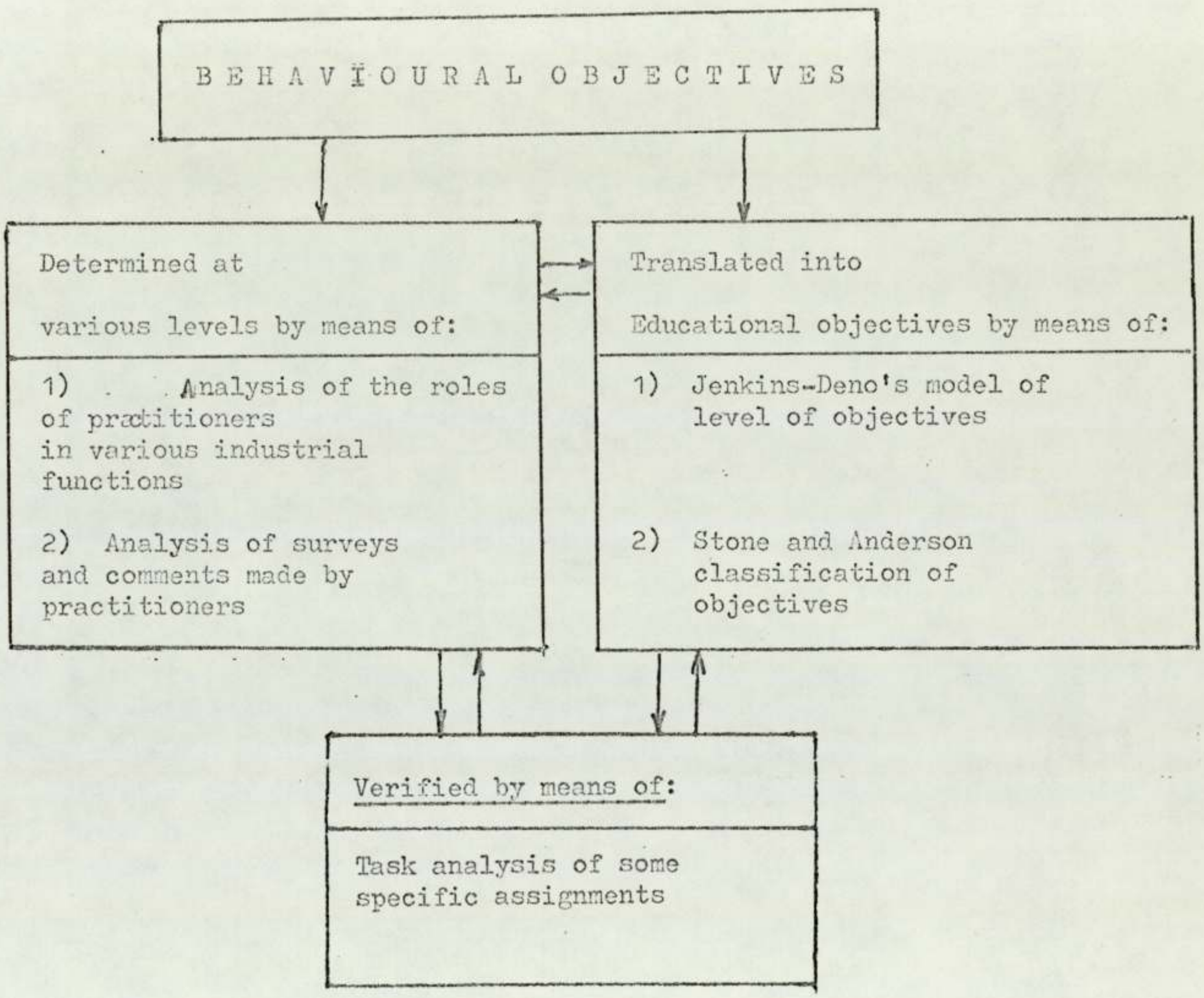
It is proposed that objectives be organised into a hierarchical structure based on the adaptation of Bloom's taxonomy and Gagne's categorization of learning behaviours by Stones and Anderson. This procedure is to be preferred for technological and professional curricula in general, in so far as it stipulates that objectives should be specified in terms of behaviours directly connected with the activities of practitioners rather than presenting them, as it is often the case, as statements of behaviours to be learned from a specific set of instructions, which may be more conveniently referred to as instructional objectives (see p. 29). In other words, at this stage of the curriculum design, although one has to take into account the fact that the stated behaviours have to be acquired from specific courses of instruction, one is not in a position yet to anticipate how the instructions are to be carried out and, indeed, whether they are achievable in practice without some modifications.

After having established the types and levels of objectives purely on the basis of the writer's competences in the field, their validity will be tested by means of task analysis on a selected number of problem solving exercises.

A model for the scheme proposed to determine the behavioural objectives for each area of study considered is shown in fig. 3.2.

Fig. 3.2

A model of sources of information and methods for derivation of educational objectives.



3.5 A procedure to establish the desirability and feasibility of integration of polymer technologies.

The idea of integrating contents from various disciplines or subjects as already pointed out, is not at all new, in fact curriculum integration is fairly common practice in both primary and secondary education.

At tertiary education level, on the other hand, there are only a few cases where this has been attempted, mainly as a result of recommendations made by various committees on the need for graduates to be 'more broadly trained'. (59, 60).

It is difficult to assess to what extent the subject matter of these courses is being integrated or whether they merely cover a wider range of subjects than the more traditional single discipline courses. Taba (61), in fact, stresses that the chief obstacle to 'integrated' curriculum is the fact that "it is rather difficult to plan an integrated curriculum adequately, and to teach it competently".

The faculty of St. Olaf College (61) points out that integration can be achieved only through acceptance of common educational objectives. These objectives must be both limited in number and general enough to apply to all the disciplines or fields of studies concerned. (This has also been pointed out in earlier sections of this chapter). Consequently, in order to establish to what extent it is both desirable and feasible to integrate the subject matter of polymer technology within the various polymeric products technologies mentioned and within the whole spectrum of materials technologies, at least two factors must be considered.

(a) Whether and how the integration of the technologies of these materials in a curriculum would better satisfy the needs of both industry and students,

(b) whether there are sufficient common elements in these various technologies, which would enable such integration to be made at an acceptable intellectual level (established on the basis of the complexity of problems which may be solved by a unified approach).

The first aspect can be dealt with by finding out whether there are graduates who are already working on more than one of the materials technologies mentioned and/or whether graduates are employed in a product technology different from that in which they have received formal education. Circulation of questionnaires to practitioners in industry and task analysis are undoubtedly the most adequate procedures to obtain this type of information and therefore it will be used as the basis for establishing needs.

The second aspect of integration can only be dealt with through a study of the literature. The feasability of integration would be judged on the availability of evidence that there are theories, concepts and procedures in one product technology, which can be applied to others without distorting the original concepts and/or questioning the validity of established procedures. Therefore it is a matter of identifying the major topics which would provide the backbone structure, i.e. the unifying threads, and to use these as the basis for integration of ideas across the various areas of studies in question. In so doing one must clearly distinguish between the basic concepts and those more specific or detailed items whose scope and responsibility may fall outside the areas of studies considered. Details on instrumentation to monitor certain behaviour may fall, for instance, in this latter category.

CHAPTER 4

EMPIRICAL EVALUATION OF THE NEEDS OF INDUSTRY AND OF THE ROLES OF POLYMER TECHNOLOGISTS

4.1 Involvements of the British manufacturing industry in polymeric materials

The first step of this analysis consisted of a survey carried out over the whole of the manufacturing industry in Great Britain in order to establish:

(a) what percentage of the industry is involved in either manufacture, handling etc. of polymeric products,

(b) to what extent industry deemed it necessary for their technologists to be experts in polymer technology,

(c) the type of background of their technologists involved with polymeric materials.

The name and address of 900 firms were taken at random from the Kelly's directory (1971) of manufacturing industries (2 firms for every page of the directory were taken, retailers and sales agencies were excluded). It was not considered necessary to classify or subdivide these firms in any way since the scope of this survey was meant to be speculative rather than to provide data for statistical inference purposes. In order to ensure a high percentage of respondents it was decided to draw up a very short questionnaire for which the answers were of the 'yes/no' or 'tick' types. Because of the industrial recession at this time (year 1972) which caused a large number of graduates to be made redundant, the questions were carefully drawn to avoid any phrases which might have been interpreted by senior industrialists that universities were contemplating producing more unwanted graduates. Also no attempt was made to specify the level of education of technologists involved for reasons given in section 2.3.

Pilot study: In order to test the response of industry a pilot survey was carried out on 20 firms, of which the activities of 10 firms were not known to the writer, whereas of the remainder, 5 were known to be involved with polymeric materials and the other 5 were not. Each questionnaire was addressed to the managing director of the company and was inconspicuously marked for identification on return. From the 13 answers received it was quite evident that the respondents had no difficulty in interpreting the questions and that the return of questionnaires was from a random section of the population. Consequently its format was retained and circulated to the remainder of the firms.

Main study: The layout of the questionnaire used is shown in Appendix I. A total of 487 questionnaires were returned, but of these only 457 were analysed. The remaining questionnaires were not answered and included firms which had changed addresses, ceased business or simply refused to have anything to do with the survey. One industrialist stated bluntly: "When you tell us what you mean by 'Polymer Technology' we shall answer the questionnaire. Our company manufactures diaphragm membranes for pumps operating over the temperature range of -150°C to +300°C."

A letter was then sent to the firm explaining the purpose of the exercise together with a reprint of an article which had recently been published by the writer jointly with a colleague, entitled: "What are we trying to do? Teaching and research in Polymer Technology". Despite the subsequent acknowledgement and encouragement by phone from the managing director and the confirmation that the firm was using polymeric materials, the questionnaire was not returned and therefore was not included in the answers received.

The answers to the questionnaire are shown below in tables 4.1, 4.2 and 4.3.

Table 4.1

Survey of the British manufacturing industry

Answers to the question: Indicate whether your company deals to any appreciable extent in polymeric materials.

	Yes	No	Total
Samples analysed	$N_Y = 167$	$N_N = 287$	$N_R = 454$
Proportion of answers and percentage of sample analysed	$\frac{N_Y}{454} \times 100 = 36.5\%$	$\frac{N_N}{454} \times 100 = 63.5\%$	$\frac{N_R}{N_Y+N_R} = 100\%$
Proportion of answers as percentage of total no. questionnaires sent out	$\frac{N_Y}{900} \times 100 = 18.3\%$	$\frac{N_N}{900} \times 100 = 21.8\%$	$\frac{N_R}{900} \times 100 = 50.5\%$

Therefore assuming that the 454 questionnaires examined are a 'true' sample of the whole of British industry it will be inferred that 36.5% of firms are dealing with polymeric materials. If the extreme view is taken that all those firms which had moved, ceased business or not returned the questionnaire were not involved at all in polymeric materials, a conservative estimate of 18.3% will result.

Even if the true figure is between 18.3 and 36.5% there can be little disagreement as to the widespread involvements of industry with polymeric materials.

Table 4.2

Survey of the British manufacturing industry

Answers to the question: Indicate whether and the extent to which expertise in polymer technology is available or desirable in your company.

	Degree of expertise		
Total	Considerable	Marginal	Not at all
N = 167	N_C = 55	N_M = 99	N_{NA} = 13
N = 100	$\frac{N_C}{167} \times 100 = 33.0\%$	$\frac{N_M}{167} \times 100 = 59.4\%$	$\frac{N_{NA}}{167} \times 100 = 7.6\%$
N = 454	$\frac{N_C}{454} \times 100 = 12.1\%$	$\frac{N_M}{454} \times 100 = 21.8\%$	$\frac{N_{NA}}{454} \times 100 = 2.8\%$

The large proportion (59.4%) of respondents indicating that only a marginal expertise in polymer technology was required in their company could be partially attributed to the fact that judgement was made on the basis of the level of qualifications and expertise of the manpower employed at present.

This can be illustrated by some of the comments made by the respondents in this category, e.g.:

(1) "We are interested in people with a knowledge on formulation and compounding of PVC pastes and properties of plastics for injection moulding of safety equipment components".

(2) "We expect the materials suppliers to provide us with the necessary know-how".

Table 4.3

Survey of the British manufacturing industry

Answers to the question: What is the background of your technologists involved with polymeric materials.

Educational background	Firms which indicated that considerable expertise was required (%)	Firms which indicated that marginal expertise was required (%)
Chemistry	39	20
Mechanical Engineering	24	39
Chemical Engineering	18	10
Physics	16	5
Electrical/ electronics engineering	5	11
Others (specifically: metallurgists, ceramics technologists)	-	9
None	-	7

It is also worth noting that in a recent survey published by the Royal Institute of Chemistry (63) it was found that a substantial proportion of chemists were employed in polymer -based industries; the statistical data given were in fact:

Food and allied products	= 13%	
Energy (gas, electricity, atomic, coal, etc.)	= 8%	
Plastics	= 8%	20%
Paints and dyes	= 7%	
Fibres and textiles	= 5%	

In another survey carried out by N. L. Day of Stafford Polytechnic (64) it was revealed that mechanical engineers were also considerably involved with plastics technology. The relative breakdown of answers to a question about topics most widely used in their employment was as follows:

High and Low Pressure Technology	= 10.5%
High and Low Temperature Technology	= 9.8%
Plastics	= 8.2%
New alloys	= 6.6%

4.2 <u>The structure and demands of industry dealing in polymeric materials</u>

(i) <u>Review of conference papers and literature</u>

The OECD meeting in Paris in 1969 on "Plastics - Gaps in technology" considered the position of "Plastics" in industry and identified two organizational structures, i.e.

(a) Vertically organized enterprises which were primarily producing polymeric products and consequently converting them into finished products. Only few industries could be identified as belonging to this category owing to the lack of financial resources that could be made available for large scale R & D programmes.

(b) Horizontally integrated organizations which merged into larger concerns with diversified markets potentials, e.g. chemical industries, engineering manufacturing industries etc.

It was revealed that owing to the involvement of large international organizations the situation is similar for most industrialized countries.

The vertical and horizontal integration of industries dealing in polymeric products is shown in fig. 4.1.

Fig. 4.1

Vertical and Horizontal structures of industries dealing in polymeric products

A'	Monomers, auxiliaries, additives etc.	A	Petrochemicals
B'	Polymers, polymeric compositions etc.	B	Chemical plants, construction etc.
C'	Fabrications, components manufacture etc.	C	Machinery, tools, general handling equipment etc.
D'	End uses, e.g. packaging, building products etc.	D	Engineering manufacture: electrical, mechanical, etc.

← Vertical integration →

← horizontal integration →

From Fig. 4.1 it is evident that what may be designated as the 'polymer-based' industry includes largely sectors B' and C' but polymer technology expertise is also required in sectors A', D', C and D, though the emphasis may be different in the various cases. D. S. Davies at the PINTEC Conference in 1972 (65) pointed out that the increasing capacity of polymerization plants and the rising costs of oil and petrochemicals (this statement was made prior to the oil crisis) necessitates a better utilization of existing materials and, therefore, a higher investment in the processing and end-use developments. He quoted: "the real question now is: what can existing polymers do for potential customers and not with what splendid chemistry can we astonish and delight an admiring society?"

His technological forecast was for a greater simplification of engineering processes which would reduce conversion costs to enable polymers to compete with cheap traditional materials such as wood, bricks, concrete, etc. The new role of a plastics technologist was seen as one of "taking from engineers but not become engineers". It is also worth noting that in recent years many engineering companies have set up special 'Plastics' or 'Polymer Engineering' divisions within their organizations in order to increase their know-how in the technology of these 'new' materials . An increasing amount of in-plant operations, e.g. compounding, is also taking place in these organizations.

The NEDO report (66) also forecast further integration of 'polymer-based' industries with the building, motor, furniture, electrical industries, etc. and it was forseen that this may necessitate an increase in manpower of over 38% for the period 1968-1975 in the processing industries but only about 1.5% in the polymer producing sectors. Furthermore it is anticipated that in the latter case there will be an increased emphasis on market development activities (67).

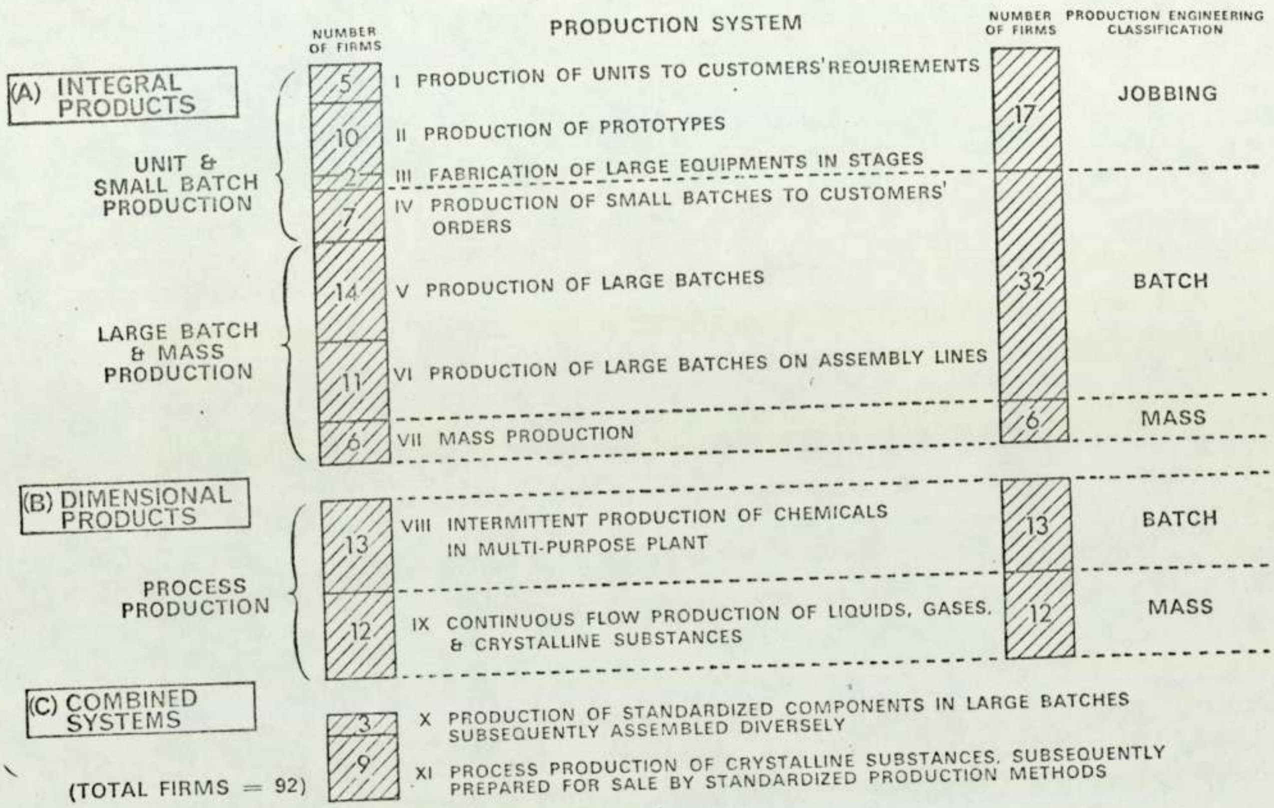
These events tend to indicate that in the near future there will be a need for an increasing flow of polymer technology expertise in the engineering and manufacturing industries.

In order to identify more closely the type of polymer technology expertise required it is worth considering in somewhat more detail the organizational structures and activities of both horizontally and vertically integrated enterprises.

Woodward et al. (68) made a careful examination of the industry in South Essex and classified the type of firms involved, on the basis of production systems used, into: a) unit and small batch production, b) large batch and mass production, and c) process production. Their relationship to types of operation is shown in fig. 4.2.

Fig. 4.2

Production systems in South Essex Industry (68)



These researchers suggested that these production systems may be typical of the whole of British Industry. A comparison with the structure shown in p. 66 would suggest that by and large the chemical sector, i.e. petrochemicals, polymer producing concerns can be identified with the process production type of organization. The difference between production of polymeric systems and auxiliaries is with respect to the type of product only; the methods and raw materials involved being quite similar.

The processing industry as such, that is that branch of the industry which at present consists largely of trade moulders, on the other hand, can be partly identified with what is generally known as the manufacturing industry, and partly as an industry with its own characteristics.

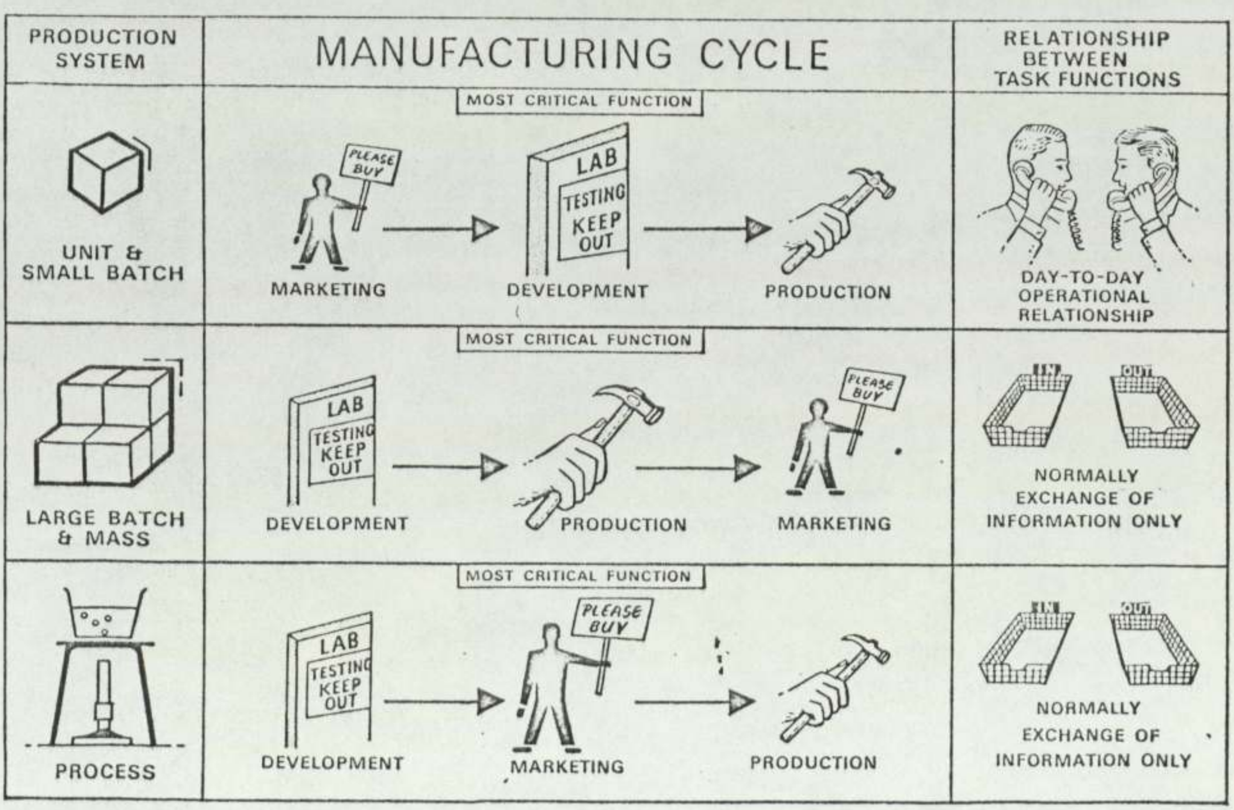
Woodwards et al. recognised that irrespective of the type of production, the whole of the industry has the same functions which consist of marketing, development and production. Finance could be added to these functions but it would be too difficult to include it into unified framework, hence for the purpose of this investigation it will be excluded.

The only difference between the various types of organization that these researchers could find was in the manufacturing cycle and in the relationship between the various task function.

This difference is shown in fig. 4.3, where it can be seen that the critical functions are respectively: development for unit and batch production systems, production for the large batch and mass production systems, and marketing for the process production systems.

Fig. 4.3

Characteristics of production systems (68)



Although the above classification was arrived at on the basis of observations made over the decade 1953-1963 and some technological changes may have occurred over the last decade, it is doubtful whether these changes are of an order of magnitude which would distort the picture given above.

On the contrary, as far as the chemical sector is concerned, from the words of D. S. Davies of I.C.I. at the 1972 PINTEC conference "The chemist must come nearer to the market", it would appear that the picture in fig. 4.3 is reinforced. Neither is any form of integration of the processing industry with the manufacturing industry likely to alter their position as unit and small batch production or as large batch and mass production systems.

Any change in these industries is likely to be a quantitative rather than a qualitative one; trade moulders, for instance, could simply become the production unit of larger concerns so that development and marketing functions would be more effectively carried out.

(ii) Survey of vacancies in the polymer based industries

To assess the demands and needs of these industries for qualified man-power possessing special expertise in polymer technology an analysis was made of vacant positions advertised in the Plastics and Rubber Weekly over the year 1973.

The subdivision of appointments shown in table 4.2 was arrived at after considering the types of advertisements which appeared in the first 10 week period of the survey. Qualifications or basic discipline background for the posts advertised were not specified in many instances, hence judgement had to be based on the description of the nature of work. For instance, process development was considered to be an engineering technology activity whereas colouring and general compounding activities were deemed chemical technology activities. Difficulties were often experienced, however, in deciding

Table 4.2 Survey of the vacancies in the polymer based industries;

Demands of Industry for the year 1973 as indicated by advertisements appearing in Plastics and Rubber Weekly

(b) Sales Personnel				(a) Technical Service		(a) Production personnel			
Executives and representatives		Management		Materials conversion	Machinery and equipment	Production superintendents		Production managers	
Raw materials and products	Machinery and equipment	Raw materials and products	Machinery and equipment			Chemical technologists	Engineering technologists	Processing and fabrications	Polymers and auxiliaries
376	115	47	7	36	78	50	220	347	2

Research and Development personnel								
(a) Materials and Products					(b) Machinery, tools, equipment, etc.			
Technologists grade			Management grade		Technologist grade		Management grade	
Chemical background	General engineering background	Engineering design background	Raw polymers & additives	Products	Tool design	Machine components design	Tool room	General
331	179	53	2	21	126	27	28	5

Cont:

Table 4.2 continued

(a) Laboratory technicians		(c) General personnel		
Chemical background	Engineering background	Work study	Estimations	Buyers
102	81	23	53	12

Notes:

(a) denotes that specialistic knowledge in polymer technology was deemed to be essential

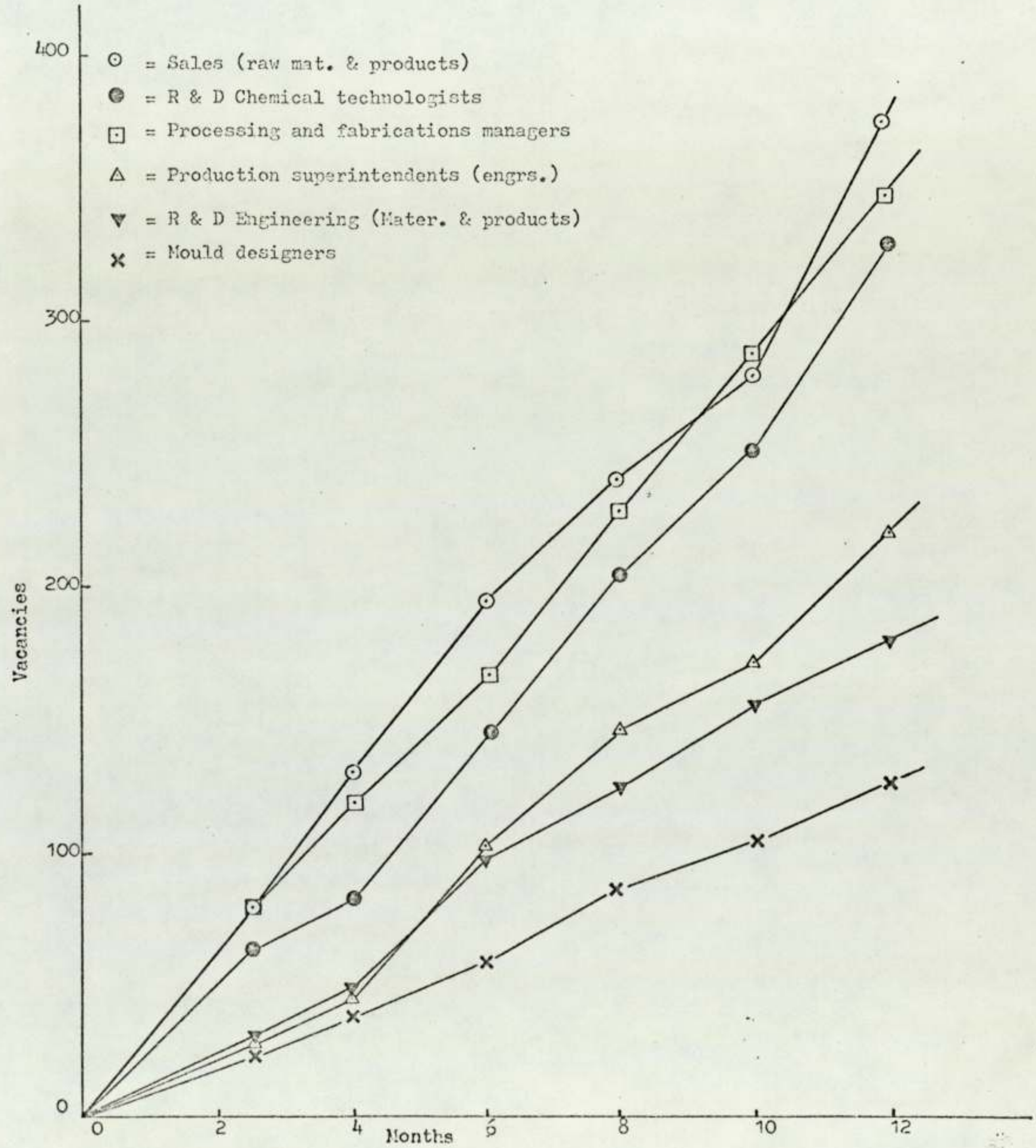
(b) denotes that knowledge of polymer technology was deemed to be desirable

(c) denotes that knowledge of polymer technology was not required.

Fig. 4.4

Survey of vacancies in the polymer based industries:

- Demands for polymer technologists (Advertisements appeared in Plastics and Rubber weekly - over the period Jan 1973 - Dec. 1973)



whether certain activities were to be regarded as a chemical or engineering type. This situation is typified by the following advertisement:

"Product Engineers required to work within our Industrial Product Extension Group, covering Conveyor Belting, Synchronous belting and Sheeting Products. The persons appointed will be directly involved in product innovations, specifications, problem-solving, economic improvement and both supplier and customer contact. Ideally they will be in the age group 20/25 and possess a degree or equivalent qualification in Polymer Chemistry or Engineering or AIRI with engineering background".

These figures do not represent, of course, the demands created by expansion programmes as these may be simply the result of a large turn-over of personnel. This is particularly likely to be true in the smaller industries and for sales and production management positions. If presented in graphical form (Fig. 4.4) it can be seen that the relative demands throughout the year for the various types of personnel shown are relatively constant and that there appears to be an overall greater demand for engineering technologists than chemical technologists. If each class of personnel is considered individually then the greatest demand seems to be for sales and production management functions, whereas for R & D activities a chemical background in technologists is demanded more than an engineering background. This is consistent with the general appraisal that hitherto innovation efforts are greater in the materials producing sectors than in the processing and polymer-using industries. One has to take into account however that, if the NEDO recommendations for a substantial increase in R & D investments in the processing sectors and the words of D.S. Davies ("chemists will have to be involved more with activities directly concerned with customer problems") were to be implemented, the situation could be reversed (65). It is interesting to note that a similar situation seems to exist in USA (69), where, despite the very high proportion of polymer technologists with a chemical engineering background, it appears that by far the greater majority is employed in the polymer producing industry. The polymer processing industry, on the other hand, is compelled to accept an informal education system, e.g. conferences, practical experience, etc. for their man-power.

4.3 Survey of metallurgists in the manufacturing industry

In view of the strong association of the activities of polymer technologists with material science and manufacturing technology revealed by both the surveys of the writer and that of the Plastics Institute of America, (see later) it was deemed necessary to obtain further insights into the role of graduates and professionals within the manufacturing industry. Furthermore, the questions raised in Chapter 1 and the curriculum principles outlined in Chapter 2 have pointed to a need for an investigation into the extent to which the technologists within the manufacturing industry may be involved with activities requiring expertise in a wide range of materials.

It was felt that metallurgists might be the most likely technologists to be involved in such activities in view of the extensive replacement of metals by plastics. In other words, it was thought that it would be more probable to find metallurgists witnessing such a technological change rather than polymer technologists owing to the much earlier appearance of the former within the manufacturing industry.

To obtain the necessary data, a questionnaire (Appendix I) was circulated to 500 members of the Institution of Metallurgists and the Institute of Metals.

In order to assess the desirability of integrating polymer technology with the technology of other materials, opinions were sought as to whether a broad understanding of the behaviour of materials in general might have improved their prospects in industry, and whether they believed that a broad education on general aspects of materials was preferable to studies on single classes of materials.

A total of 235 questionnaires have been returned by the respondents within one month, 37 were returned by the G.P.O. owing to changes of address, and 30 arrived after the data had already been collated. Six of the questionnaires had not been filled in as the respondent felt not to be qualified to give judgement. The analysis of the main batch of questionnaires received (N = 229, i.e. 45.3% of the sample population) and of the late arrived answers (N = 30, i.e. 6.0% of the sample population) is reported below. The two samples have been treated separately in order to assess whether the delay in the return of questionnaires was at all associated with a "negative attitude" towards the survey.

By far the great majority (99.5%) of respondents had received formal education in metallurgy. The answers were subdivided according to age groups in order to determine whether the length of industrial experience influenced the response.

Table 4.3

Survey of metallurgists and materials technologists:

Answers for respondents formally educated in matallurgy (N = 214)

Q. 1 Involvement in plastics or plastics composites to the extent that understanding their nature and behaviour is required.

	Age groups											
	25-35				36-45				over 45			
	Yes	No	No answer	Total	Yes	No	No answer	Total	Yes	No	No answer	Total
Number	26	62	-	88	25	35	1	61	24	39	2	65
% within the groups	29.5	70.5	-	100	40	58.3	1.7	100	37.0	60.0	3.0	100
	Total involvement = 34.7%											

Q. 2 Involvement in other forms of polymeric materials, e.g. surface coatings, adhesives etc.

	Age groups											
	25-35				36-45				over 45			
	Yes	No	No answer	Total	Yes	No	No answer	Total	Yes	No	No answer	Total
Number	38	49	1	88	31	30	-	61	32	31	2	65
% within the groups	43.4	55.8	0.8	100	50.8	48.2	-	100	49.2	47.7	3.1	100
	Total involvement = 47.3%											

Q. 1 and Q. 2 combined. Involvement in plastics and other polymeric materials.

	Age groups											
	25 - 35				36 - 45				over 45			
	Yes	No	No answer	Total	Yes	No	No answer	Total	Yes	No	No answer	Total
Number	19	42	1	88	18	24	-	61	20	26	2	88
% within the groups	21.8	48.0	0.8	-	29.5	39.3	-	-	30.8	40.0	-	-
	Total involvement in plastics and other forms of polymeric materials = 26.8%											

Table 4.3 (continued)

Q.3 Opinions on whether a broad understanding of materials in general, acquired through formal education, might have improved prospects in industry.

Distribution of opinions	Age groups							
	+25-35		36-45		over 45		overall	
	N	% of total	N	% of total	N	% of total	N	% of total
Yes when answer to Q.1 and Q.2 is also Yes	30	34.2	23	38.3	25	38.5	78	36.6
Yes when answer to Q.1 and/or Q.2 is No	27	30.7	11	18	9	13.7	47	22.1
TOTAL Yes	57	64.9	34	52.4	34	52.4	125	58.7
No when the answers to Q.1 and/or Q.2 is Yes	5	5.7	7	11.5	5	7.7	17	8.0
No when answers to Q.1 and/or Q.2 is also No	9	10.2	5	8.2	13	20	27	12.6
Total No	14	15.9	12	19.7	18	27.7	44	20.6
Don't know	17	19.2	15	24.0	13	20.0	45	20.7
GRAND TOTAL	88	100	61	100	65	100.1	214	100

Q. 4 Opinions on whether a broad education on general aspects of materials is preferable to studies on single classes of materials

Distribution of opinions	Age groups							
	+25-35		36-45		over 45		overall	
	N	% of total	N	% of total	N	% of total	N	% of total
Yes when answer to Q.1 and/or Q.2 is also Yes	34	38.5	30	49.3	26	40.0	90	42.0
Yes when answer to Q.1 and/or Q.2 is No	34	38.5	16	26.3	17	26.2	67	31.2
YES TOTAL	68	77.0	46	75.6	43	66.2	157	73.2
No when answer to Q.1 and/or Q.2 is Yes	8	9.2	3	4.9	7	10.8	18	8.4
No when answer to Q.1 and/or Q.2 is also No	6	6.9	5	8.2	6	9.2	17	8.0
NO TOTAL	14	16.1	8	13.1	13	20.0	35	16.4
Don't know	6	6.9	7	11.3	9	13.8	22	10.4
GRAND TOTAL	88	100	61	100	65	100	214	100

Note: +Denotes that 3 respondents were under 25 years of age.

Analysis of answers of respondents not formally educated in metallurgy (N = 12)

Owing to the small number of respondents in this category the answers have not been divided according to age groups. The response of non-metallurgists can be summarised as follows:

(i) Total involvement in plastics materials = 50.0%

(ii) Total involvement in other forms of polymeric materials = 83.5%

(iii) Total involvement in plastics and other forms of polymeric materials = 50.0%

(iv) Opinions on whether a broad understanding of materials, acquired through formal education, might (or may) have improved prospects in industry:

Yes = 50.0%

No = 33.1%

Don't know = 11.7%

(v) Opinions on whether a broad education on general aspects of materials is preferable to studies on single classes of materials

Yes = 83.6%

No = 8.2%

Don't know = 8.2%

Analysis of late arrived answers

Because of the small number of respondents in this group, the answers have not been classified according to age group. Only one respondent did not receive formal education in metallurgy (3.7%). The results of the analysis of the answers of this group of respondents is shown below.

Table 4.4

Survey of metallurgists and materials technologists:

Analysis of late arrived questionnaires (N = 30)

Q.1 Involvement in plastics or plastics composites to the extent that understanding their nature and behaviour is required.

	Yes	No		Total
Number	11	19	0	30
% within the group	36.7	63.3	0	100

Q. 2 Involvement in other forms of polymeric materials e.g. surface coatings, adhesives, etc.

	Yes	No	No answer	Total
Number	16	13	1	30
% within the group	53.0	43.7	3.3	100

Q. 2 and Q.3 combined. Involvement in plastics and other polymeric materials

	Yes	No	No answer	Total
Number	11	12	1	30
% within the group	36.7	63.3	3.3	100

Table 4.4 (continudd)

Q. 3 Opinions on whether a broad understanding of materials in general, acquired through formal education might have improved prospects in industry.		
Distribution of opinions	N	%
"Yes" when answers to Q.1 and/or Q.2 is also "Yes"	7	23.3
"Yes" when answers to Q.1 and/or Q.2 is "no"	7	23.3
"Yes" Total	12	40.0
"No" when answers to Q.1 and/or Q.2 is "yes"	5	16.7
"No" when answers to Q.1 and/or Q.2 is also "no"	4	13.5
"No" total	9	30.0
Don't know	7	23.3

Q. 4 Opinions on whether a broad education on general aspects of materials is preferable to studies on single classes of materials		
Distribution of opinions	N	%
"Yes" when answers to Q.1 and/or Q.2 is also "Yes"	11	36.7
"Yes" when answers to Q.1 and/or Q.2 is "No"	8	26.7
"Yes" Total	17	56.8
"No" when answers to Q.1 and/or Q.2 is "Yes"	4	13.3
"No" when answers to Q.1 and/or Q.2 is also "No"	2	6.7
"No" total	6	20.0
Don't know	5	16.6

A comparison of these data with those obtained on the main group of respondents reveals that overall the answers do not differ significantly. There was, however, a slight decline in the type of answers which supported a broad approach to studies of materials.

Analysis of comments made by respondents

A few comments have been made by the respondents, either by a letter attached to the questionnaire or as a short qualifying sentence adjacent to their answer. Most were elaborating on question 4 and some examples of the comments made are given below:

"I am currently a Blast Furnace Manager and therefore it is important for me to understand the chemical and physical processes involved. Thus formal education in metallurgy/chemistry is essential. However, I have also had to cope with problems associated with wear on shutes, belts, etc. made of polymeric materials. Very often these materials have failed because of the lack of understanding of their basic properties. "

Several people commented that whereas a broad education in general aspects of materials, possibly initially, is desirable it is equally necessary to provide some degree of specialised education on single classes of materials, e.g. metals, polymers, ceramics.

Others emphasised the importance of breadth in education, as for instance:

"I feel that a specialized knowledge on specific materials can only be acquired in industry and not at the Tech."

"A better breakdown of materials properties and their handling is necessary".

"Provided it is broad and precise and not broad and woolly".

"I have been a practising metallurgist for over 5 years and therefore feel unqualified to answer your questions. As a recruiter of graduates to a management training scheme I would subscribe to the concept of a broader approach".

From the above data the following conclusions can be drawn:

Metallugists are strongly involved with polymeric materials. The involvement is significantly more with surface coatings and adhesives than with plastics.

The older members are somewhat more involved with plastics than the younger ones.

There is a strong feeling among metallurgists that a broad understanding of materials in general improves the prospects of technologists in industry.

A broad education on general aspects of materials is considered to be preferable to specialized studies on single classes of materials. A few respondents, however, expressed the opinion that specialization may be still desirable at some later stages of a course.

4.4 The activities of graduates and professionals in the traditional polymer based industry

In order to clarify the position of polymer technology as a subject of study and its relationship to polymer science and engineering it was deemed necessary to consider the views of graduates and professionals in industry and to reap the benefit of their judgement on somewhat specific matters related to both their work and previous education. It was decided to make this analysis in two steps. First a pilot survey by means of a questionnaire (Appendix 1c) was made using a sample of graduates of this University who have taken a course with polymer technology content. The results of this survey were then used to modify, as deemed appropriate, the questionnaire format for a second survey which included a much larger sample, and therefore also a wider range of both academic background of technologists and industrial activities involved (Appendix 1d).

In compiling the questionnaires, the views of post-graduate students, who had spent some time in industry, were taken into account. There seemed to be a general consensus that the use of nominal variables to describe orders of magnitude, e.g. "highly relevant", "moderately relevant", "some relevance" and "no relevance" was to be preferred to numerical designations such as "1 to 5", where 5 is highest and 1 is lowest. Furthermore, having been made aware of the pit-falls of questionnaires by the words of Burroughs (100):

> "Even if the instrument has been made with the utmost care, with due concern for defining purposes, establishing categories, items, recording and coding systems, the recipient is rarely in a highly joyous state in receiving it, and his motivation to respond carefully and honestly, if at all, is low,"

and by the experience of a previous survey (see comments in p. 63 for instance), the writer took the view that the surveys could only be speculative.

It was also decided to use weighting factors to quantify the nominal variables according to the importance attached to a particular answer and to check at random their validity by comparing the results against those obtainable with alternative weighting factors.

4.4.1 Survey of B.Sc. and M.Sc. graduates in the "Chemistry and Technology of polymers" from Aston University

The B.Sc. and M.Sc. structure of these courses can be identified with the model in fig. 1.2. The only significant differences between the two courses are level of chemistry of the entrants and the length of the project involved (approximately 40 and 90 days of practical work for the B.Sc. and M.Sc. respectively). Furthermore the B.Sc. course contains a chemical engineering unit which is absent in the M.Sc. course; the latter includes, instead, a substantial content of industrial administration.

A random sample of 100 past students, graduated between 1964 and 1971, has been used (approximately 50 students from each course) and a total of 56 answers have been received. Of these, six have not been included in the analysis: three were from teachers who had specifically attended the M.Sc. course to acquire the necessary knowledge for teaching on their own courses (mostly technician and professional courses); one was unemployed at the time and felt that the questions were unapplicable to his situation; one was working for an agency of computers; and the last one was received after the results had been processed and collated. Because of the small number of samples involved and since it was meant to be only a brief survey, a desk calculator was used and statistical tests for significance have been kept to a bare minimum.

(i) Relation between salary, qualifications and job nature

Apart from providing suggestions for modifying the questionnaire for the subsequent survey, the objective of this exercise was to establish whether the employers made a distinction between the two qualification levels both in remuneration and type of job offered. A comparison of the response of these two groups is shown in tables 4.4, 4.5, 4.6 and fig. 4.5, 4.6, 4.7.

Table 4.4

Relationship between salary, year of graduation and qualification

(Questionnaire circulated in Spring 1972)

Salary: (£/p.a.)	Overall salary range	
	1250-3500 + car	1700-3000
Year of graduation	B.Sc.	M.Sc.
1970-1971	1250 - 2000	1700 - 3000
1968-1969	1800 - 3000	1800 - 2500
1966-1967	2200 - 2600	-
1964-1965	2000-3500 + car	2200 - 3000

Notes; (a) Age and experience before graduation may have had significant effect on salary.

(b) The low salary range for graduates between 1966 and 1967 may be due to the low number of respondents in this group.

From the data shown in the table above it is quite clear that employers are not generous in rewarding the extra academic effort made by graduates in studying for an M.Sc., except initially, perhaps due to their age.

Table 4.5

Frequency distribution for the number of times graduates changed their job since graduating and benefit of course taken in obtaining employment (BSc and MSc respondents)

(a) Changing of jobs

	N	%
Never	25	59.5
Once	10	23.8
Twice	3	7.2
Three times	4	9.5
Total	42	100

Table 4.5 (continued)

(b) Reasons for changing job

	N	%
Redundancy	2	7.7
Promotion	7	27.0
Dissatisfaction	11	42.5
Personal reasons	4	15.1
Other reasons	2	7.7
Total	26	100

(c) Usefulness of course in obtaining employment:

	N	%
Yes	40	92.5
No	2	4.6
Don't know	1	2.9
Total	43	100

Table 4.6 Distribution of respondents according to year of graduation, course attended and nature of the business of their company (BSc and MSc)

Year of graduation	graduates number	%
1970-1971	15	32
1968-1969	15	32
1966-1967	6	12.5
1964-1965	11	23.5
Total	47	100

Table 4.6 (continued)

Course attended	Graduates Number	%
B.Sc.	26	55.2
M.Sc.	21	44.8

Nature of the business of company	Number	%
Polymers and Polymeric composition producers	21	44.8
Processers, fabricators, end-users of polymeric products	19	40.2
Others: Petrochemicals, additive manufacturers etc.	7	15.0

Note: the job title description given varied from loose titles such as Chemist and Technical Manager to more specific ones such as Research Chemist, Technical Service Technologist etc.

In order to find out whether and to what extent these graduates were employed in a capacity of scientists or technologists they were asked to state to which of the following descriptions they considered their jobs to be most nearly rdated:

Industrial Chemistry, Manufacturing Technology/Engineering and Physical Chemistry.

The term engineering was used in conjunction with manufacturing technology to ensure that thoe involved in producing polymers were not misled and included themselves in this category. Since none of the respondents considered their work to be in the area of physical chemistry, despite the fact that the majority of the M.Sc. graduates have taken their first degree in pure chemistry, it was inferred that the nature of their job was essentially technological. This may seem somewhat surprising since the greater proportion of the respondents are employed in the chemical sector of industry, where, according to Woodwards et al. (68) and to the writer's experience, there is considerable amount of pure research being carried out. The answers for both B.Sc. and M.Sc. graduates were almost equally divided as shown below.

Table 4.7

	BSc		MSc	
	N	%	N	%
Industrial Chemistry	12	46	11	52
Manuf. Technology/Engineering	14	54	10	48
Total:	26	100	21	100

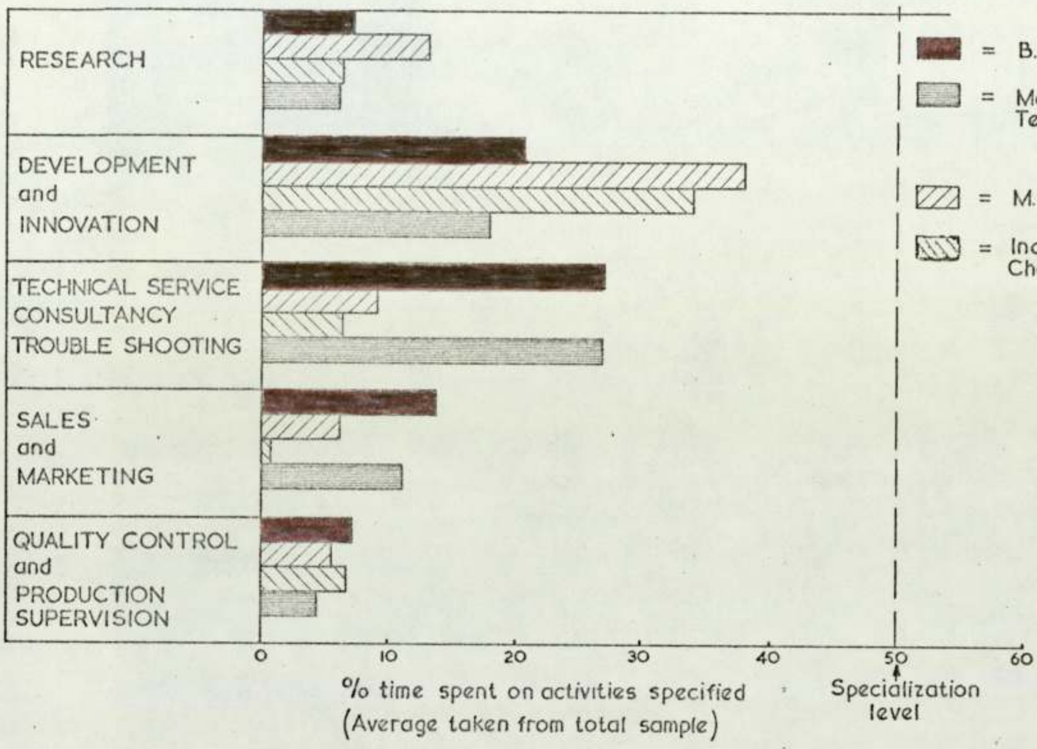
(ii) Areas of industrial activity and degree of involvement

The graduates were asked to indicate the approximate degree of involvement, using the % time spent as a guide, in various activities ranging from fundamental research to sales and marketing. This question was intended to reveal also the range of tasks they are required to perform.

The detailed breakdown of the answers to this question is shown in tabular form in Appendix II, whereas in fig. 4.5 below these results are presented as bar charts to facilitate the comparison. The very small percentage of time spent on research, as opposed to development, supports the earlier inference that these graduates are to be regarded as technologists.

Fig. 4.5

Distribution of time spent on various industrial activities by BSc and MSc graduates



From the data in fig. 4.5 it can be seen that BSc graduates are employed over a wider range of activities than MSc holders. For the latter the distribution is biased towards development work, whereas for the BSc graduates the greatest involvement is in technical service and trouble shooting tasks.

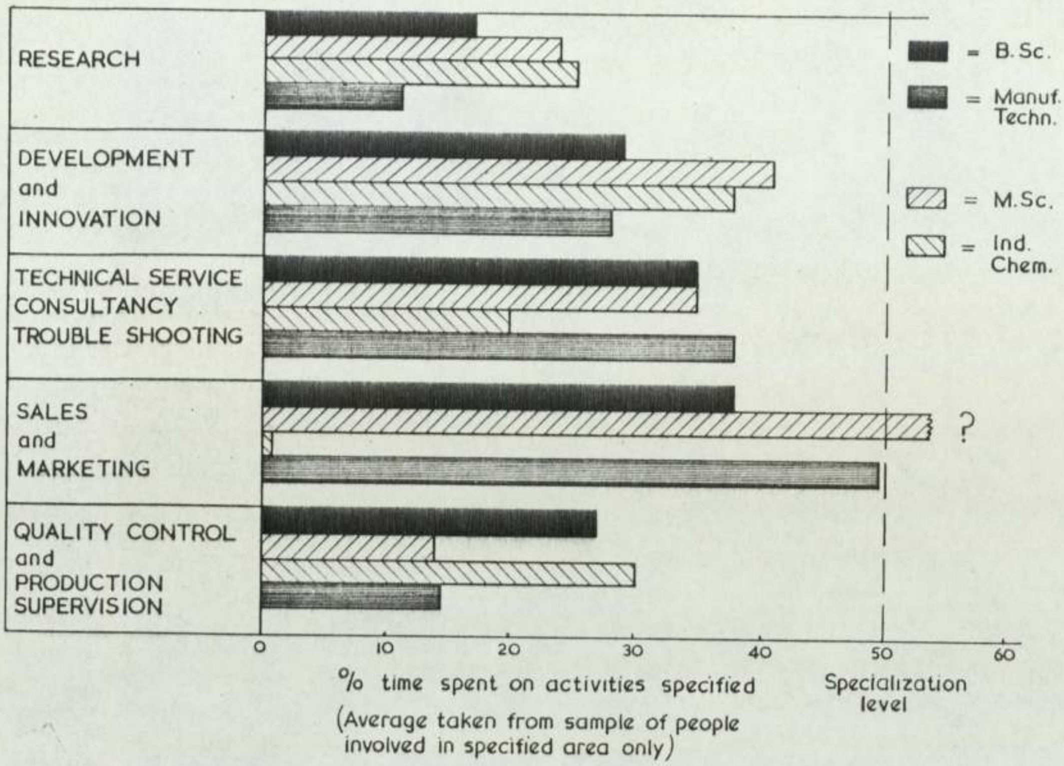
When the answers are divided according to the statements on the nature of their work, into industrial chemistry and manufacturing technology/engineering respectively, the two types distribution described above are maintained (fig. 4.6). The distinction that employers make between BSc and MSc graduates is now becoming apparent, and, no doubt, the fact that the first degree of the MSc holders is in chemistry is taken into account on the assignment of tasks. One must bear in mind, however, that the BSc graduates have spent one year in industry for practical training before completion of the course and that some of them had industrial experience even before entering the course. The majority of MSc graduates, on the other hand, have had no industrial experience prior to their first employment. (One of the purposes for establishing the MSc courses in technological universities was, in fact, to ease the transfer of graduates into industry).

Since over 50% of respondents had not changed jobs since graduation it is possible that the associations described above may be related somehow to the length of industrial experience. Neither the BSc nor the MSc graduates appear to be employed in specific functions (see detailed brakdown in Appendix II, table AII2) and therefore cannot be regarded as what may be termed 'task-oriented specialists'. In order to identify those areas of activities which entail the greatest degree of single task functions, another histogram (fig. 4.6) has been drawn. In constructing this chart those were excluded, who indicated that they did not have any involvement in the area of activity specified.

Taking the minimum level of 50% average time spent on one particular activity to indicate 'task-oriented specialism' it is apparent that only sales and marketing activities approach this situation. Woodwards also found that in the chemical sector specialization is greatest in sales functions (68).

Fig. 4.6

Degree of 'task-oriented' specialism in the polymer based industry



(iii) Factors contributing to technological skill

Question 5 was designed to obtain information about the factors which contribute to the skills of graduates in industry. Graduates employed in research and/or development activities, in general, found it difficult to specify more than one area of proficiency, whereas those in technical service and marketing appeared to have experience in a variety of areas of work. It appeared, however, that the first part of this question was not clear to a large number of respondents and for this reason it has not been taken into account in the analysis. The respondents were in good agreement with one another and stated that the factors stated in the questionnaire contributed to their skills (table 4.8) and in particular:

knowledge of methods and practical skills

ability to acquire relevant information

high level of 'common sense'

Table 4.8

Survey of BSc and MSc graduates of Aston University:

Factors contributing to technological skills

weighting wholly = 5
mainly = 4
partly = 2
not at all = 0

Average scores:

		BSc	MSc	Man.Tech.	Ind.Chem.
a) Fundamental knowledge		2.1	2.4	2.4	2.5
b) Knowledge of methods and practical skills		2.5	3.0	2.5	3.0
c) Ability to acquire relevant information		2.6	3.0	2.6	3.0
d) High level of common sense		3.0	3.0	2.9	2.85
e) Creativity and imagination		1.8	2.8	2.2	2.05
f) Course taken at Aston		2.6	2.3	2.5	2.7
g) Previous basic education		1.5	1.9	1.8	1.8
h) Training within the firm		1.7	1.3	1.0	1.7
i) Other courses attended		0.6	1.2	0.8	1.2
e) Work experience		2.75	3.0	3.1	3.1

Rank correlation coeff. between BSc and MSc $R = 0.815; \quad t = 3.84$

Furthermore, work experience was considered to be one of the most important contributory factors. A majority considered that their courses in polymer science and technology served a greater purpose than their previous basic education. The difference in score between previous basic education and the course in polymers, however, was less in the case of the MSc than BSc graduates. This may be the result of the greater association of MSc graduates than BSc holders with R & D functions.

(iv) Relative usefulness of subjects taught

The results in table 4.9 and fig. 4.7 indicate that apart from chemistry and perhaps rubber technology, BSc and MSc graduates agreed quite substantially on the relative usefulness of the various subjects taught. It is quite evident that those subjects which had been studied without appreciable reference to or concern for problems directly related to polymer technology, polymer science or polymer engineering were consequently not deemed to be sufficiently useful in their industrial employment. This seems to reinforce the problem of transferability of knowledge, already outlined by the writer in Chapter 1, p 13 . In analysing these results, consideration was given to the type of rating to be used in computing score averages.

The advantage of using greater weighting factors for the scores at the higher end of the scale can be inferred from fig. 4.8 where a comparison is made with the results obtained with ratings spaced at equal intervals. By taking the scores equivalent to the designation "some use" as a standard to monitor the subjects which failed to reach a minimum level of usefulness, the latter ratings show that every subject has reached the minimum score, whereas the rating which puts greater weighting to the higher scores reveals a "defectiveness" in subjects like physics, mathematics, chemical engineering and industrial administration.

An alternative to the above reasoning would be to use equal-intervals ratings and select as a standard the score point which falls somewhat above the "some use" designation. The problem would arise, however, with regard to the selection of this point, in so far as if logically the mid-point between the two designations "some use" and "quite useful" was chosen, this would coincide with the score point used to identify those subjects which are deemed to be satisfactory and would fail to reveal other significant differences such as between (say) chemistry and physics. The writer, however, is convinced that the details of the procedures used in the computation of the data are, by far, less valuable than the overall judgement given at the beginning of this section, which can be inferred from the use of either ratings.

Fig. 4.7

Survey of B.Sc. and M.Sc. graduates of Aston University:
"Usefulness of subjects taught" in industrial situations

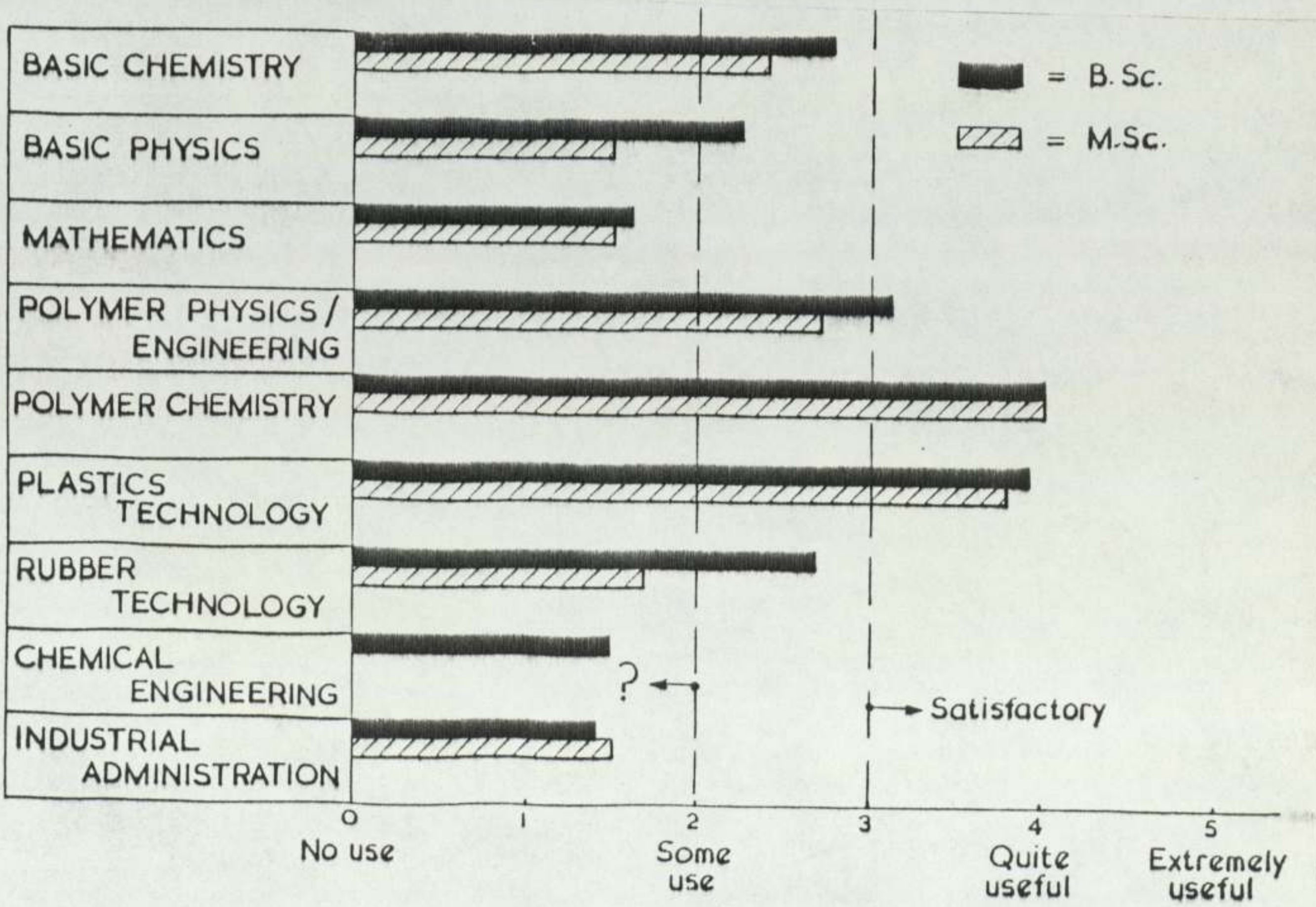


Table 4.9

Survey of BSc and MSc graduates of Aston University :

Relative usefulness of basic subjects to industrial employment

		Extremely useful	Quite useful	Some use	No use
Basic Chemistry	BSc	0%	30%	65%	5%
	MSc+	0%	50%	45%	5%
	Aver.	0%	40%	55%	5%
Basic Physics	BSc	5%	5%	75%	15%
	MSc	0%	5%	70%	25%
	Aver.	2 1/2%	5%	72 1/2%	20%
Mathematics	BSc	5%*	10%	70%	15%
	MSc	0%	0%	80%	20%
	Aver.	2 1/2%	5%	75%	17 1/2%

* Respondent job title = Technical/marketing manager

\+ 2 respondents holding PhD qualification

Owing to the extremely high importance attached to the use of mathematics in polymer technology activities in industry by a previous researcher (4) the graduates were asked to state how often they used a mathematical analysis to their work.

The above researcher wrote:

"One of the reasons for teaching mathematics to students of polymer technology is that they are going to use it in their future employment, both as a tool for the solution of problems and as a philosophy for the examination of ideas. Therefore the emphasis should be on the application of mathematics rather than upon formal theory".

Judging from the extremely low scores in tables 4.9 and 4.10, and since the question asking to specify whether they found mathematical modelling difficult or redundant in their job was not answered by a large proportion of respondents, further clarification is needed on this aspect.

Table 4.10

Survey of BSc and MSc graduates of Aston University :

Usage of mathematics in industrial employment

Rating: very often = 5
often = 3
rarely = 1
never = 0

Average Score	BSc	MSc
1. Standard analysis available in text books, literature etc.	2.3	1.5
2. Analysis specifically obtained in Polymer Science and Technology course	1.0	1.0
3. Analysis derived by yourself	1.0	0.35

Fig. 4.8

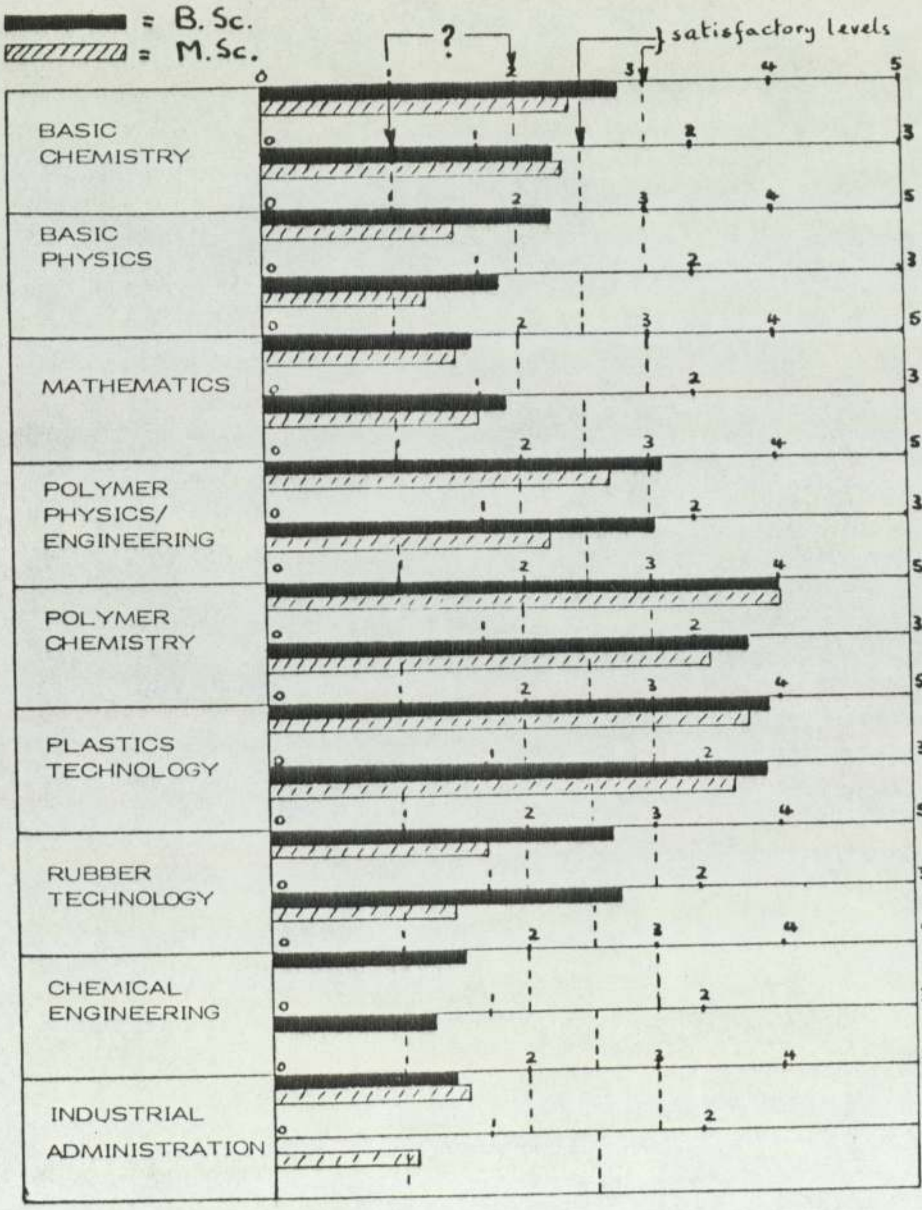
Survey of the BSc and MSc graduates of Aston University : Comparison of degree of usefulness of subjects taught using two different ratings

3 & 5 = Extremely useful

2 & 4 = Quite useful

1 & 2 = Some use

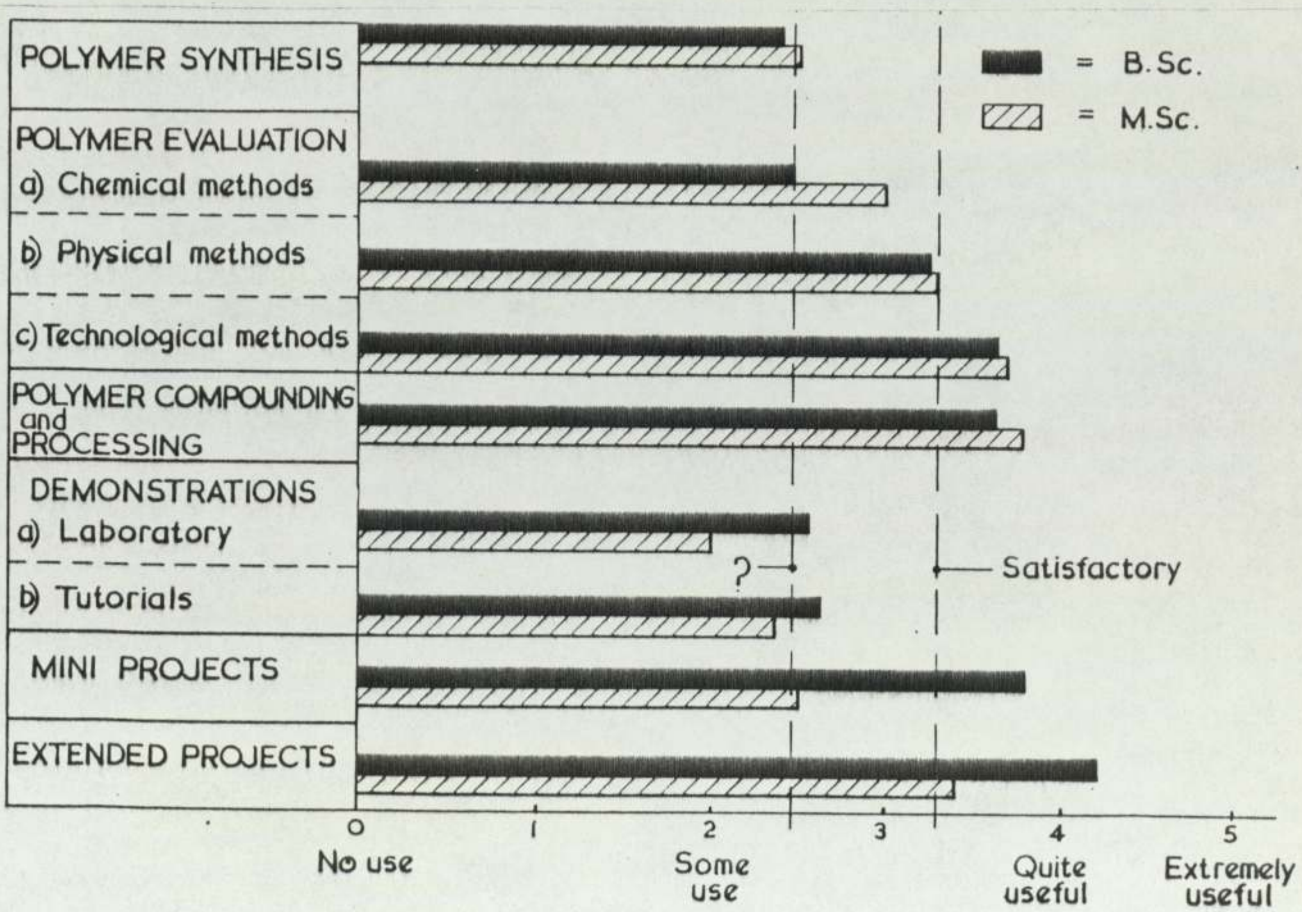
0 & 0 = No use



(v) Usefulness of laboratory assignments

The graduates were asked to indicate the relative usefulness of various experimental techniques used at Aston for the purpose of developing practical skills. The results, in fig. 4.8, show that the average score for both BSc and MSc are fairly close together. By drawing a line at a score level of 2.5 one can obtain an indication of those methods which are considered by the students to have been least effective and need reconsideration. In both cases it is quite obvious that demonstrations did not seem to be very useful. Demonstrations however are only effective if very well conceived and carefully prepared, hence the method used may need reconsideration.

Fig. 4.9: Survey of BSc and MSc graduates of Aston University: Usefulness of laboratory assignments



(vi) Relevance of topics of study to industrial situations

In question 9 graduates were asked to indicate the degree of relevance of about forty topic areas to their jobs, and to express their views as to whether the necessary information could readily be acquired in industry without having to take a formal course in polymer science and technology. Most respondents did not answer this part of the questionnaire, but by and large the views expressed were that it is difficult to obtain the necessary knowledge while in industry, especially initially when the graduate is completely unfamiliar with industry and is making an adjustment to it. In any case they say that the background acquired in a formal course speeds up the acquisition of the 'bank' of knowledge necessary to start work. The average score of the first eleven most relevant topics areas are shown, in ascending order, in figs. 4.10. The only appreciable difference in response between the two courses seems to be the degree of relevance of 'mechanisms of polymerisation reactions'. The results have been divided according to the views expressed about the relation of the work to industrial chemistry or manufacturing technology (fig. 4.11). In each case the average scores of the two alternative activities has been shown, in order to bring to light those topics which are considered to be relevant to each activity. An average score of 1.5 and above has been used for this purpose. This information has been rearranged i n fig. 4.12 in a slightly different way and it appears to suggest that there are two types of technologists required for industry, one based on engineering and one on chemistry. There appear to be, however, eight areas of activities common to both types of technologists which accounts for the difficulty by certain employers (mentioned in section 4.2) to specify the subject discipline background for many advertised posts.

Fig. 4.10

Survey of BSc and MSc graduates of Aston University:

Relevance of topic areas studied to industrial employment

5 = highly relevant

3 = moderately relevant

1 = some relevance

0 = no relevance

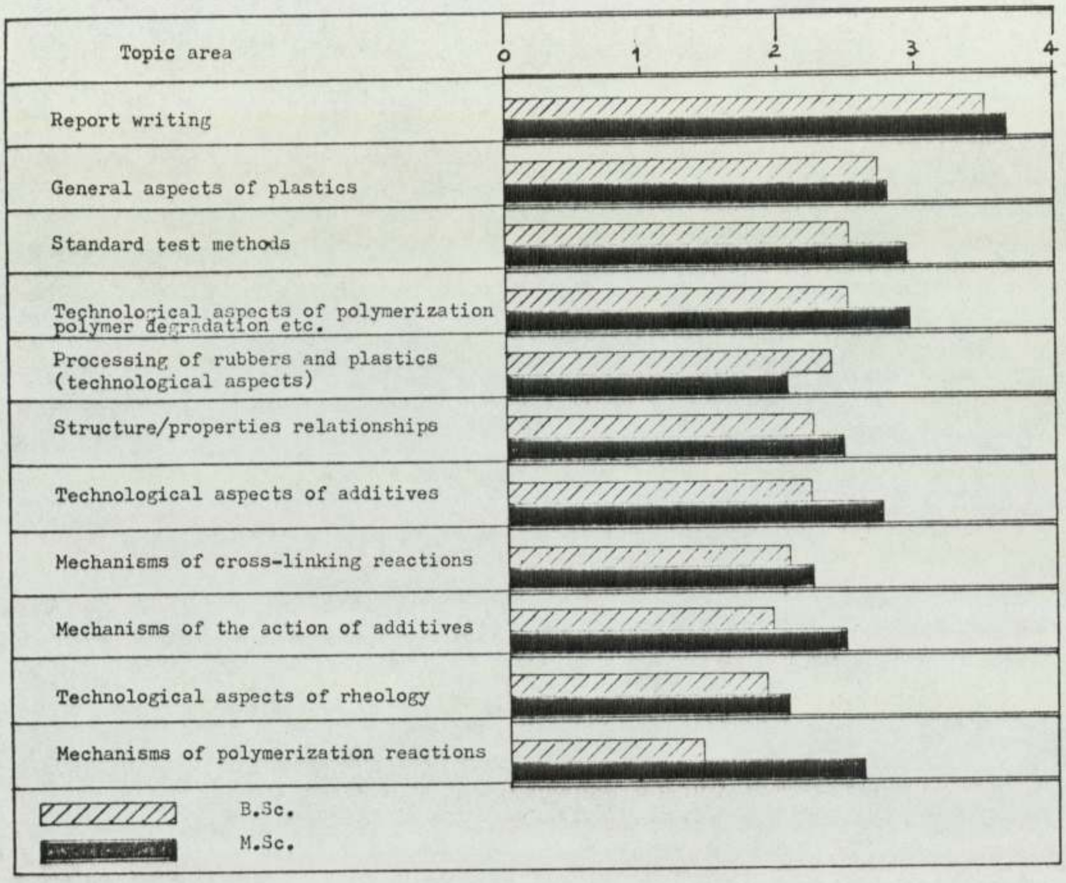
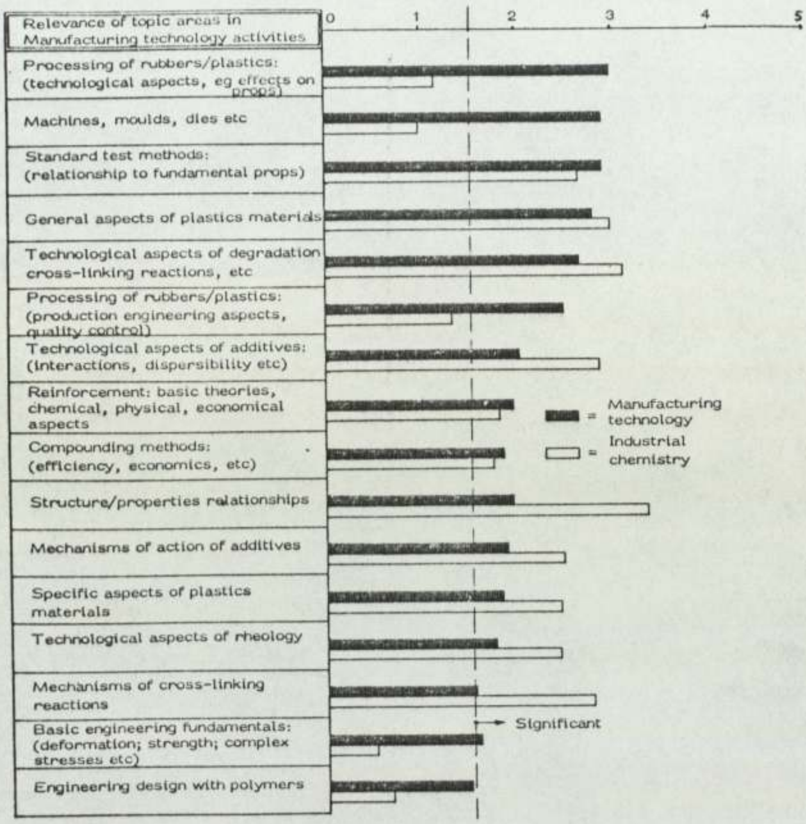


Fig. 4.11

Survey of BSc and MSc graduates of Aston University: comparison of relevance of topic areas studied to industrial employment

5 = highly relevant
3 = moderately "
1 = some relevance
0 = no "



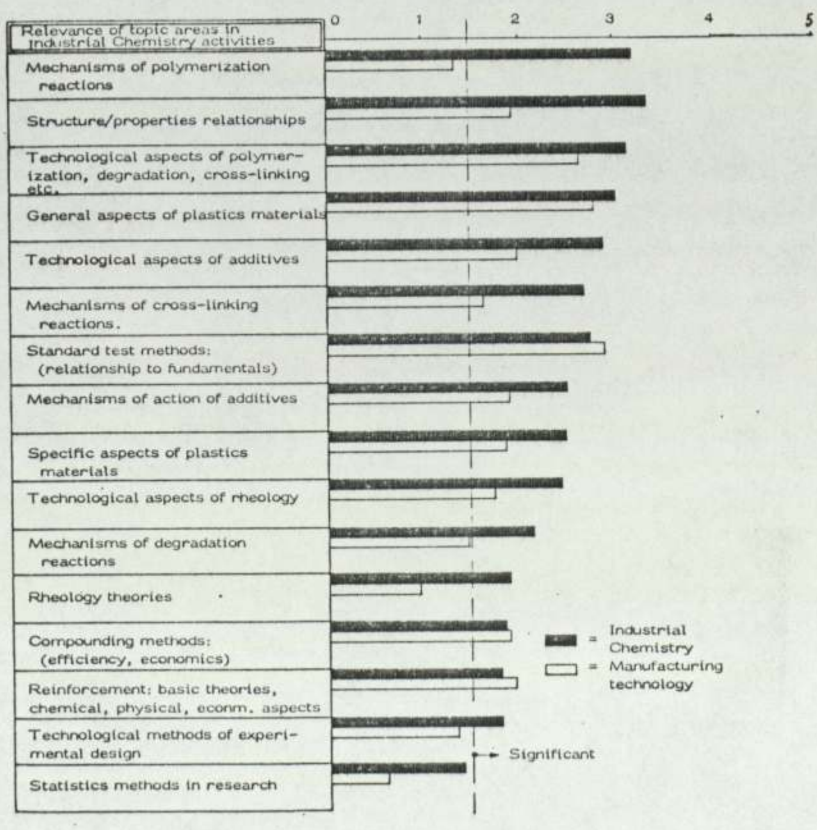


Fig. 4.12

Survey of BSc and MSc graduates of Aston University :

Identification of areas of activities of polymer technologists in relation to nature of the underlying disciplines.

Common areas of activities for all polymer technologists

1. Standard test methods.
2. General aspects of plastics.
3. Technological aspects of additives.
4. Reinforcement.
5. Compounding.
6. Structure/properties relationships.
7. Specific aspects of plastics.
8. Technological aspects of rheology.

Specific areas for industrial Chemistry activities

1. Mechanisms of polymerisation.
2. Technological aspects of polymerization, degradation etc.
3. Mechanisms of cross-linking.
4. Mechanisms of action of additives.
5. Mechanisms of degradation reactions.
6. Rheology theories.
7. Experimental design.
8. Statistics for research.

Chemistry based

Specific areas for manufacturing technology activities.

1. Processing of rubbers/plastics (technological aspects)
2. Machines, moulds, dies etc.
3. Technological aspects of degradation, cross-linking reactions, etc.
4. Processing of rubbers/plastics (Production aspects, quality control).
5. Basic engineering fundamentals.
6. Engineering design with polymers.

Engineering based

Various correlation coefficients have been worked out to compare the response of BSc and MSc graduates and their possible association with the two types of technologies mentioned above. The detailed data, presented both as scatter diagrams and in tabular form are shown in Appendix II.

A summary of these correlations is shown in table 4.11, together with their statistical significance.

Table 4.11

Survey of BSc and MSc graduates of Aston University:

Correlation coefficients and statistical significance of scores on relevance of topic areas.

	R value	Student's 't' value	Comments
Rank correlation coefficient between "Industrial Chemistry and "Manufacturing technology" scores, for all topics specified	0.66	5.48	Correlation is significant; due to large number of low scores
Rank correlation coefficient between "BSc" and "MSc" scores, for all topics specified	0.76	7.13	As above
Rank correlation coefficient between "Industrial Chemistry" and "Manufacturing technology" for the 14 topics of highest score	-0.2	0.70	The inverse correlation is not statistically significant
Rank correlation coefficient between "BSc" and "MSc", for 11 topics of highest score	0.70	2.97	The response to the most important topics is correlated There is sufficient scatter, however, and significance may be doubtful.
Product moment correlation coefficient between "Industrial chemistry" and "Manufacturing technology", for the 21 topics of highest score.	0.086	0.377	Correlation is extremely small. Not significant statistically
Product moment correlation coefficient, "BSc" and "MSc", for the 21 topics of highest score	0.55	2.88	There is a certain correlation which is significant
Product moment correlation coefficient between "MSc" and "Industrial Chemistry", for the 21 topics of highest score	0.84	6.74	Highly correlated; statistically very significant
Product moment correlation coefficient between "BSc" and Manufacturing technology" for the 21 topics of highest score	0.48	2.44	There is a certain correlation, but statistical significance is doubtful.
Product moment correlation coefficient between "MSc" and "Manufacturing technology for the 21 topics of highest score	0.56	3.0	There is a certain correlation, which is statistically very significant.
Product moment correlation coefficient between "BSc" and "Industrial chemistry" for the 21 topics of highest score	0.55	2.88	There is a good correlation, but statistical significance is doubtful

From the above statistical correlation ooefficients it would appear that MSc graduates are by and large connected with chemical activities tn industry, which together with the implications made earlier leads us to infer that they tend to be employed (at least for the first few years) as chemical technologists for development and innovation functions owing to their first degree being in Chemistry.

The average response of BSc graduates, on the other hand, does not display a strong correlation with scores for either industrial chemistry nor manufacturing technology. The spread of their type of employment shown in fig. 4.5, together with the poor correlation of their response with that of MSc graduates, strongly suggest that the first degree holders are employed in more diversified functions than MSc graduates. It is not clear, however, whether this is largely due to the industrial training which the former have received prior to their entering industry.

It was not possible to obtain further evidence to clarify the situation on the reative types of employment of BSc and MSc graduates because of the relatively short history of the MSc courses.

(vii) Analysis of comments made by the respondents

Approximately 70% of respondents made some comments about the courses taken at the University. These can be broadly classified into:

(a) Criticisms on specific subjects (N = 7)

(b) Criticisms on the organization or structure of the course (N = 13)

(c) Advocation for more technological and industrial orientation of the course (N = 16).

Typical criticisms on specific subjects

(i) B.Sc. graduate: structure/properties relationships and adhesion should be emphasised more. Greater coverage on the uses of plastics in surfaces coatings is required.

(ii) B.Sc. graduate: My own feeling is that plastics and rubbers are too specialized and more emphasis should be placed on surface coatings and fibres; after all much of the technology is relevant to all polymeric materials

(iii) M.Sc. graduate: Provide more information on properties of plastics and the reasons why plastics are useful materials. Also approach the course in a more comparative manner, rather than isolated lectures on individual topics.

(iv) M.Sc. graduate: The subjects stressed were those particular to the lecturer's research and not related to industrial activities.

Typical criticisms on organization and structure of the course.

(i) M.Sc. graduate: Try to improve time-tabling of lecture/practical sessions. This will assist understanding the principles.

(ii) B.Sc. graduate: Four terms on polymers is hardly sufficient to cover the field satisfactorily. Plastics technology is dealt with too quickly, and a large part of rubber technology is left out. I suggest to reduce part I by one term.

(iii) B.Sc. graduate: Add industrial administration to your course.

(iv) B.Sc. graduate: Include company structure, financial aspects, project assessment and costing. These are far more important than much of the 'chemical' polymer science.

Typical comments advocating for a more technological and industrial oriented course.

(i) M.Sc. graduate: More liaison with industry is required, less time on pure chemistry topics and more on technology.

(ii) M.Sc. graduate: The course could be improved by:

(a) Less emphasis on molecular weights determinations, in polymer science practicals.

(b) Less detailed knowledge on stabilizers etc.

(c) More emphasis on reinforcement and polymer technology generally.

(iii) M.Sc. graduate: University training gave me no help in solving the kind of problems which I have been asked to solve in industry, where many variables have to be considered, both in product formulation and processing.

(iv) B.Sc. graduate: It should be assured that all students of plastics technology can read engineering drawings.

(v) B.Sc. graduate: Possibly you could do more on engineering aspects of rubbers and plastics. More emphasis could be placed on economic aspects of polymer processing.

(vi) M.Sc. graduate: More time should be devoted to the technology part of the course. Basic polymer chemistry is required but only references should be given to the more complex parts, e.g. molecular weights by high scattering etc. Also it would be useful to have more lectures from people actually working in industry.

4.4.2 Survey of a random cross-section of graduate scientists, technologists and engineers working in the polymer-based industry

The purpose of this survey, which will be designated as the "main survey" was:

a) To find out whether the graduates from Aston were a 'true' representation of the population of those graduates with a chemical background who have taken a formal course in polymer science and technology.

b) To strengthen or modify some of the inferences derived from the previous survey by including in the analysis the answers of graduates in different disciplines, and to obtain the view of older graduates.

c) To obtain additional information which would help to clarify the roles of polymer technologists.

The major modifications which were introduced in the questionnaire (Appendix Id) can be summarised as follows:

(i) The addressee was asked to specify the year in which he graduated and the length of time spent in his present job. This was included to find out whether the length of post-graduate experience and the amount of experience might have an effect on the type of answers given, therefore providing a mechanism for differentiating between graduates (or junior technologists) and professionals (or mature technologists).

(ii) All questions were of the "forced-choice" type to enable a more precise classification of answers to be made, except for the usual open-end question to allow the respondent to make comments, criticisms, etc. so that he would feel that he was contributing something of his own to the study.

(iii) The question on relevance of topics was expanded to include subjects not specifically connected with polymer science or technology.
In addition the addressee was asked to specify those topics on which he would have liked to receive further formal instruction in the course of his studies. To obtain an indication as to how effectively the present courses with a polymer science and technology content (in general) are meeting industrial needs, an additional question was included, asking which topics were dealt with in depth and which had not been covered at all.
A further question was asked to obtain possible explanations as to why certain topics were deemed to have only "some relevance" and to differentiate between areas where only a broad knowledge is required and those for which specialists are employed.

(iv) The question in which it was asked to indicate to which branch of a general discipline or field of study their work could be related, was expanded to include material science. The designation "science" was used instead of technology because it was felt that many graduates would have experienced some difficulty in discerning between the true implications of science and technology. The R & D worker might have been inclined to regard himself as a scientist either because of the greater elitistic connotation which the term may convey, or simply on the basis of a general job title designation with which he is normally associated. Furthermore, the respondent may have found it even more difficult to differentiate materials technology from manufacturing technology.

(v) Those questions which in the previous survey did not produce particularly useful results (e.g. topics which had been used over the last 5 working days) and those less applicable to the new population (e.g. usefulness of various types of laboratory assignments) were omitted.

The survey was carried out on a sample of 400 graduates taken at random from the list of members of the Plastics Institute and the Institution of the Rubber Industry. A sample of 50 graduates, whose names and addresses were taken from the list of members of the Oil Chemists and Colourists Association, was included in order to ensure that there was sufficient representation from specialists concerned with additives. 50 questionnaires were distributed to various processing firms, through personal contacts, to ensure that a sufficiently large sample of the population in this important branch of the industry was taken into account in the analysis.

To each addressee were sent two questionnaires and an accompanying letter asking him to pass one on to a colleague employed in a different capacity and who had taken a degree which was substantially different in content from his own.

A total of 256 answers ($\simeq$ 28.5% of the possible maximum number in the sample were received; of which 31 were either from retired people, academics or people employed in clerical functions, who felt that the questionnaires were not applicable to their position; hence only 225 answers were included in the analysis. The data were processed using a survey analysis computer programme devised by Mr. P. A. Golder of the Management Centre, Aston University.

In this analysis the tests for statistical significance are respectively χ^2 for nominal variables, correlation coefficients for numerical variables, and F ratios of the variance when one variable is nominal and the other numerical. For the case of nominal variables the χ^2 values are given as a test of hypothesis that the two variables are independant.

(i) Distribution of graduates and response according to the year of graduation

Academics often claim that the benefits of education are felt at a much later stage of life, and suggestions have been made (70) that teaching curricula should not be concerned with the possible immediate utility of course contents. To test the above hypothesis, the answers were divided in 4 groups according to the year of graduation. In this way the response of the first group which included respondents graduated over the period 1965-1972 could be directly compared with that of Aston graduates in the previous survey. The distribution of answers according to the type of course taken and the number of years spent in their present job is shown in tables 4.12 and 4.13. Both a cursory inspection of the results and the χ^2 values suggest that there was a reasonably even distribution of graduates in all year-groups. Consequently the sample is adequate to test the influence of post-graduate experience on the types of answers. It would appear that over the period 1965-1972 there has been an increasing tendency to employ graduates in Polymer Science and Technology (chemistry route) in preference to 'pure' chemistry graduates.

The distribution according to length of employment in the present job did not show any discrepancy from what was to be expected, that is the earlier the graduation the longer the average length of time spent on a particular job. This may indicate, however, that employment in the polymer based industry has been reasonably stable.

Table 4.12 ; Main Survey:

Distribution of graduates (%) according to type of degree taken and year of graduation.

Type of degree	Year of graduation				Total N
	1965/ 1972	1955/ 1966	1945/ 1956	Pre 1945	
Polym. Sci & Tech. (chemistry route)	48.2	27	15.3	9.4	85
Chemistry	25.7	34.6	26.9	12.8	78
Polym. Sci & Tech. (Physics route)	60	40	0	0	5
Physics	15.4	46.2	38.5	0	13
Mechanical Engineering (+ Polym.Eng./Tech	57.1	28.6	14.3	0	7
Mechanical Engineering	29.3	35.3	17.6	17.6	17
Chemical Engineering (+ Polym. Eng./Tech)	0	75	0	25	4
Chemical Engineering	0	100	0	0	4
Electrical Engineering	33.3	33.3	33.3	0	3

Table 4.12 (Cont.)

Others (Metallurgy, Forestry, Mathematics	0	67	33	0	3
Total distribution	34.7%	34.7%	20.5%	10.0%	219
$\chi^2 = 43.91$, Degree of Freedom = 27, $\alpha = 0.02$					

Table 4.13 ; Main Survey

Distribution of graduates (%) according to year of graduation and length of time spent in their present job

Year of graduation	Number of years spent in present job			Total N
	less than 2	2 - 5	greater than 5	
1965 - 1972	42.1	46.1	11.8	76
1955 - 1966	23.7	34.2	42.1	76
1945 - 1956	4.4	26.6	68.9	45
Pre 1945	4.5	22.7	72.7	22
Total distribution	24.2%	35.6%	40.2%	219
$\chi^2 = 62.40$, D.F. = 6, $\alpha = 0.001$				

The questions on factors contributing to their skills, and the usefulness of fundamental subjects to their overall employment were included in order to obtain the opinions from practitioners, which would aid the formulation of some general educational objectives. The results are summarised in table 4.14 and 4.15, for which the rating used was similar to that of the survey of Aston graduates.

From the data in table 4.14 it would appear that the year of graduation makes little difference to the score on the various skills specified. The results are also very similar to those obtained in the

Table 4.14; Main Survey

Factors contributing to skills of graduates in industry, distributed according to year of graduation

Skills due to:	Year of Graduation 1965-1972		1955-1966		1945-1956		Pre 1945		Statistical Inferences
	Mean score	S.D.	Mean score	S.D.	Mean score	S.D.	Mean score	S.D.	
Scientific knowledge	2.8	1.1	2.6	1.1	2.5	0.9	3.0	1.0	$F_{ratio} = 1.4654$ significant at $\alpha = 0.1$
Knowledge of methods	2.9	1.1	2.8	1.1	2.3	1.1	2.4	0.8	$F_{ratio} = 2.67404$ $\alpha \simeq 0.1$
Ability to acquire relevant information	2.8	1.2	2.7	1.1	2.7	1.1	3.0	1.1	$F = 0.4470$ $\alpha \simeq 0.1$
Clear thought and expression	2.9	1.2	3.3	1.2	3.1	1.1	2.8	1.1	$F = 1.4824$ $\alpha \simeq 0.1$
High level of common sense	3.2	1.2	3.0	1.2	3.0	1.1	2.7	1.0	$F = 0.8005$ $\alpha \simeq 0.1$
Creativity and imagination	2.4	1.1	2.3	1.1	2.8	1.1	2.6	0.9	$F = 1.896$ $\alpha \simeq 0.1$
Training provided by the firm	1.5	1.4	1.6	1.1	1.6	1.4	1.4	1.3	$F = 0.1802$ $\alpha = 0.1$

Table 4.14 cont.

Work experience	3.1	1.1	3.2	1.0	3.1	1.1	2.9	1.3	$F = 0.7206$ $\alpha \simeq 0.01$
Other courses attended	1.3	1.1	1.5	1.1	1.1	1.0	1.8	0.6	$F = 2.1314$ $\alpha \simeq 0.1$
Grand mean score:	2.54	-	2.55	-	2.47	-	2.51	-	

Note: wholly = 5, Mainly = 4, Partly = 2, not at all = 0 analysis of the Aston graduates survey. In both cases the highest average score was for "high level of common sense", and practical skills are deemed to be at least as important as scientific knowledge. Furthermore graduates do not attend other courses to improve their skills for the job, nor do the firms provide special training.

In table 4.16 and 4.17 are summarized the answers to the question on how often graduates use a mathematical analysis to their work.

Table 4.15 ; Main Survey

Usefulness of fundamental subjects to the global employment of graduates

Subjects	Year of graduation							
	1965 - 1972		1955 - 1966		1945 - 1956		Pre 1945	
	Mean score	S.D.	Mean score	S.D.	Mean score	S.D.	Mean score	S.D.
Basic Chemistry	3.4	1.4	3.1	1.5	3.5	1.3	4.1	1.1
Basic Physics	2.8	1.4	2.9	1.4	3.2	1.5	3.0	1.4
Mathematics	3.1	1.3	3.1	1.3	3.3	1.3	3.6	1.3
Statistics	2.2	1.4	2.9	1.3	3.1	1.3	3.1	1.1
Extremely useful = 5; quite useful = 4; some use = 2; no use = 0								

The older graduates appear to attach slightly more importance to fundamental subjects than younger graduates, but in every case basic chemistry was accorded somewhat a higher score than for other basic disciplines, which is also concordant with the views of Aston graduates.

Table 4.16 ; Main Survey:

Usage of mathematics in industrial employment, classified according to year of graduation (mean scores).

	Year of Graduation			
	1965 - 1972	1955 - 1966	1945 - 1956	Pre 1945
Standard mathematical analysis	1.4	1.3	1.5	1.1
Analysis derived by the graduate	0.9	1.1	1.3	0.8
very often = 5 often = 3 rarely = 1 never = 0				

Of the following three alternatives offered :

a) difficulty in formulating mathematical models,

b) difficulty in obtaining solutions to mathematical models and

c) graphical or descriptive presentation of results is adequate in their job,

the latter was given in every case as the main reason for the lack of use of mathematical analysis.

When compared with the scores from the survey of Aston graduates, an appreciable difference in response may be noted only with respect to the usefulness of physics and mathematics but there is reasonably good agreement with regard to their application of mathematics.

The distribution of answers to the question on the relationship of the nature of their job to one or more general fields of studies specified was also reasonably uniform, table 4.17.

For all year-groups, there is a strong association of the nature of the work with manufacturing technology, followed by material science and then by industrial chemistry. Once more the association of the work with physical chemistry is negligible, and the similarities in comments made indicate that, by and large, Aston graduates can be considered to be typical of the total population of graduates who have been formally trained

Table 4.17 ; Main Survey:

Distribution of respondents (%) on the basis of the nature of the field of study or discipline to which their work is related.

General field of study or discipline	Year of Graduation				Total N
	1965-1972	1955-1966	1945-1956	Pre 1945	
Manufacturing technology (Engineering)	40.5	44.0	36.4	47.6	89
Industrial Chemistry	21.6	20.0	20.5	14.3	43
Physical Chemistry	2.7	1.3	2.3	0	4
Material Science	27.0	13.3	34.1	28.6	51
Material Science/ Man. Tech.	2.7	10.7	4.5	0.0	12
Ind. Chem./Phys. Chem.	0	1.3	0	0	1
Eng./Ind.Chem./ Mat. Sci.	4.1	4.0	2.3	4.8	8
None of disciplines specified	1.4	5.3	0	4.8	6
Total N	74	75	44	21	214
Total (%)	100	100	100	100	

$\chi^2 = 22.36$, D.F. = 21, $\alpha = 0.04$

Table 4.17 ; Main Survey:

Distribution of respondents (%) on the basis of the nature of the field of study or discipline to which their work is related.

General field of study or discipline	Year of Graduation				Total N
	1965-1972	1955-1966	1945-1956	Pre 1945	
Manufacturing technology (Engineering)	40.5	44.0	36.4	47.6	89
Industrial Chemistry	21.6	20.0	20.5	14.3	43
Physical Chemistry	2.7	1.3	2.3	0	4
Material Science	27.0	13.3	34.1	28.6	51
Material Science/ Man. Tech.	2.7	10.7	4.5	0.0	12
Ind. Chem./Phys. Chem.	0	1.3	0	0	1
Eng./Ind.Chem./ Mat. Sci.	4.1	4.0	2.3	4.8	8
None of disciplines specified	1.4	5.3	0	4.8	6
Total N	74	75	44	21	214
Total (%)	100	100	100	100	

$\chi^2 = 22.36$, D.F. = 21 , $\alpha = 0.04$

in polymer science and technology.

(iii) The response of graduates classified on the basis of the nature of the degree taken

It has often been said (71) that graduates in "pure" disciplines are preferred in those jobs where originality and an analytical mind are required, e.g. Research and Development activities.

Therefore to test this hypothesis, the respondents were divided into conventional-discipline graduates, e.g. Chemists, Physicists, Chemical Engineers and Mechanical Engineers, and 'applied' discipline graduates, e.g. those who had received formal training in polymer science and technology. For both pure and applied discipline the number of respondents were almost equal, but the number of respondents with a physics and engineering background was rather small.

(a) Relationship between the nature of degree taken and job title designation

The distribution of job titles according to the nature of degree taken is shown in table 4.18, from which the following observations can be made:

- There is no appreciable difference in job titles distribution between 'pure' chemistry graduates and those trained in polymer science and technology by the chemistry route, (who will be referred to as chemists and polymer chemists/technologists respectively throughout this report), except for sales and production activities, where the latter type of graduates are in the majority. The reverse appears to be true for managerial and directorship of Research and Development. However, the number of respondents in the latter category is too small to enable one to derive any realistic conclusions. On the other hand, age, post-graduate qualifications and experience, and elitistic connotations attached to the more traditional universities may have a predominant influence on these types of posts.

Table 4.18 ; Main Survey:

Distribution of respondents (%) on the basis of the nature of their degree and job title

	Polym. Scien & Techn. (Chemistry route)	Chemistry	Polym. Scien. & Tech. (Physics route)	Physics	Mech. Eng. (+Poly.Eng./ Tech.)	Mech. Eng.	Chem. Eng. (+ Poly.Eng./ Tech.)	Chemical Eng.	Electrical Eng.	Others
Res. Chemist	10.2	17.7	16.7	-	-	-	-	-	-	-
Res. Physicist	-	-	16.7	38.5	-	-	-	-	33.3	-
Devel. Chemist	22.7	17.7	-	-	-	-	-	-	-	-
Devel. Technol.	20.5	15.2	50.0	15.4	-	22.2	-	25.0	-	-
Devel. Engineer	2.3	-	-	-	57.1	11.1	-	25.0	-	-
Tech. Service	9.1	11.4	-	7.7	-	11.1	25.0	-	-	-
Production Tech.	9.1	2.5	16.7	-	28.6	5.6	-	25.0	33.3	-
Sales	9.1	1.3	-	-	-	-	-	-	-	-
R & D Manager or Director	4.5	17.7	-	15.4	-	5.6	25.0	-	-	-
Production Manager or Director	4.5	2.5	-	-	14.3	11.1	25.0	-	-	-
Others	8.0	12.9	-	23.1	-	33.3	25.0	25.0	-	33.3
Total N	88	79	6	13	7	18	4	4	3	3

$\chi^2 = 169.8$, D.F. = 90 $\alpha = 0.005$

- There appears to be a somewhat greater number of 'pure' physicists employed in research than counterparts who had taken a polymer science and specialization. It would seem that employers may prefer 'applied' graduates for non-R & D functions merely on grounds of their breadth of knowledge extending outside the pure discipline areas.

- There appears to be no substantial difference in job titles for mechanical engineers on the basis of whether or not they have been formally trained in polymers.

(b) Distribution of graduates types in the various sectors of industry dealing with polymeric materials

The distribution of the major groups of respondents, e.g. chemists and polymer chemists/technologists in those industrial concerns dealing with polymeric materials is quite uniform (table 4.19). For both groups the majority were employed in the polymer producing and polymers processing sectors. About 15% were in the chemical sector of industry which produces additives for polymers.

(c) Distribution of tasks according to the nature of degree taken

To investigate further the distinction that employers may make between chemists and polymer chemists/technologists and to obtain an indication of the tasks performed by the various types of graduates, a detailed table with appropriate statistical tests of significance has been constructed (Appendix IIb, table BII1).

The results, based on the average time spent on each industrial function, are summarised below in figs. 4.13 and 4.14.

Results obtained on a small number of respondents are not shown, as they cannot be taken to be representative of the population concerned.

Table 4.19 ; Main Survey

Distribution of respondents , according to the nature of the business of various industrial concerns (% age)

	Additive Manufacturers	Polymers & Compositions Manuf.	Engineering fabricators & processing	Machinery manufacturers	End users of polymeric mats.	Others *	N
Polym.Scien. & Tech. (chemistry route)	47.8	44.4	37.9	28.6	23.5	42.9	88
Chemistry	52.2	37.0	31.8	14.3	5.9	14.3	79
Polym.Scien. & Tech. (Physics route	-	1.2	3.0	-	38.2	7.1	6
Physics	-	2.5	7.6	-	5.9	28.6	13
Chemical Eng. (Polym.Eng./Tech.)	-	3.7	-	-	2.9	-	4
Chemical Eng.	-	1.2	-	-	8.8	-	4
Mechan. Engin. (Polym. Eng./Tech.	-	1.2	6.1	14.3	2.9	-	7
Mechan. Eng.	-	7.4	9.1	42.9	8.8	-	18
Electr. Eng.	-	1.2	1.5	-	2.9	-	3
Others	-	-	3.0	-	-	7.1	3
Total N	23	81	66	7	34	14	225

$\chi^2 = 65.72$, D.F. = 45 $\alpha = 0.025$

Note: *= Research Associations and Government Laboratories

Table 4.20 ; Main Survey:

Relative importance of several factors contributing to graduates' skills in the polymer based industries (average scores)

Rating: wholly = 5, mainly = 4, partly = 2, not at all = 0	Polymer Chem/ technologists	Chemists	Physicists	Mechanical Engineers
Scientific knowledge	2.7	2.6	2.5	2.5
Knowledge of methods, practical skills etc.	2.9	2.5	2.3	2.7
Ability to acquire relevant information	2.6	2.7	3.0	2.9
Clear thought and expression	2.8	3.0	3.5	3.5
Common sense	3.0	3.0	3.5	3.1
Creativity and imagination	2.2	2.5	2.5	2.9
Training in the firm	1.5	1.3	0.8	1.8
Other courses attended	1.0	1.5	1.1	1.3
Work experience	3.0	3.5	3.0	3.7

Fig. 4.13; Main Survey:

Distribution of tasks of graduates with chemistry background, working in the polymer based industry.

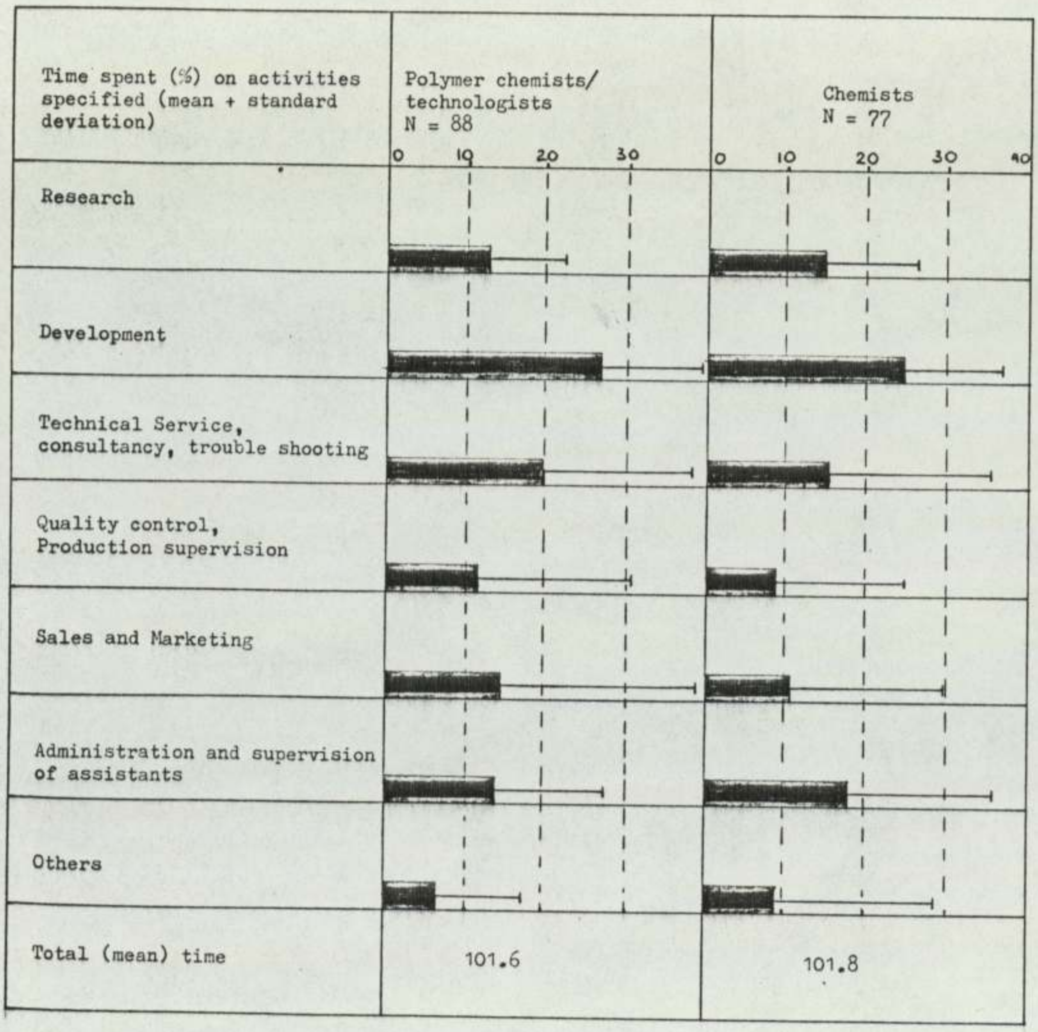
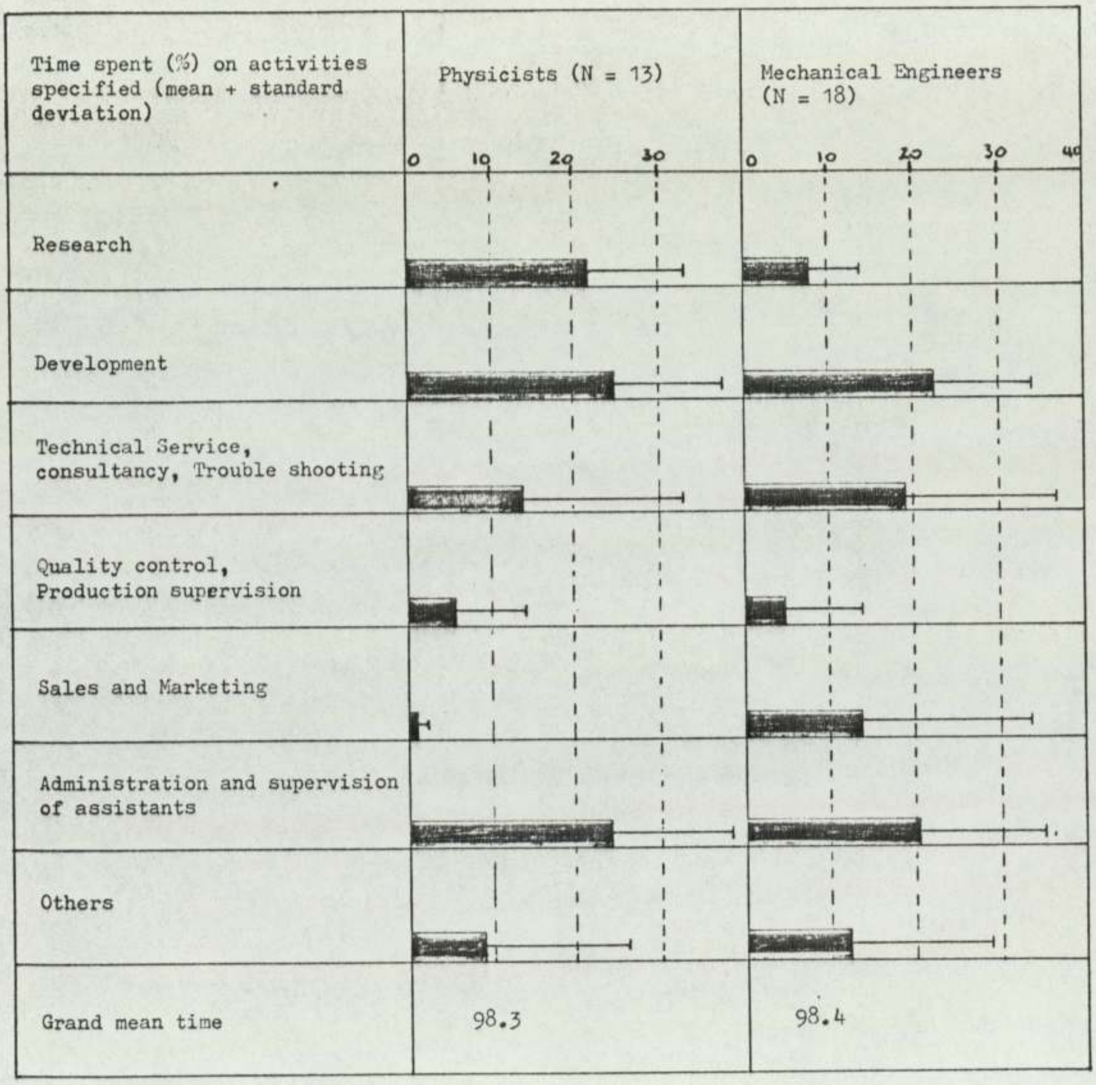


Fig. 4.14; Main Survey:

Distribution of tasks of physicists and mechanical engineers in the polymer based industries.



From the histograms in figs. 4.13 and 4.14 one is inclined to deduce that the major areas of employment of graduates is in Research, Development and Technical Service/Trouble Shooting. As for the case of Aston graduates, it was observed that invariably graduates have indicated some involvements in all the activities specified. (Quantitative data of the relative levels of specialization for the latter survey are not shown owing to computing difficulties with the programme used). In addition there appears to be little use made of physicists in sales functions and that the distribution of tasks for polymer chemists/technologists and chemists is very similar.

The overall distribution of tasks of graduates with a chemical background is also very similar to that found for Aston graduates (BSc and MSc combined).

(d) The relative importance of various abstract behaviours classified on the basis of the nature of degree taken

The response of various types of graduates to the question regarding the relative importance of several specified abstract behaviours is shown in Appendix II, BII 2, and summarised in table 4.20.

It is quite clear that, irrespective of type of degree taken, the graduates in the polymer based industries consider behaviours such as "ability to acquire relevant information", "common sense" and "clear thought and expression" to be somewhat more important than knowledge, both scientific and practical. (The term "common sense" is taken to indicate skills acquired through normal life experiences).

The relative scores for these behaviours are even greater for graduates in physical disciplines, such as physics and mechanical engineering; but the latter did not appear to attach a similar importance to "creativity and imagination". This may suggest that technologists have to work within well defined boundaries, in terms of both resources and objectives. Pelz (72), in fact, found that creative abilities impair performance in restrictive situations, such as industrial research and development work. It is also noteworthy that graduates in the polymer based industries do not receive further training on completion of their formal education, but they consider the experience gained by working in the industry one of the most contributory factors to the efficiency of their performance.

(e) Relative usefulness of various subjects dealt with in various degree courses to the graduate's career in industry

From the results in table 4.21 it is evident that those graduates who have studied technological subjects consider them to have been at least as useful as the basic underlying disciplines. As for the case of Aston graduates, polymer chemists/technologists did not consider chemical engineering to have been particularly useful.

(f) Application of mathematics in the polymer based industries

The preliminary survey carried out on graduates from Aston indicated that little use was made of mathematics in their employment. It was therefore considered necessary to investigate whether this situation differs for the case of similar graduates from other universities and those who normally receive a more intensive mathematical education in their degree course, e.g. physicists and engineers (table 4.22).

Table 4.21 ; Main Survey;

Relative usefulness of various subjects, classified on the basis of degree taken

5 = extremely useful 4 = quite useful 2 = some use θ = no use Usefulness of:	Chemistry/Polym.	Chemistry	Physics/Polym.	Physics	Chem.Eng./Polym.	Chem. Eng.	Mech.Eng./Polym.	Mech. Eng.
Basic Chemistry	3.4	3.9	2.7	2.7	2.7	2.7	2.0	2.0
Basic Physics	2.7	3.1	4.2	4.6	2.5	2.5	2.8	2.8
Mathematics	3.0	3.1	3.8	4.5	2.5	3.0	3.0	3.6
Statistics	2.4	2.8	2.5	4.8	3.3	2.0	2.4	3.2
Chemical Engineering	1.8	(1.9)	-	-	4.3	4.2	(1.0)	(2.3)
Mech.Eng./Prod.Eng.	-	-	-	-	-	-	4.3	4.1
Elec./Electronic Eng.	-	-	-	-	-	-	2.8	2.5
Ind.Admin/Tech.Econ.	2.6	1.8	3.7	(3.5)	3.7	-	2.0	3.9
Polymer Chemistry	3.7	-	(4.5)	-	2.5	-	2.0	-
Polymer Plastics/Eng.	2.9	-	3.5	-	2.5	-	4.0	-
Plastics Technology	3.5	-	3.7	-	3.7	-	4.0	-
Rubber Technology	3.5	-	(1.0)	-	3.7	-	4.0	-
Surface coatings/Adh. Technology	2.6	-	3.0	-	(2.0)	-	(5.0)	-

Note: Figures in brackets denote that the number of respondents involved is very small.

Table 4.22 ; Main Survey:

Usage of mathematics in the polymer-based industries (Mean scores).

Rating: very often = 5, often = 3, rarely = 1, never = 0	Standard mathematical analysis	Analysis derived by the graduate
Polym.Chem/technologists	1.0	0.9
Chemists	1.35	0.9
Polym.Phys/technologists	(2.3)	(2.7)
Physicists	(2.7)	(2.1)
Mech.Eng. (Polymer specialists)	(1.8)	(1.0)
Mechanical Engineers	1.3	1.3
Chem. Eng. (Polymer Specialists)	(1.6)	(2.0)
Chemical Engineers	(1.1)	(0.5)

Note: Figures in brackets denote that the number of respondents was very small.

It would appear from table 4.22 that only physicists make appreciable use of mathematics. Since a large proportion of this type of respondents was from the sample of the population working in Government research laboratories, it may be that their greater use of mathematics than the rest of the population is associated with the more academic nature of their work. Hence the claims made by Langton (4) that polymer technologists use mathematics as a tool for the solution of industrial problems must be discounted and, therefore, the objectives for mathematics units would have to be modified.

It must be emphasized that the lack of involvement with mathematical analysis is not restricted to polymer technologists; Prof. Edgeworth-Johnstone (52) in fact obtained similar results in his survey of chemical engineers.

(g) <u>Relationship between type of degree taken and areas of study associated with industrial tasks</u>

Table 4.23 above indicates that the majority of graduates consider their work to be related to engineering/manufacturing technology (40.9%) and material science (24.1%), to which must be added an appreciable proportion of respondents (6.4%) who indicated a combination of material science and manufacturing technology. The majority of the rest of graduates considered their work to be related to industrial chemistry. It is worth noting that chemists preferred their activities to be designated as material science and engineering/ manufacturing technology respectively rather than industrial chemistry, and only a minute fraction (3.9%) associated their work with physical chemistry.

(h) <u>An assessment of the relevance of various topics to industrial employment for the main groups of respondents, divided according to the nature of degree taken</u>

The list of topics used in the survey of Aston graduates was extended to include those topics more likely to be dealt with by respondents with a different academic background. As in the previous case, the graduate was asked to indicate the degree of relevance of each topic, but in addition he was required to select those which were dealt with in depth and those on which they would have liked to receive further instruction in the course of their studies.

Only the answers of those graduates who had taken a formal course in polymer science and technology have been included in the analysis of the response to question of whether the topics indicated have been treated in depth or not at all in the course of their studies. The answers of those who had taken a polymer course by the physics and engineering routes have not been taken into account owing to the small number of respondents involved.

Table 4.23: Main Survey: Relationship between degree taken and fields of study associated with industrial tasks

Areas of studies specified	Polymer Chemists/ Technologists	Chemists	Polymer Physicists/ Technologists	Physicists	Chem. Engs. (Polymer specialists)	Chem. Engs.	Mech. Engs. (Polymer specialists)	Mech. Engs.	Electrical Engs.	Others	Total N	Total %
Man. Techn./Engineering	36.5	29.9	33.3	23.1	100	50	100	77.8	66.7	66.7	90	40.9
Industrial Chemistry	28.2	22.1	0	0	0	25	0	5.6	0	0	43	19.5
Physical Chemistry	0	3.9	0	7.7	0	0	0	0	0	0	4	1.8
Material Science	20.0	31.2	33.3	53.8	0	25	0	0	33.3	33.3	53	23.1
Mat.Scie/Man.Techn.	8.2	3.9	33.3	7.7	0	0	0	5.6	0	0	14	6.4
Ind.Chem./Phys.Chem	0	0	0	0	0	0	0	5.6	0	0	1	0.5
Eng./Ind.Chem./Mat.Sci.	3.5	6.5	0	0	0	0	0	0	0	0	6	2.7
None of areas specified	2.4	2.6	0	7.7	0	0	0	5.6	0	0	3	2.7
Total N	85	77	6	13	4	4	7	18	3	3	220	100
Total (%)	100	100	100	100	100	100	100	100	100	100	100	100

$\chi^2 = 86.36$, D.F. = 72 $\alpha = 0.05$

In table 4.24 are shown topic areas considered to be most relevant by each of the groups indicated and in table 4.25 those which were deemed to be of least relevance. The values shown represent the mean scores, using the rating: Highly relevant = 5, Moderately relevant = 3, Some relevance = 1, No relevance = 0. The increasingly larger weighting factors for the higher scores widen the distribution curves towards the upper end of the scale and, therefore, produce a shift in the position of the mean pro-rata to the frequency of higher scores. This has the advantage over evenly spaced ratings in so far as it puts greatest emphasis on the most decisive scores, i.e. those designated as "highly relevant" and "no relevance" respectively. The effects of such weightings on various types of distribution are shown in fig. BII1 and table BII8 Appendix IIb. It is clear from these data that the smallest and largest shifts occur for distributions skewed respectively towards the zero scores and the highest scores.

From an analysis of the data in tables 4.24 and 4.25 it is possible to make the following observations:

- Those topics concerning the general behaviour of polymeric materials and their processing, including production aspects, are regarded to be of considerable relevance (score > 2) by all types of graduates. There was also an appreciable response regarding the desirability for further instruction on these topics in all degree courses specified. Particularly high is the frequency of statements on the desirability for more instruction on costing methods and production aspects of polymer processing (Appendix II, Table BII6). Those topics concerning molecular structure determinations, on the other hand, were considered to have extremely low relevance to industrial situations (tables 4.26 and 4.27).
- The scores for chemists and polymer chemists/technologists are very similar and those for physicists appear to be more related to the above types of graduates than to mechanical engineers.

Table 4.24 ; Main Survey

Relevance of topics to industrial employment, classified according to the nature of degree taken by the respondents

Rating: Highly relevant = 5 Moderately relevant = 3 Some relevance = 1 No relevance = 0	Polym.Chem./Techn. N=87			Chemists N=75	
	Relevance (Mean)	Frequency (%). Topic dealt with in depth	Frequency (%). Topic on which would have liked more instruction	Relevance (Mean)	Frequency(%). Topic which would have liked more instruction
Processing of rubbers and plastics: Technological aspects, e.g. variable interactions.	3.15	48.9	28.4	2.04	27.8
Technological aspects of degradation, cross-linking reactions etc.	2.95	67.1	28.4	2.83	31.4*
General aspects of plastics, e.g. comparative analysis of behaviour	2.63	48.9	29.5	2.65	43.0*
Compounding methods: efficiency etc.	2.58	35.2*	38.6*	1.97	25.3
Processing of rubbers and plastics: production engineering aspects, e.g. quality of control	2.62	29.5*	39.8*	1.56	20.2
Technological aspects of additives	2.56	37.5*	34.5*	2.54	29.1
Specific aspects of plastics, e.g. stabilization, processing characteristics	2.36	48.9	25.0	1.32	43.0*
Structure/property relationships	2.43	59.1	21.6	2.28	32.9*
General aspects of rubbers, e.g. relationships to synthetic and thermoplastics rubbers	2.23	54.5	19.3	1.32	20.2
Standard test methods, e.g. relationship to fundamental behaviour	2.61	43.2	28.4	2.55	29.1
Moulds, dies, machines, etc.	2.08	37.5*	21.6	1.35	20.1
Mechanism of action of additives	2.14	39.8	28.4	2.26	34.2*
Technological aspects of rheology	1.83	36.4*	27.3	2.24	29.1
General aspects of adhesives	1.72	17.1*	37.5*	2.10	35.4*

Table 4.25; Main Survey

Relevance of topics to industrial employment, classified according to the nature of degree taken by the respondents

Rating: Highly relevant = 5; Moderately relevant = 3; Some relevance = 1; No relevance = 0	Physicists N = 13		Mechanical Engineers N = 18		Mechanical Engineers (Polymer specialization) N = 7	
	Relevance (Mean)	Frequency (%) Topic on which would've liked further instruction	Relevance (Mean)	Frequency (%) Topic on which would've liked further instruction	Relevance (Mean)	Frequency (%) Topic on which would've liked further instruction
Technological methods of experimental design	3.84	38.5	1.17	0	2.00	28.3
Rubber elasticity theories	2.84	53.8	0.11	5.5	0.43	0
Statistical methods: errors, variance etc.	3.31	46.2	1.00	0	1.43	0
Technological aspects of rubber elasticity	2.46	53.8	0.11	5.5	0.43	0
Technological aspects of visco-elasticity	2.54	38.5	0.39	16.6	0.86	14.3
Structure properties relationships	2.92	61.5	0.67	11.1	1.14	14.3
Processing of rubber and plastics: technological aspects	2.61	38.5	1.50	22.3	3.14	14.3
Reinforcement and composites	3.15	38.5	0.39	22.3	2.00	28.3
Basic engineering: fundamentals of stresses and strains	3.23	38.5	2.16	0	3.85	0
Engineering design with polymers	2.69	46.2	1.61	22.3	1.50	42.8*
General aspects of plastics: comparative behaviour	2.46	46.2	2.00	16.7	2.43	28.3
Specific aspects of rubbers:e.g. vulcanization	2.08	38.5	0.27	5.5	1.00	28.3
Technological aspects of degradation, X-linking etc.	2.38	30.8	0.67	11.1	0.71	0
Processing of rubbers and plastics: production aspects	2.15	38.5	2.00	22.3	3.57	28.3*
Fracture mechanisms and large deformations	2.85	46.2	0.39	11.1	1.14	28.3*
Orientation and anistropy: product design	2.30	30.8	0.44	5.5	2.00	14.3
Thermal behaviour of polymers	2.07	30.8	0.94	22.3	1.43	14.3
Moulds, machines, dies	1.00	23.1	2.33	11.1	4.71	14.3
Specific aspects of plastics: stabilization, processing behaviour	1.31	30.8	1.44	16.7	2.57	28.3
General aspects of adhesives and surface coatings	1.07	38.5	1.00	11.1	0.86	42.8*
Standard test methods: limitations etc.	3.00	38.5	1.28	11.1	3.14	14.3

Table 4.26 ; Main Survey

Topics of least relevance to industrial employment, classified on the basis of degree taken

Rating: Highly relevant = 5 Moderately relevant = 3 Some relevance = 1 No relevance = 0	Polym. Chem./Techn. N = 87			Chemists N = 75	
	Relevance (Mean)	Frequency (%) Topic dealt with in depth	Frequency (%) Topic on which respondents would have liked more instruction	Relevance (Mean)	Frequency (%) Topic on which respondents would have liked more instruction
Solution thermodynamics theories	0.21	43.2*	5.7	0.24	5.1
Gas and liquids diffusion kinetics	0.27	28.4	7.9	0.36	7.6
Mass transfer theories	0.32	7.9	17.1	0.39	8.8
Thermal analysis	0.50	30.7	4.5	1.05	12.6
Technological aspects of gas diffusion	0.59	11.4	10.2	0.73	12.6
Combustion inhibition theories	0.64	2.3	18.2	0.89	22.8*
Optical properties (effects of additives etc)	0.64	17.0	18.2	0.99	12.6
Rubber elasticity theory	0.72	55.7*	6.8	0.74	13.9
Viscoelasticity theory	0.72	50.0*	7.9	1.01	16.4
Molecular weight determinations	0.72	71.6*	2.3	0.78	6.3
Kinetics of polymerization, degradation etc.	0.66	47.8	7.9	1.03	16.4
Methods of structure determination	0.79	60.2*	10.2	1.01	10.1
Heat transfer theories	0.77	23.9	17.1	0.55	8.8
Technological aspects of polymer solutions	0.80	30.7	18.2	0.95	15.2

Table 4.27 ; Main Survey:

Topics of least relevance to industrial employment, classified on the basis of degree taken

Rating: Highly relevant = 5 Moderately relevant = 3 Some relevance = 1 No relevance = 0	Physicists N = 13		Mech. Engrs. N = 18	
	Relevance (Mean)	Frequency (%) Topic on which would've liked further instruction	Relevance (Mean)	Frequency (%) Topic on which would've liked further instruction
Molecular weight determinations	0.38	7.7	0.22	5.5
Gas and liquids diffusion kinetics	0.30	7.7	0.11	5.5
Solution thermodynamics theories	0.53	15.4	0.17	5.5
Mechanisms of polymerization	0.54	23.1	0.77	16.6
Methods of structure determinations	0.84	15.4	0.28	11.0
Mass transfer theories	0.58	23.1	0.55	5.5
Moulds, machines, dies etc.	1.00	23.1	(2.33)	(11.1)
Technological aspects of gas liquids diffusion	0.61	15.4	0.17	5.5
Kinetics of polymerization, degradation etc.	0.67	30.8	0.11	11.0
Optical properties of polymers	1.00	7.7	0.23	0.0
Combustion inhibition theories	0.77	30.8	0.22	0.0
Mechanisms of action of additives	0.92	23.1	0.22	11.0
Dielectric properties of polymers	(1.54)	(0.0)	0.38	5.5
Technological aspects of M.W.'s and structure determinations	(1.38)	(0.0)	0.17	11.1
Thermal analysis	0.92	7.7	0.17	11.1
Rubber elasticity theories	(2.84)	(53.8)	0.11	5.5
Technological aspects of rubber elasticity	(2.46)	(53.8)	0.11	5.5
Technological aspects of additives	(1.30)	(23.1)	0.23	11.1

Figures in brackets denote an anomaly in the list shown

- At least 30% of graduates in the Science and Technology of polymers by the chemistry route considered those topics of highest relevance (with the exception of "General aspects of adhesives") to have been dealt with in depth in their degree course. At the same time, however, there is a considerably larger percentage (≃ 50%) in many cases, who indicated that those subjects of extremely low relevance (table 4.26) have also been dealt with in depth.

Whilst the association of mechanical engineers with polymeric materials and their processing is quite high, these graduates appear to be more concerned with machinery aspects (score 3.52 ; % employed in machinery manufacture = 63% - table 4.19) than product performance e.g. orientation and anisotropy effects, fracture etc.
It must be emphasized, however, that the number of respondents in this category was only 18, which may not constitute a realistic representation of the true population of mechanical engineers in the polymer based industries. This is also suggested by the fact that those mechanical engineers who have taken a polymer specialization (albeit only 7 in number) gave higher scores almost for every topic specified, and furthermore the score for orientation and anisotropy, as related to product design and performance, was quite high (i.e. 2.00)

(j) Analysis of comments made by the respondents

The comments made by the respondents, apart from those who were simply expressing their best wishes and good luck, or making humorous remarks, can be broadly classified as follows:

- Criticism of the survey: These criticisms (total 9) were made by chemists, mostly by those graduated in the 1965-1972 period (N=5). The majority (N=7) criticised the survey on grounds that the questionnaire was designed only for those who had taken a formal course in polymer science and technology. It is noteworthy also that the majority

(N=5) were employed as research chemists. Typical comments were:

"You should not have assumed that everybody working in the polymer industry has taken a course in polymer science and technology. My colleagues in Sales or Management could not possibly fill in your questionnaire as they would not understand even the terminology" (Development chemist)

"My generalised chemical education has not prevented me from acquiring fairly rapidly a detailed polymer background, over a fairly wide area, by reading, job experience etc. In fact I believe myself to be pretty expert in my field as I am publishing a major book on polymers later this year. Too specialized an education can be very limiting - especially if your speciality is not much in demand when looking for a job. Specialization at post-graduate state is a reasonable compromise for many 'prime-movers' to be. Technicians-to-be should specialize in 1st degree and stop there". (Research Manager - polymer producing firm).

"Your questions leave little scope for people like myself who are concerned primarily with cryogenic fluids".

- <u>Criticisms of pure chemistry courses:</u> Several chemists (N=7), mostly in functions other than research, expressed some criticisms about the 'degree course' which they had taken. Typical comments were as follows:

"My formal education taught me the language of science but little else. The vast bulk of my technical knowledge has been assembled by working in industry, and learning from my own work and that of others. The most useful graduates on my staff have arrived via the Polytechnics sandwich courses, e.g. Borough Polytechnic" (Chemist: Section Leader).

"My first job in industry was to measure solution viscosities and $\bar{M}n$'s. Though I have used my university training at the beginning when I worked on polymerization, for the job I have been doing over the last 22 years I have had little or no formal training. I like to think that graduates today going into the plastics industry are better equipped". (Chemist: Technical Service Manager).

"My formal education attempted to turn me into a quite inferior organic research chemist. I did not care much for that so I joined a rubber company as a lab. assistant. I remained poor for years but ultimately I made it." (Technical Director).

- Comments indicating that a more industrial orientated approach is required in degree courses: (N=8)

Most of these types of comments were made by graduates in the science and technology of polymers via the chemistry route, and are very similar to those on the survey of Aston graduates, e.g.

"The polymer courses leading to API/AIRI are orientated towards the needs of research chemists, i.e. too much emphasis is placed on organic/physical chemistry of polymers and not enough on technology. There may be a need to have two routes, one based on science and one based on technology".

"Courses specializing in polymers concentrate too much on theoretical aspects of polymer science. For a course which is aimed at producing technologists there should be more training in mould design, material selection, costing etc."

- There were also similar comments from engineers; e.g.

"On reflection the course which I have taken was too "pure". I may have been trained in simple problem-solving but in no way applicable to the multi-dimensional world of industry".

"University courses completely lack in mentioning that money makes a chemical or physical process work in industry. While I do not agree entirely with this thought it is well advised to consider that the best technical argument is one penny/lb. less" (Sales Manager: Chemical Engineer).

"From what little I know of polymer technology training it seems to have little bearing for companies such as ours which are processing materials supplied by large chemical concerns" (Director).

- Comments regarding the attributes that graduates should possess:

The older graduates, irrespective of the type of degree taken, emphasised the importance of non-cognitive behaviours and basic knowledge, e.g. "The important qualities of graduates should be:

(a) Humility and ability to become interested in dull problems

(b) Sound basic knowledge" (Chemist).

"A good basic training coupled with sound common sense are probably the most important attributes of an industrial technologist. Common sense, however, is the most uncommon of all senses". (Research Manager: Chemist).

"I believe that the two most desirable attributes are: Common sense and enthusiasm. Over the last 20 years the only thing which has changed in education is the matter and not the manner. There is still too much emphasis on memory work, when what matters most is the ability to apply knowledge to practical problems. My impression is that your questionnaire can only influence what is being taught and not how it is being taught. I think you should find out how graduates perform in industry". (Chief chemist).

"It is better to teach the student how to think, investigate, report and justify his results and ideas in a commercial situation. Do not cram them full of facts which are better looked up in reference books when required" (Chemical Engineer: Production Manager).

I would place greatest emphasis on the development of clear thought and expression".

"My job could be done by anybody with a good qualification in common sense. I would like to emphasise the importance of clear thinking and planning".

- General comments: The majority of comments were sporadic and could not be classified. Therefore only those which are considered to be helpful to this investigation are reported here, e.g.

"The possession of a qualification is a rough indication of a man's intellectual ability and willingness to work. Therefore the exact type of qualification is relatively unimportant.

Qualifications which can be acquired by simple learning (memorizing) can give misleading impressions.

The present trend to drag more people through the educational process does not produce more able people.

I can't spell" (Physicist: General Manager.

"In my engineering training an appreciation of plastics technology (with some relevant chemistry) would have been beneficial" (Development technologist".

"Being a mechanical engineer involved in machine design I should know a little about chemical aspects of polymers. I would have liked to spend one year at the university studying some aspects of polymer science and technology". (Development Engineer).

"This form recalls the opinions of a physicist working in a field making some use of the skills required by a paint technologist and other skills which have no relevance at all to polymer science".

"Since 1964 I have not been engaged in polymer science or technology, but I find my knowledge of plastics quite useful in my present job which concerns the application of industrial gases" (Polymer chemist/technologist.)

Suggestions have often been made that a working knowledge of a foreign language would be quite useful especially as a result of Britain joining the European Economic Community.

(iii) The response of graduates, classified on the basis of job title description

Table 4.18 shows that graduates from different disciplines have used in many instances the same job title designation. Hence it is worth classifying the response on the basis of job title as a means of obtaining a better insight into the type of tasks of graduates in various functions.

From an inspection of table 4.28 it can be inferred that the majority of respondents who used the job title designation of "research chemist" and "development chemist" were employed in the polymer producing sector of industry, whereas the majority of development technologists were employed in the processing industry.

Table 4.28 Main Survey:

Distribution of job title designations (%) according to the type of industry dealing in polymeric materials

	Additives manufacturers	Raw polymers and polymeric composition manufacturers	Processors, fabricators, engineering	Machinery manufacturers	End users of polymeric materials	Others	Total N
Research chemists	8.4	58.0	3.0	0	12.5	8.4	24
Research physicists	0	28.5	53.0	0	0	28.5	7
Development chemists	5.8	50.0	17.6	0	17.6	8.8	34
Development technologists	10.0	25.0	55.0	0	20.0	0	40
Development Engrs.	0	33.3	33.3	11.2	22.2	0	9
Technical service technologists	37.2	12.5	21.0	8.4	21.0	0	24
Production technologists	6.25	31.2	31.2	0	31.2	0	16
Tech. Sales Representatives	23.0	77.0	0	0	0	0	9
Res. Managers or Directors	4.5	36.2	32.0	9.1	13.6	4.5	22
Production Managers or Directors	10.0	30.0	50.0	0	10.0	0	10
Others	6.6	26.6	36.5	6.6	3.3	19.8	30
Total N	23	81	66	7	34	14	225

$\chi^2 = 98.13$, D.F. = 50 $\alpha < 0.005$

(a) Distribution of tasks according to job title

Bar charts in figs. 4.15 and 4.16 (see also Appendix II, table BII3) were constructed with the view in mind to determine the degree of task orientated specialization in various industrial activities. The values reported are the average (%) and standard deviation of the time spent on the activities specified.

From an inspection of figs. 4.15 and 4.16 and table BII3, Appendix II, it would appear that the highest level of specialization occurs in sales and marketing functions.

This situation seems to exist also with regard to technical service functions, which confirms the existence of a high level of specialization in customer orientated activities.

Research chemists are not involved to a large extent in marketing functions, whereas development chemists and development technologists in particular, are at the lowest level of task specialization owing to their appreciable involvement in both research, technical service and production matters.

Task specialization, however, appears to depend more on the size and business nature of the firms involved than on type of degree held by the graduates employed. In fact, from the data in table 4.28 it can be seen that for most job titles (research chemists, development chemists and development technologists in particular) there is a substantial proportion of both chemists and polymer chemists/technologists. However, whilst graduates in sales and research functions (table 4.30) were mostly employed in polymer producing organizations (normally fairly large), development chemists and development technologists were employed in polymer processing concerns (normally rather small).

These findings seem to be in reasonable agreement with those of Woodward et al. (68), who discovered that for continuous processes organisations (mostly chemical concerns) the ctitical function is marketing,

Fig. 4.15; Main Survey:

Distribution of tasks according to job titles .

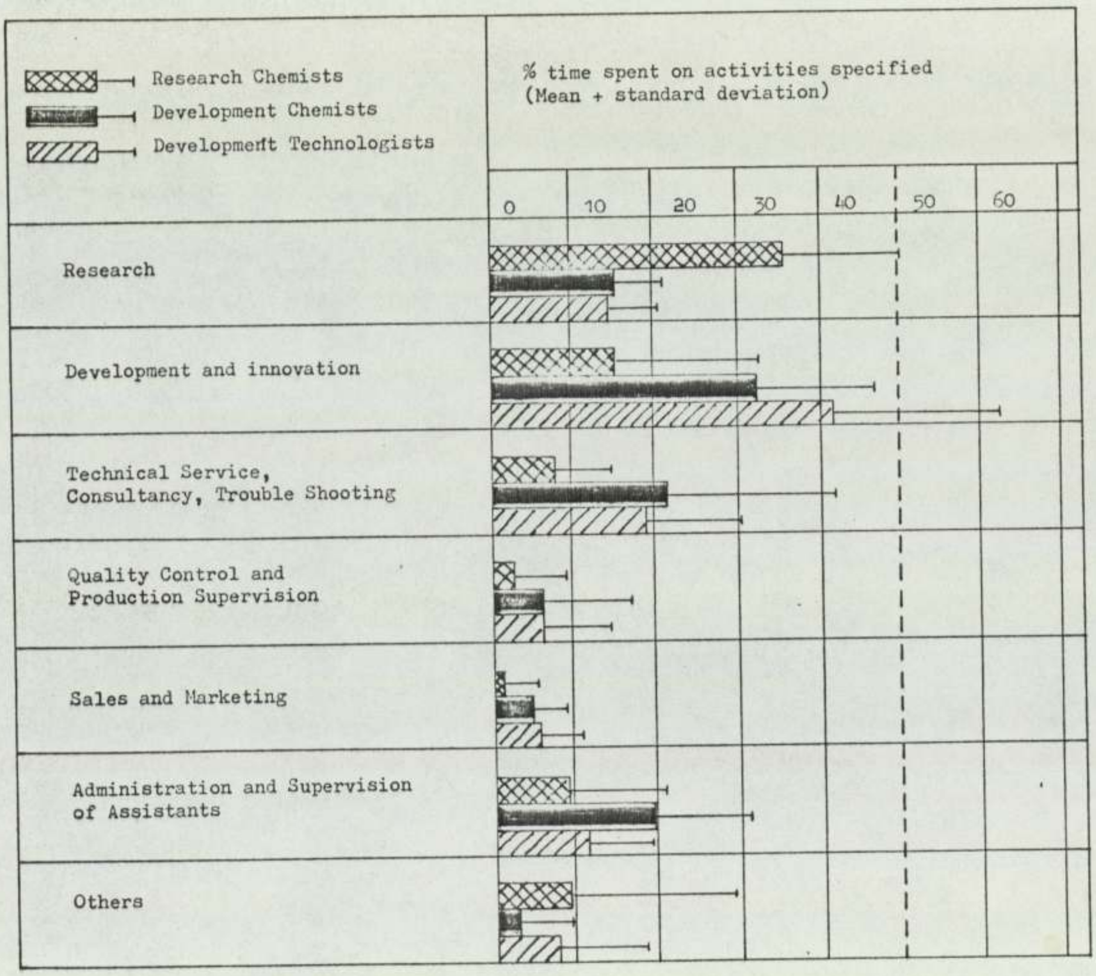
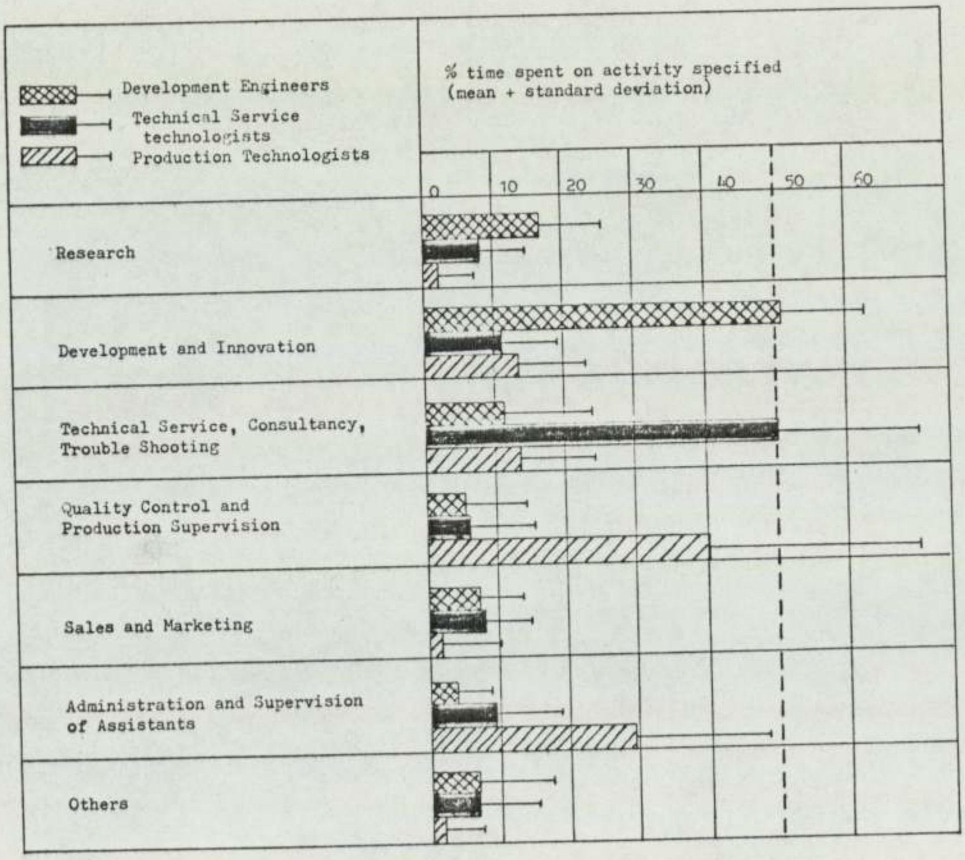


Fig. 4.16; Main Survey:

Distribution of tasks according to job title.



hence the high level of specialisation in these activities. On the other hand, in batch production systems (mostly engineering concerns) the critical functions are respectively development and production, depending on the size of the industrial concern. Consequently it is to be expected that the latter type of industry will use graduates for a wider range of functions. In other words, the development and production personnel can be frequently called upon to assist in marketing matters.

(b) The relative importance of some general abilities, classified on the basis of job titles designations

Owing to the erratic distribution of different types of graduates in the industries involved, the relative importance of various skills has been classified and rated on the basis of job titles. The results are shown in table 4.29 as mean values using the rating: 5,4,2,0. Scientific knowledge was rated highest by research and development chemists, whereas in almost every other case its scores were lowest. Even research physicists rated common sense and clear thought and expression above scientific knowledge. Development engineers and technical sales representatives, on the other hand, gave the highest score to practical skills. Furthermore, it can be seen that to common sense was accorded a high score seven times, whereas to scientific knowledge only twice.

Generally creativity and imagination received a low score.

These values being based on rated opinions, the total number of respondents in each category considered must be reasonably high in order to make a realistic estimate. Consequently, the scores given by the samples of research physicists, development engineers, and technical sales personnel are probably not representative of the respective populations.

(c) Usefulness of subjects studied and application of mathematics, classified on the basis of job titles

The relative scores for the usefulness of subjects studied and the use of mathematics are given in Appendix II, table BII4. In this rating research chemists placed chemistry at the highest level of usefulness, development chemists rated polymer chemistry highest and development technologists recorded the highest score for rubber technology.

Although these scores may be largely influenced by the relative proportions of various types of graduates in a given sample, it is noteworthy that overall polymer chemistry, plastics technology and rubber technology showed a high incidence of high scores and that chemical engineering received consistently low scores.

Table 4.29; Main Survey

The relative importance of general "abstract" abilities, classified on the basis of job titles

5 = wholly 4 = mainly 2 = partly 0 = not at all Skills due to:	Research Chemists N=24	Development Chemists N=33	Research Physicists N=7	Development Technologists N=40	Development Engineers N=9	Technical Service Technologists N=23	Production Technologists N=16	Sales Representatives N=9	Res. & Dev. Managers N=22	Production Managers N=9	Others N=28	Total number of highest (H) and lowest (L) scores
Scientific knowledge	3.1(1)	3.2(1)	2.8(4)	2.6(5)	2.7(6)	2.5(5)	2.6(4)	2.2(6)	2.5(5)	2.2(5)	2.3(6)	2(H)
Practical skills	2.5(5)	2.8(4)	2.0(6)	2.6(5)	3.6(1)	3.2(1)	3.2(2)	2.4(5)	1.9(6)	2.9(4)	2.6(5)	3(H)1(L)
Ability to acquire relevant information	2.6(5)	2.8(4)	2.7(5)	2.7(3)	3.0(3)	2.7(4)	2.5(5)	2.9(3)	2.6(4)	3.2(2)	2.9(3)	2(H)
Clear thought and expression	2.9(3)	2.9(2)	2.9(3)	2.9(2)	3.2(2)	3.0(3)	3.1(3)	3.8(1)	3.4(1)	2.9(4)	3.3(2)	6(H)
Common sense	2.9(3)	2.7(5)	3.4(1)	3.0(1)	2.9(4)	3.1(2)	3.2(2)	3.2(2)	2.7(3)	3.2(2)	3.3(2)	7(H)
Creativity and imagination	2.5(6)	2.5(6)	3.0(2)	2.5(6)	2.8(5)	2.0(6)	1.6(6)	2.8(4)	2.7(3)	1.7(6)	2.8(4)	1(H)2(L)

Note: numbers in brackets represent ranking order.

Table 4.30: Main Survey:

Relationship between job title and area of study to which the work of graduates is related (%)

	Eng/Man Technology	Industrial Chemistry	Physical Chemistry	Material Science	Mat. science/Man.techn.	Ind.Chem/Phys.Chem	Eng/Ind.Chem/Mat.Sc.	Neither	Total N	Total (%)
Research Chemists	13	30	5	43	0	0	9	0	23	100
Research Physicists	14	0	0	86	0	0	0	0	7	100
Devel. Chemists	15	41	29	23	9	0	9	0	34	100
Devel. Technologists	45	41	29	23	19	0	0	0	38	100
Devel. Engineers	89	0	0	11	0	0	0	0	9	100
Tech. Serv. Technol.	58	8	0	25	0	0	4	4	24	100
Prod. Technologists	55	12	0	37	0	0	6	6	16	100
Tech. Sales Repres.	44	44	0	0	11	0	0	0	9	100
R & D Mans./Direcs	33	20	0	29	0	0	9	5	21	100
Prod. Mans. or Dirs	70	10	0	10	0	0	10	0	10	100
Others	51	14	0	17	4	3	0	7	29	100
Total N	90	43	4	53	14	1	8	6	219	

$\chi^2 = 125$; D.F.= 80; $\alpha = 0.001$

(d) Relationship between job title and area of study to which the work of graduates is related

Apart from development chemists, the majority indicated that their work is related to manufacturing technology and material science or a combination of these. Even research chemists preferred the designation of material science to industrial chemistry and only a very small minority (4.4%) considered their work to be related to physical chemistry.

(e) An analysis of the relevance of various topics, classified on the basis of job title designation

The average rated values and standard deviations for the relative relevance of all topic areas specified are shown in Appendix II, tables BII5 and BII6 and have been classified on the basis of nature of degree taken and job title designation used. In addition, these tables show the frequency of response to the rating of "some relevance" and the relative frequencies of the three specified reasons as to why the rating of "some relevance" has been used. In fig. 4.17 and 4.18 below are shown the topics of highest score for the main groups of respondents, i.e. research chemists, development chemists, development technologists, technical service technologists, development engineers and production engineers. The criterion used to select suitable topics for these tables was that of minimum average score equivalent to "some relevance"

Fig. 4.17: Main Survey:

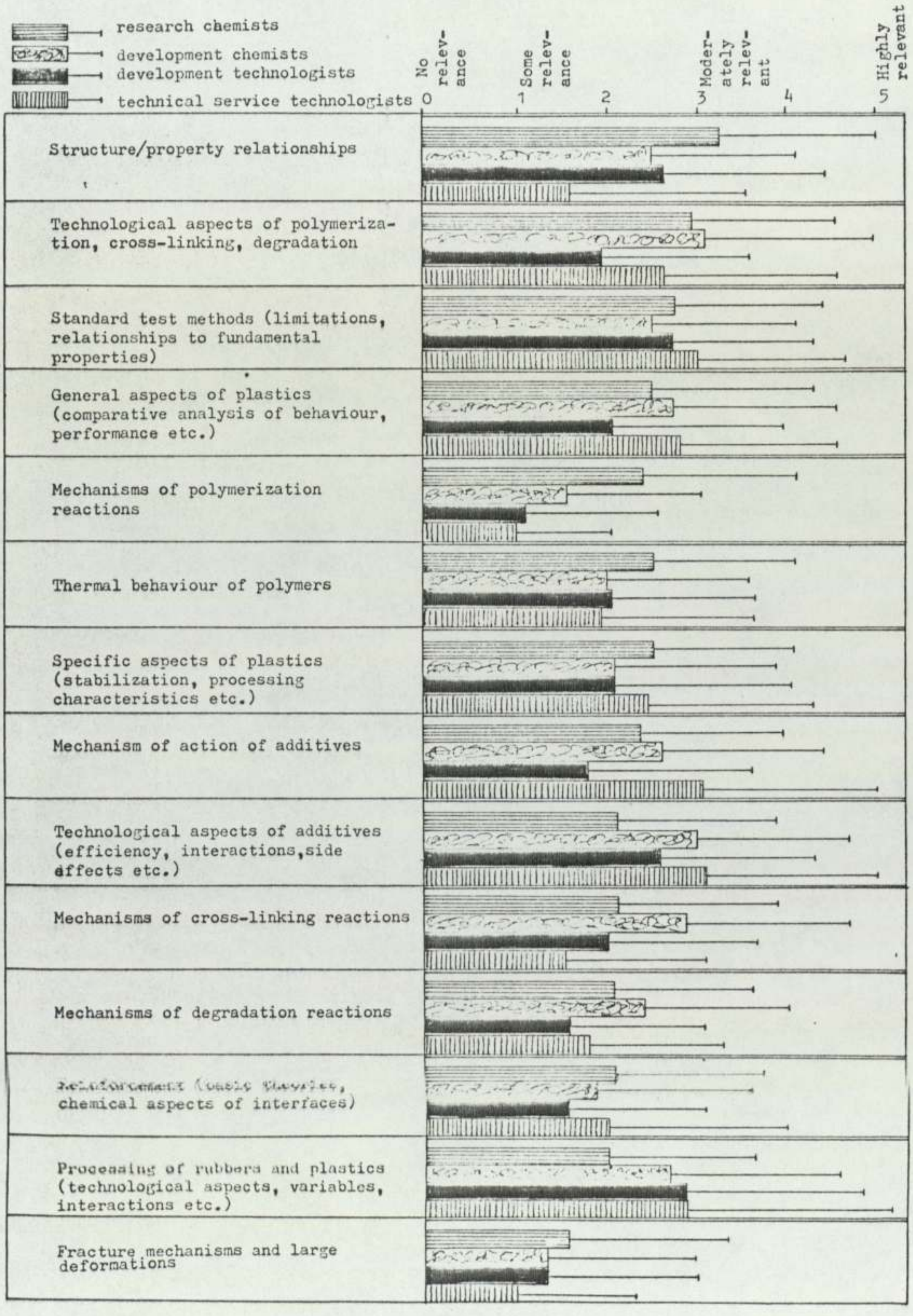
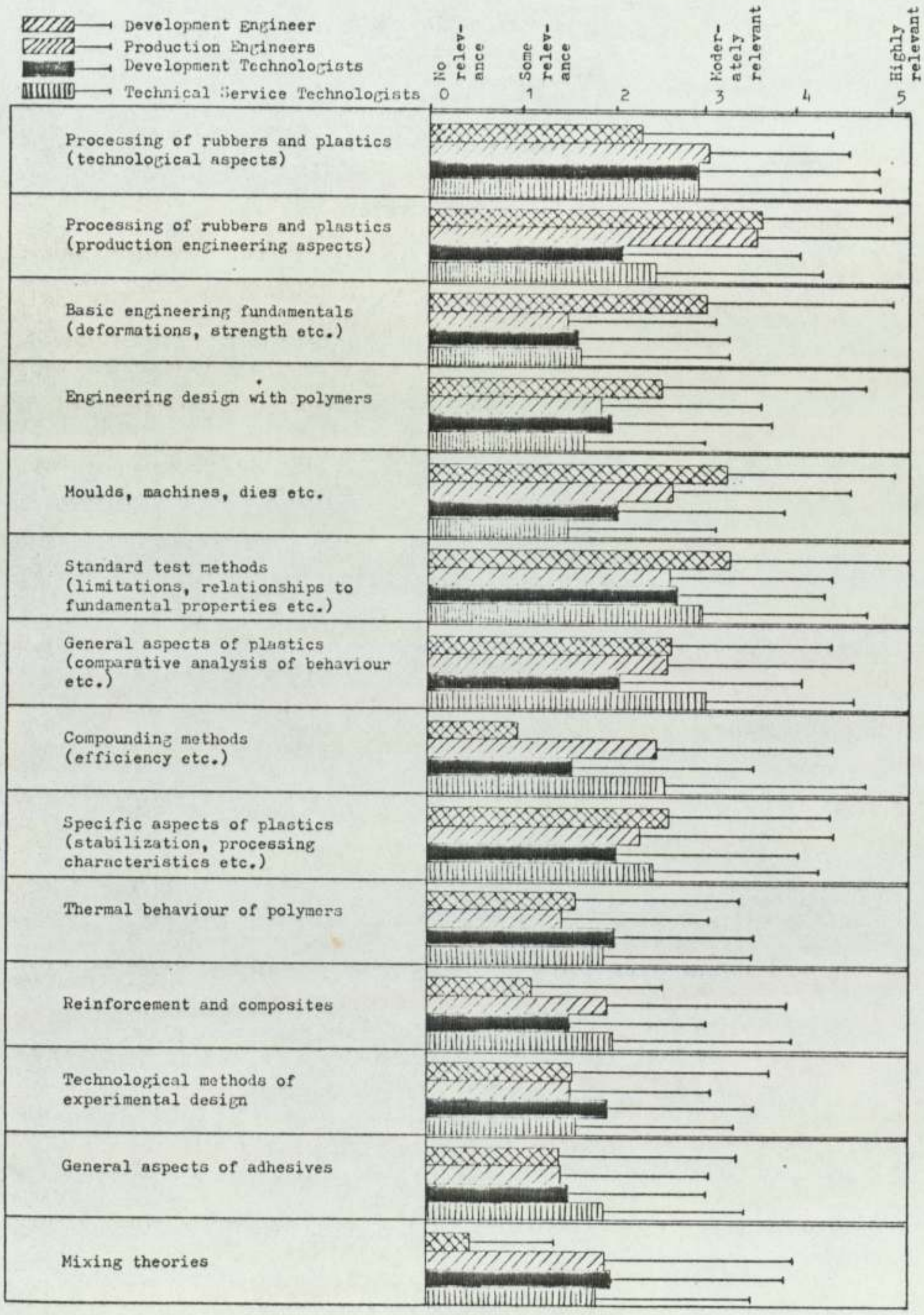


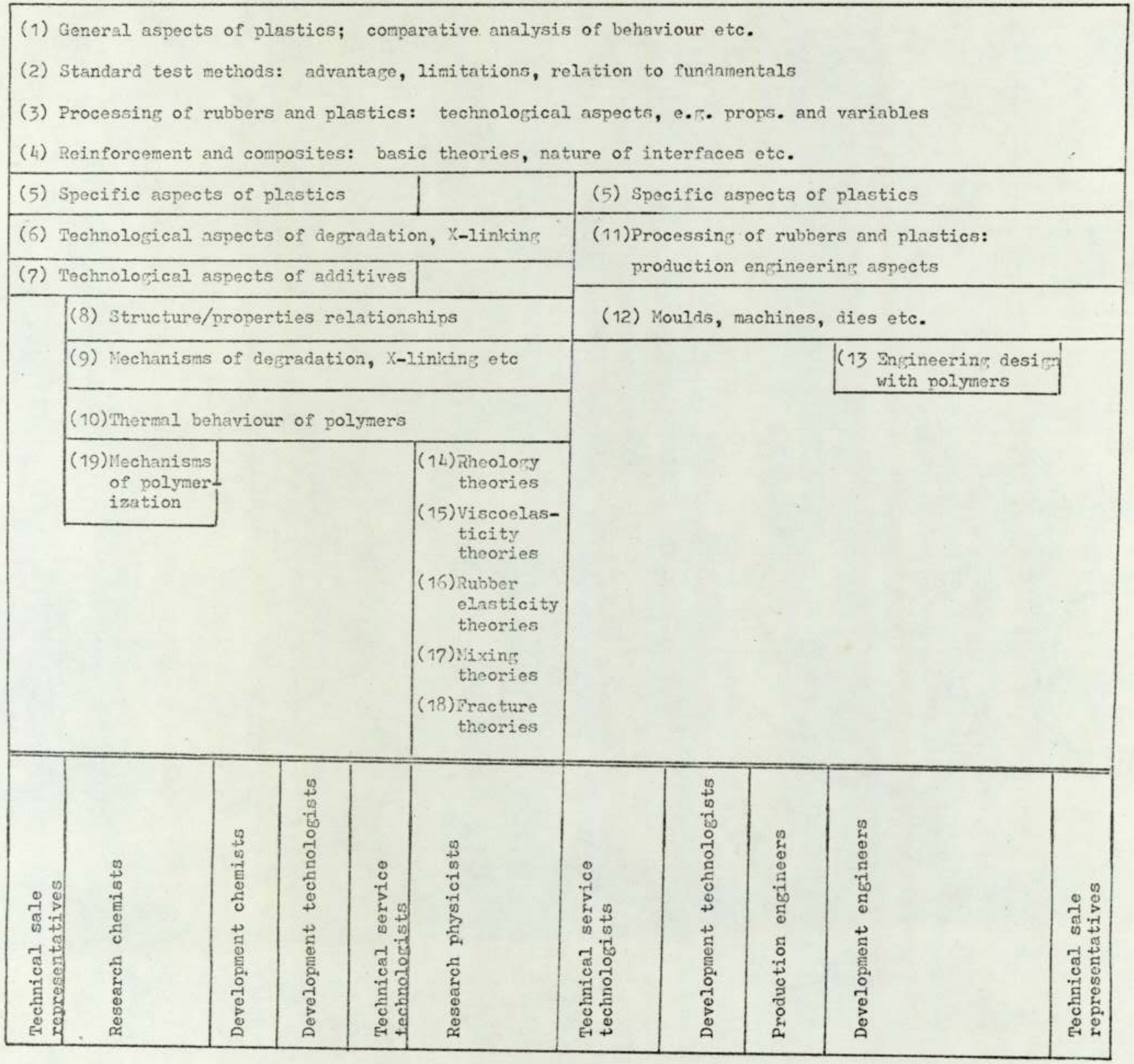
Fig. 4.18: Main Survey



(i.e. rating = 2) and average score + 1 standard deviation falling between "some relevance" and "moderately relevant" (i.e. rating = 3). Fig. 4.17 shows the highest scores for research chemists, development chemists, development technologists and technical service technologists, whereas in fig. 4.18 are included the appropriate scores for development engineers, production engineers, development technologists and technical service technologists. In other words development technologists and technical service technologists have shown a strong association, with respect to most relevant topics, with both chemists and engineers. With a few exceptions there seems to be also a strong association between research chemists and development chemists. The above associations can also be inferred from the data in table 4.30 with respect to the relationship between area of study and nature of the work of respondents, but do not seem to hold as regarding their relative distribution in the various sectors of industry (table 4.28). Inadequate representation in the sample could, however, account for the latter observation. Apart from the scores for 'compounding' and 'mixing theories' (highly related topics), development technologists and technical service technologists are strongly associated also with development engineers and production engineers. The association of these four types of workers is shown also with respect to both their distribution within various industrial sectors and their relationship to areas of study to which their work is related. (The anomaly of development engineers in the latter aspect is, perhaps, due to the small number of respondents in the sample).

In order to obtain an indication of the breadth of involvement in various topics of graduates employed in different job functions, a chart has been constructed (fig. 4.19) which clusters together those topics whose average score equals or exceeds the mid-point

Fig. 4.19: Main Survey: Topics of highest relevance, classified on the basis of job titles (scores ≥ 2)



between "some relevance" and moderately relevant", (i.e. scores $\geqslant 2$).

Technical service technologists and technical sales representatives are associated with both chemical functions and engineering functions. This may be expected for the former group of respondents owing to the wide-spread of activities of the firms from which the sample had been drawn (table 28). The latter group, on the other hand, are only representative of additives and polymeric compositions manufacturers and, therefore, it must be taken to indicate that the nature of their work is highly inter-disciplinary.

A similar chart was constructed (fig. 4.20) to identify those topics of least relevance, i.e. those topics whose average score did not exceed the 0.8 rating. An inspection of figs. 4.19 and 4.20 reveals that those topics concerning the general properties and processing behaviour of polymeric materials (plastics in particular) reached the highest level of relevance for all job titles specified. Chemical aspects of polymeric materials received high scores with respect to "mechanisms and technological considerations of additives, degradation and cross-linking reactions".

Mechanisms of polymerization reactions, on the other hand, reached the level of significant relevance (i.e. $\geqslant 2$) only in the case of research chemists. The traditional topics of polymer science such as mechanisms of polymerization, rubber elasticity theories, visco-elasticity theories, etc. were considered to be relevant only by those who are largely involved in research activities. It is also worth noting that neither the scores for methods of molecular weight determinations nor for solution thermodynamics theories reached the level of significance for any of the specified job titles. Furthermore, research chemists produced a higher score for "basic engineering principles" than for either of these topics, which is congruent with the finding that 43% considered their work to be related to material science and only 30% considered it to be associated with industrial chemistry. It is noteworthy also that 54.3% of research chemists ticked the "some relevance" column for molecular weight determinations and 61.7% indicated that specialists are available in their companies who deal specifically with these aspects of the work.

In general for most of the topics deemed to have "some relevance" (Appendix II, table BII7) the reason specified was that "a broad knowledge" is adequate for their work. The only topics for which there was an appreciable proportion of respondents (i.e. > 45%) who indicated that "specialists were available in their company" were:

(a) Molecular weight determinations,

(b) Chemical structure characterisation

(c) Thermal analysis, and

(d) Machinery.

The topics, on the other hand, which the respondents indicated to have "some relevance" but in which they would have liked to get more involved were: Mechanisms of action of additives; technological aspects of additives; mixing theories and compounding methods.

(iv) <u>The response of graduates, classified on the basis of areas of study to which their work is related</u>

There is little difference in the distribution of tasks of various graduates when classified on the basis of the selected areas of studies to describe the nature of their work. Those who chose the designation of "material science" are, however, somewhat more involved in research and less in technical service and sales than the others (Fig. 4.21), which may account also for their somewhat greater involvement in mathematics (table 4.32). While the distribution of employment of material scientists was wide spread, industrial chemists were mostly employed with polymer producers and engineers/manufacturing technologists mainly in the processing sector of the industry (table 4.31). By selecting topics on the basis of a minimum value of the average score equivalent to the designation "some relevance" i.e. rating = 1) and a minimum value for the average score + 1 standard deviation falling between the designation "some relevance" and "moderately relevant" (i.e. rating = 2), it is possible to bring to light those areas which are mostly related to the field of study selected by the graduates to describe the nature of their work (Fig. 4.22 and 4.23).

In addition to those topics which received a low score, irrespective of the type of classification used, there are others which failed to reach the minimum relevance score level in each of the areas of study specified. These are respectively:

(a) For Industrial Chemistry: fracture mechanisms; engineering design with polymers; moulds, machinery etc; basic engineering fundamentals and technological aspects of rubber elasticity.

(b) For Material Science: technological aspects of polymer solutions.

(c) For Engineering/Manufacturing Technology: methods of structure determination; technological aspects of polymer solutions. It is worth noting that for those four respondents who chose the description "Physical Chemistry" to describe the nature of their work, the ranking and rating of the relevant topics were as follows:

1. Technological aspects of experimental design (2.75 $\pm$ 2.28)
2. Statistical methods for research (2.50 $\pm$ 1.60)
3. Optical properties (effects of additives, processing etc.) (2.25 $\pm$ 1.92)
4. Technological aspects of rheology (2.25 $\pm$ 1.30)
5. Molecular weights determinations (1.75 $\pm$ 1.30)
6. Surface and interfacial properties (1.75 $\pm$ 1.29)
7. Standard test methods (limitations etc.) (1.50 $\pm$ 0.86)
8. Critical path and net-work analysis (1.50 $\pm$ 2.06)
9. Mixing theories (1.50 $\pm$ 1.50)
10. Mechanisms of degradation reactions (1.25 $\pm$ 1.10)
11. Mechanisms of polymerization reactions (1.00 $\pm$ 1.22)
12. Mechanisms of cross-linking reactions (1.00 $\pm$ 1.22)
13. Technological aspects of polymer solutions (1.00 $\pm$ 0.00)

Those topics which reached a minimum mean score of 2.0 using the weighted rating 0,1,3,5 have been listed in fig. 4.24 and clustered according to the area of study specified by the respondents.

Fig. 4.20: Main Survey:

Topic areas of least relevance, classified on the basis of job titles used. (Topics shown are those whose averages score was below 1.00)

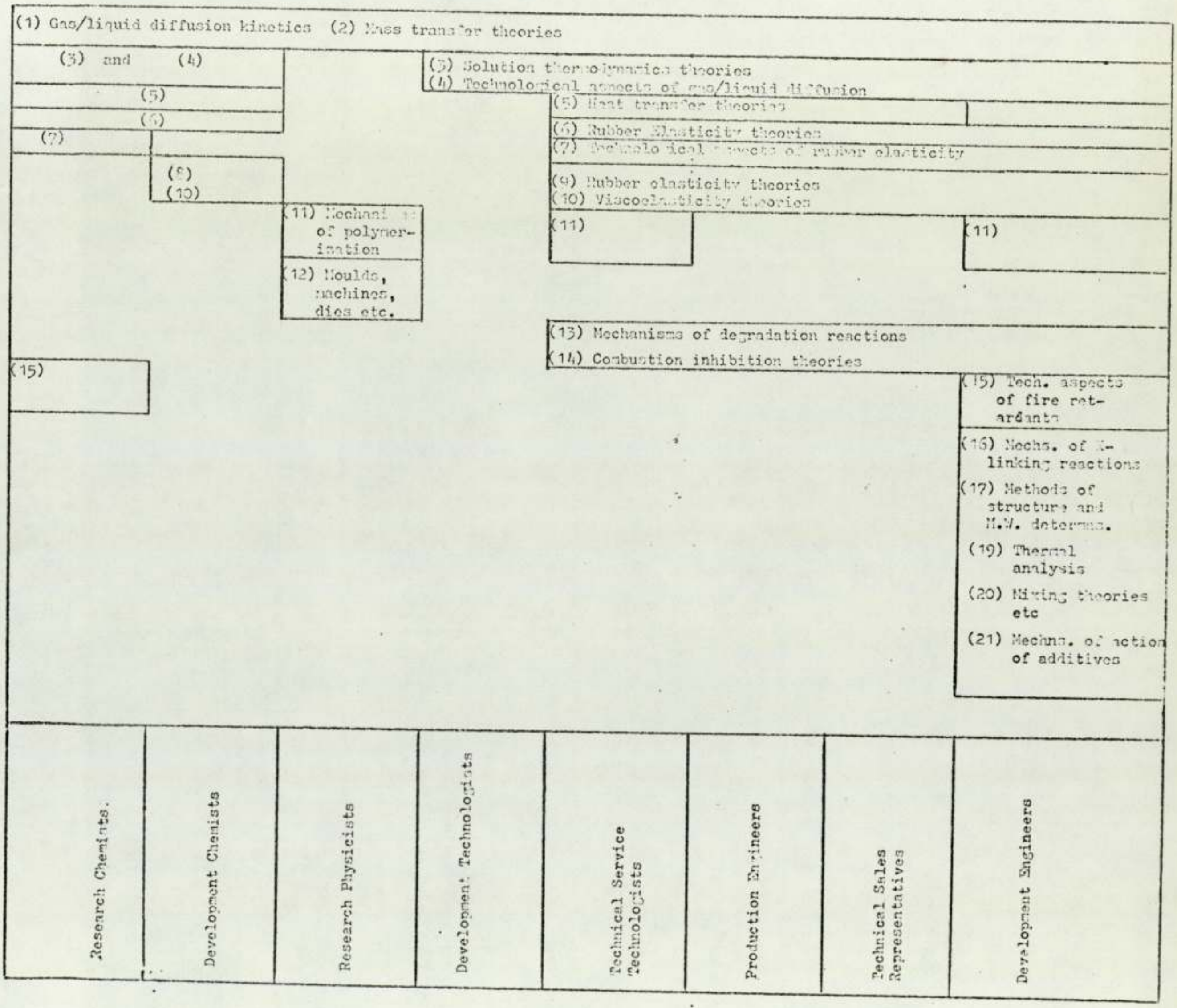


Fig. 4.21: Main Survey:

Distribution of tasks, classified on the basis of area of studies related to the nature of the work of graduates
(Mean + standard deviation)

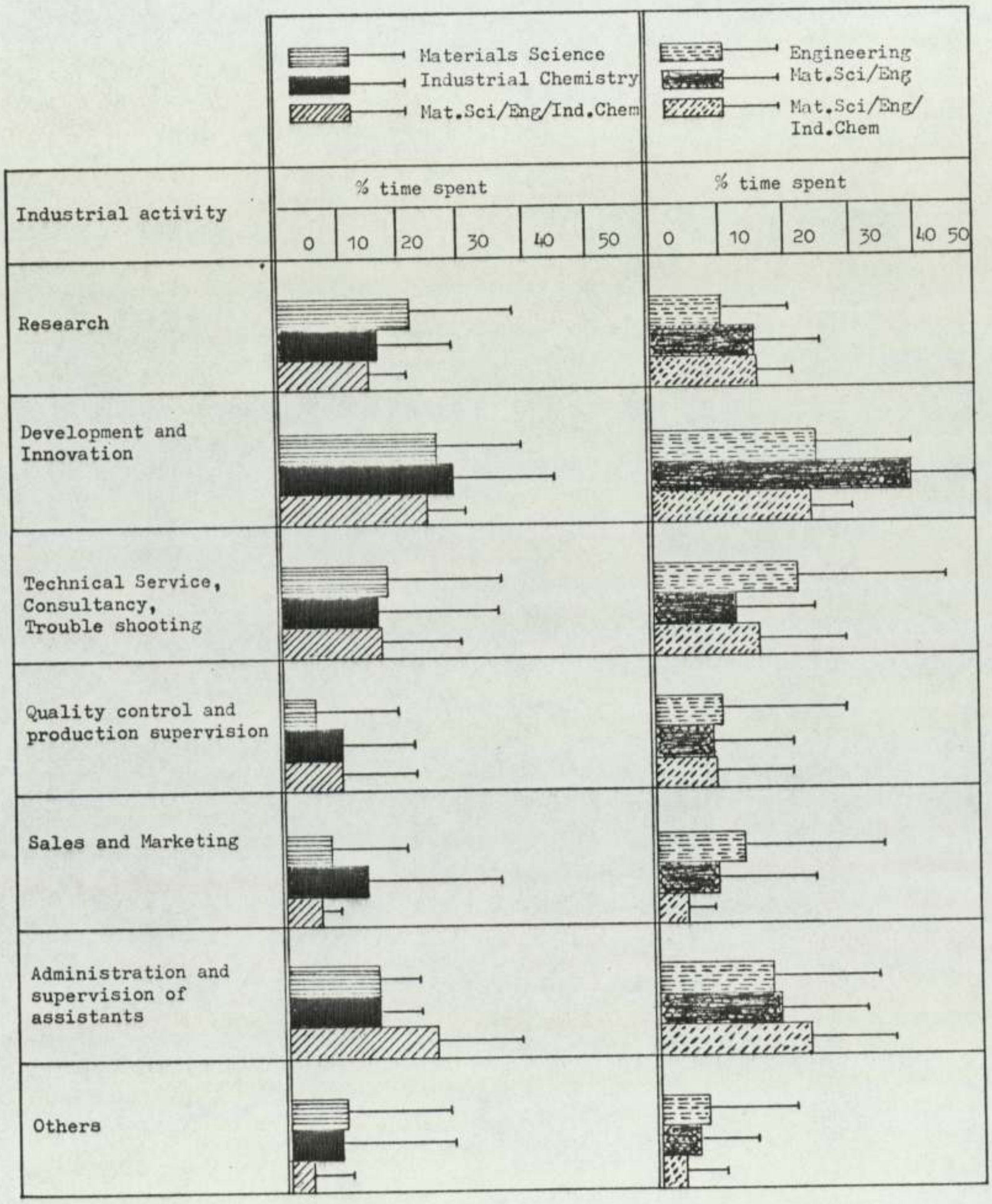


Fig. 4.22: Main Survey:

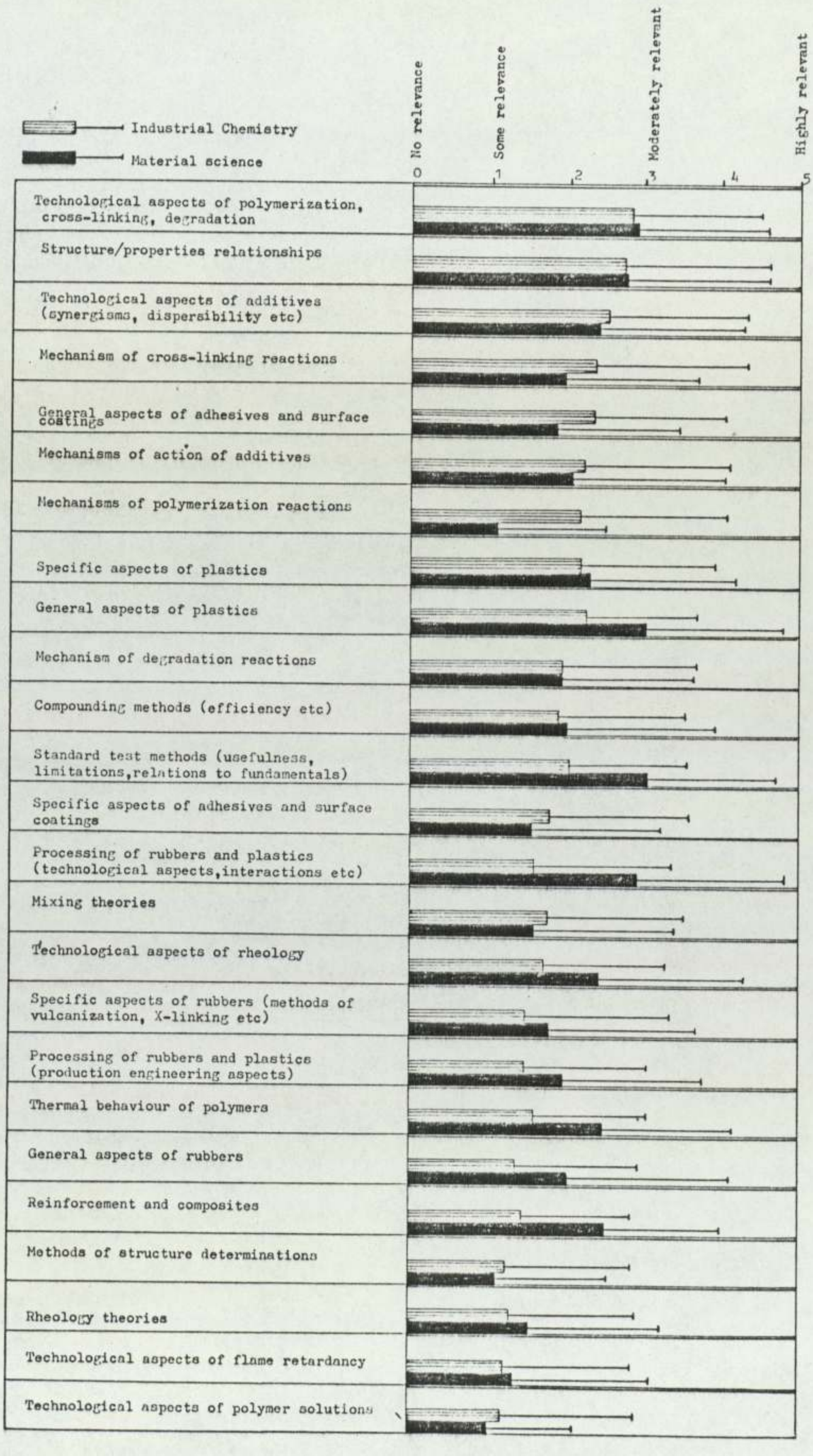


Fig. 4.23: Main Survey:

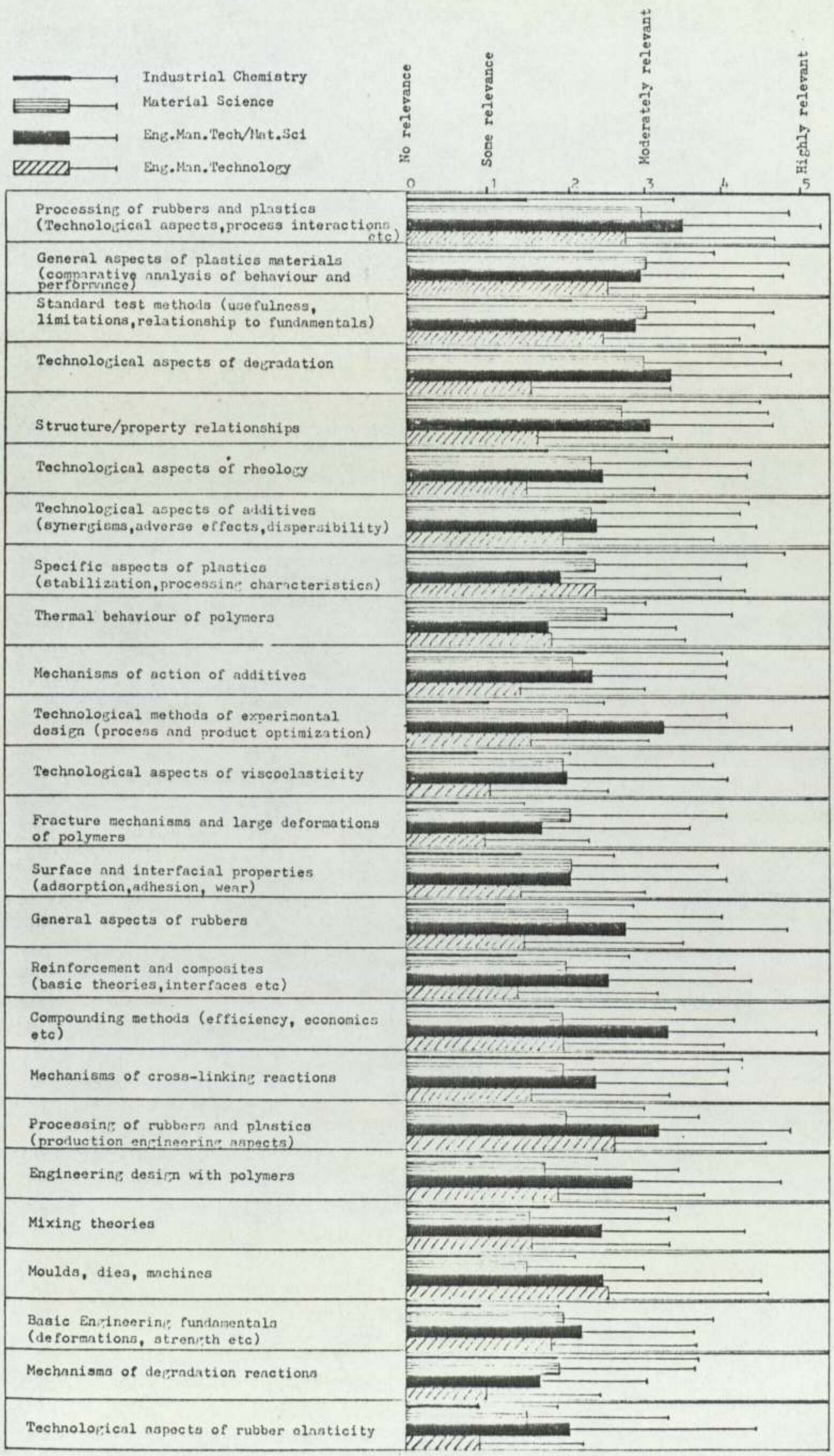


Table 4.31 : Main Survey :

Distribution of graduates (%) in the different sectors of the polymer based industries, classified according to the field of study to which their work is related .

	Ind. Chem.	Mat. Sci.	Mat.Scien/ Eng.	Manuf. Techn.	N
Additive manufacturers	11.6	17.0	7.2	11.6	20
Polymers and compositions manufacturers	54.5	32.0	28.5	30.0	72
Engineering/Processors	11.8	18.9	50.0	40.0	58
Machinery manufacturers	0.0	.0.0	0.0	7.8	7
End users of polymer products	16.0	18.9	7.2	13.3	30
Others (e.g. Research Associations, Govern. labs)	4.6	13.2	7.2	3.3	13
Total N	43	53	14	90	

$\chi^2 = 65.70$; D.F. = 40; $\alpha = 0.005$

Table 4.32 : Main Survey :

The relative importance of some general technological abilities.

Mean rating values	Ind. Chem.	Mat. Sci.	Mat.Sci/ Eng.	Man.Tech.
a) Scientific knowledge	3.0±1.2	2.7±1.0	2.4±0.8	2.5±1.0
b) Practical skills	2.6±1.15	2.5±0.9	2.8±1.2	2.8±1.2
c) Ability to acquire relevant information	2.7±1.2	2.5±1.0	3.1±1.4	2.9±1.2
d) Common sense	2.8±1.0	2.9±1.1	2.7±0.9	3.2±1.2
(i) Application of mathematics	1.07	1.56	1.50	1.27

Note:- rating for (a), (b), (c) and (d): wholly = 5, mainly = 4, partly = 2, not at all = 0
- rating for (i): very often = 5, often = 3, rarely = 1, never = 0.

From this table it can be seen that the majority of relevant topics fall within the designation of "material science" with leans towards both the chemical and engineering aspects of the technology of polymeric materials. At the chemistry end of the range of disciplines there are topics concerning mechanisms of polymer degradation whereas at the engineering extreme one finds topics dealing with machinery and tooling aspects.

For those few respondents who chose the designation Industrial Chemistry/Material Science/Manufacturing Technology the score for the relevance of topics specified is intermediate between the scores for each area of studies when considered individually. (Appendix IIb, table BII7) It is to be noticed that topics on general and specific aspects of rubbers do not feature in the list of topics of highest relevance, when the classification is made on the basis of the field of study selected by the respondents to describe the nature of their work. These topics, however, showed a high level of relevance for the classification made on the basis of nature of degree taken (score for polymer chemists / technologists on general aspects of rubbers = 2.23 ± 2.05) and on the basis of job title designation. Topics on general aspects of surface coatings and adhesives appear in fig. 4.24 and there was also a high proportion of polymer chemists/technologists who indicated both in their answers to Q.9 (Appendix Id) and in the form of comments that it is desirable to place greater emphasis on studies of adhesives. Furthermore about 25% of respondents gave the rating 3 or 5 to both general aspects of adhesives and plastics, and about 50% have given a similar rating to a combination of either general aspects of plastics, adhesives, surface coatings and rubbers. This seems to point, therefore, to a need to include all the major classes of polymeric products in courses dealing with polymer technology.

Table 4.31 reveals that the majority of those who have indicated that their work is in the field of industrial chemistry are employed in the polymer producing sector and those who have chosen the designation manufacturing technology are employed mainly in engineering/processing organisations. Those who have indicated that their work is related to material science, on the other hand, are spread throughout the various sectors of the "polymer" based industry.

From table 4.32 it can be inferred that the technologists involved in manufacturing and engineering functions value highly "common sense" and the "ability to retrieve information" in performing their tasks, whereas those who have associated themselves with chemical functions regard the underlying scientific principles as being the most important.

Taken in combination with the data in fig. 4.24, these findings seem to reinforce the generally accepted view (see the SRC working party report on polymer engineering - February 1975) that the chemical aspects of polymer science and technology are reasonably well established and are within the reach of industrial workers, whereas the underlying physical and engineering concepts are not well understood. Alternatively, it may well be that the physical and engineering principles available either are not within the grasp of industrial workers or cannot be applied directly to the solution of industrial problems.

(v) Other inferences from the classification of responses on the basis of the areas of study

In table 4.33 are shown the correlation coefficients between mean relevance-scores for those topics contained in fig. 4.24 and the scores afforded for the same topics by respondents in various job functions. In every case the correlation is rather low and the R values are not statistically significant (i.e. $\alpha \gg 0.05$) This, however, is mostly due to the fact that the distributions of responses are rather broad.

Despite the lack of statistical accuracy, it is possible, however, to make the following qualitative inferences:

- Topics associated with industrial chemistry exhibited the highest correlation with research chemists, development chemists and technical service technologists.
- Topics associated with material science showed the highest correlation with research chemists, development chemists, development technologists and technical service representatives.
- Topics associated with material science/engineering were mostly correlated with development technologists and production engineers.
- Topics associated with engineering/manufacturing technology displayed the highest correlation with development technologists, production engineers, sales representatives and development engineers.
- The sum of correlation coefficients was greatest for the case of material science, which seems to confirm that the topics associated with this area of study are the most relevant ones in the polymer based industries.
- Research Physicists displayed the lowest R values for all four main areas of study specified, which indicates clearly that they were the least typical of the population.

Fig. 4.24 Main Survey:

Relevance of topics, classified according to the area of study specified by the respondents as being related to their work in industry. (The selection criterion for the topics shown is based on an average score ≥ 2 on the rating 0-1-3-5)

Industrial Chemistry	Material Science	Mater.Science/ Manuf. Techn.	Material Science	Material Science/ Manuf. Techn.	Engineering/ Manuf. Techn.
1. General aspects of plastics; 2. Specific aspects of plastics; 3.* Technological aspects of additives; 4. Technological aspects of degradation etc.					
5. Technological aspects of cross-linking reactions; 6. Mechanisms of cross-linking reactions. 7. Mechanisms of action of additives; 8. Structure/property relationships			9. Processing of rubbers and plastics (techn. aspects) 10. Processing of rubbers and plastics (prodn. aspects) 11. Standard test methods; 12. Engineering fundamentals (Basic principles) 13. Compounding		
14. Mechanisms of degradation reactions				15. Moulds, dies, machinery etc.	
26. Mechanisms of polymerization reactions	17. Technological aspects of experimental design and statistics 18. Technological aspects of rheology; 19. Technological aspects of visco-elasticity; 20. Reinforcement and composites; 21. Surface and interfacial properties.				
27. General aspects of adhesives and surface coatings	22. Thermal behaviour of polymers 23. Fracture and large deformations	24. Engineering design with polymers 26. Techn. aspects of rubber elasticity	22. Thermal behaviour of polymers 24. Fracture and large deformations	24. Engineering design with polymers 26. Tech. aspects of rubber elasticity	
Mostly Chemistry based topics	Chemistry/Physics/Engineering based topics				Largely Engineering based topics

Note: * mean score for Eng./Manuf. Techn. = 1.86

Fig. 4.25 : Main Survey:

Topics of least relevance, classified on the basis of field of studies to which the work of respondents is related . (Topics shown are those whose average score was below 1.00).

<table>
<tr><td colspan="4">1) Solution thermodynamics theories; 2) Kinetic aspects of polymerization, degradation and cross-linking reactions; 3) Technological aspects of solution thermodynamics; 4) Combustion inhibition theories; 5) Heat transfer theories. 6) Mass transfer theories; 7) Molecular weights determinations.</td></tr>
<tr><td>8) Engineering principles
9) Moulds, machines dies etc.
10)Engineering design with polymers
11)Fracture mechanisms and large degradations
12) Orientation and anisotropy (methods of determination and significance in product performance
13) Dielectric properties
14) Optical properties</td><td></td><td colspan="2">14) Methods of structure determination
15) Thermal analysis
16) Gas/liquids diffusion in polymers
17) Techn. aspects of diffusion
18) Orientation and anisotropy (methods of scientific determination)
19) Optical properties</td></tr>
<tr><td></td><td></td><td></td><td>20) Rheology theories
21) Viscoelasticity theories
22) Techn. aspects of rubber elasticity
23) Fracture mechanisms and large deformations
24) Orientation and anisotropy (determination and significance in design)
25) Dielectric properties
26) Optical properties</td></tr>
<tr><td>Industrial Chemistry</td><td>Material Science</td><td>Mat.Science/ Man. Techn.</td><td>Engineering/ Man. Tech.</td></tr>
</table>

Table 4.33 : Main Survey:

Correlation coefficients between mean scores on topics of relevance between areas of study and job title designations

Topics selected for the calculation of R are those shown in fig. 4.2.4	Industrial Chemistry			Material Science			Mat.Sci/ Eng.Man. Tech.			Engin./ Man.Techn.			
	R	t	α	R	t	α	R	t	α	R	t	α	Σ R
Research chemists	0.13*	0.6	0.05	0.10*	0.5	0.05	-0.004	0.2	0.05	0.02	0.1	0.05	0.25
Development chemists	0.13*	0.6	"	0.12*	0.6	"	0.07	0.3	"	0.07	0.3	"	0.39
Research Physicists	-0.05	-0.2	"	0.06	0.3	"	0.04	0.2	"	-0.05	0.2	"	0.00
Development Technol.	0.08	0.4	"	0.11*	0.5	"	0.10*	0.5	"	0.12*	0.6	"	0.41
Tech. Service Techn.	0.10*	0.5	"	0.11*	0.5	"	0.09	0.4	"	0.11*	0.6	"	0.41
Production Engrs.	0.07	0.3	"	0.08	0.4	"	0.11*	0.5	"	0.13*	0.6	"	0.39
Sales Reps.	0.09	0.4	"	0.07	0.3	"	0.06	0.3	"	0.12*	0.6	"	0.34
Development Engrs.	-0.05	-0.02	"	0.05	0.2	"	0.06	0.3	"	0.12*	0.6	"	0.18
Σ R	0.50			0.70			0.53			0.64			

4.4.3 Survey carried out by the Plastics Institute of America

During the writing of the thesis, the author has come across a publication of the survey carried out by the Plastics Institute of America (Plastics Engineering, July 1974, pp 47-48) which recorded the opinion of senior industrialists representing material suppliers, material converters, machinery manufacturers and end users of polymeric materials. These results bear a strong similarity to those obtained by the present investigation and are shown below as they appeared in the original publication. In the interpretation of these data it must be taken into account that Plastics Technology was defined as practical training at technician level. The general consensus was also that Material Science of polymers is the most important area of study (see table 3 below). The comments varied considerably, but it is worth quoting the following abstract:

"Several respondents referred to practical knowledge and problem-solving ability as primary requirements, although one machinery manufacturer said that 'practical knowledge useful to industry will not come out of formal schooling'. Finally one end-product user summed up by saying: 'we would like to avoid students infatuated with ...narrow, impractical, dogmatic studies which are of little use. Universities should continually re-examine what the world needs and should avoid aloofness and isolation from the industry'"

Table 1. Importance of undergraduate study programs to the plastics industry

a. On a scale 1 (high) to 5. Only top 5 courses in each area are listed. b. Tie

Program	Rating[a] End user	Machinery or engineering	Material converter	Material supplier	Consensus
Polymer science and engineering					
Organic chemistry of macromolecules	3	5	3	2	3
Physical chemistry of macromolecules	1	4	2	3	2
Biopolymers	-	-	-	-	-
Polymer characterization	2	3	1	1	1
Morphology of polymers	5	-	5	4	-
Solution properties of polymers	-	-	-	-	-
Non-Newtonian and viscoelastic flow	-	1	4	5	4
Polymerization engineering principles	4	2	-	-	5
Polymer conversion					
Plastics processing theory	3	1	1	1	1
Material and energy balances	4	3	5	5	4[b]
Extrusion of plastics	2	2	2	2	2
Molding of plastics	1	5	3	3	3
Process control systems	-	4	4	4	4[b]
Principles of fiber and textile eng.	5	-	-	-	-
Material science (of polymers)					
Composite materials and structure	3	2	2	3	3
Mechanical behaviour of polymers	1	1	1	1	1
Polymeric materials laboratory	2	3	3	2	2
Dielectric properties of materials	4	5	4[b]	4	4
Basic fiber science	5	4	4[b]	5	5
Part design and applications					
Plastics applications techniques	1	1	1	1	1
Product design	2	2	2	2	2
Color science	3	3	3	3	3
Plastics technology					
Plastics laboratory	1	1	1	1	1
Plastics fabrication workshop	2	3	3	2	2
Basic electronics and hydraulics	4	2	4	5	4
Mold, tool & die design	3	5	2	3	3
Technical drawing	5	4	5	4	5

4.4.3 Survey carried out by the Plastics Institute of America

During the writing of the thesis, the author has come across a publication of the survey carried out by the Plastics Institute of America (Plastics Engineering, July 1974, pp 47-48) which recorded the opinion of senior industrialists representing material suppliers, material converters, machinery manufacturers and end users of polymeric materials. These results bear a strong similarity to those obtained by the present investigation and are shown below as they appeared in the original publication. In the interpretation of these data it must be taken into account that Plastics Technology was defined as practical training at technician level. The general consensus was also that Material Science of polymers is the most important area of study (see table 3 below). The comments varied considerably, but it is worth quoting the following abstract:

> "Several respondents referred to practical knowledge and problem-solving ability as primary requirements, although one machinery manufacturer said that 'practical knowledge useful to industry will not come out of formal schooling'. Finally one end-product user summed up by saying: 'we would like to avoid students infatuated with ...narrow, impractical, dogmatic studies which are of little use. Universities should continually re-examine what the world needs and should avoid aloofness and isolation from the industry'"

Table 2. Importance of graduate study programs to the plastics industry

Program	Rating[a]				
	End User	Machinery or engineering	Material converter	Material supplier	Consensus
Mechanical Engineering	-	1	3	-	5
Chemical Engineering	5[b]	3	4	2	3
Electrical Engineering	-	-	-	-	-
Material sciences	3	-	-	-	-
Polymer science	1	5	5	1	2
Chemistry	5[b]	-	-	-	-
Industrial technology	-	-	-	-	-
Plastics engineering	2	2	1	4	1
Plastics technology	4	4	2	3	4

a On a scale from 1 (high) to 5. Only top five courses in each area are listed
b tie

Table 3

Order of importance, in your area of expertise, of courses of study in the following five disciplines?

	Res.	Dev.	Mfg.	Mkt.	Adm	Age	Average for 35 Questionnaires
Polymer science & eng.	1	1	3*	2	4	1	2
Polymer conversion	2	3	2	3	2	3	3
Material science (of polymers)	3	2	1	1	1	2	1
Plastic part design and applications	4	5	5	5	5	5	5
Plastics technology	5	4	3*	4	3	4	4

4.5 The HMSO Report on recommendations for graduate training in manufacturing technology

The committee of Manpower Resources for Science and Technology set up a working party in 1965 to look specifically into the needs of the manufacturing industries (mainly electrical and mechanical). Two reports containing recommendations of training needs were issued in 1968 by the Chairman Dr. G.G. Bosworth. The first report on "Product technology", deals specifically with industrial products such as turbines, electrical switch gear., semi-conductor devices etc., and emphasises the methods and systems of production related to ranges of components and assemblies.

The second report on "Manufacturing Technology" deals with the general aspects of production, that is the means by which ideas and materials are converted into goods. It is, therefore, the latter which has direct relevance to this investigation.

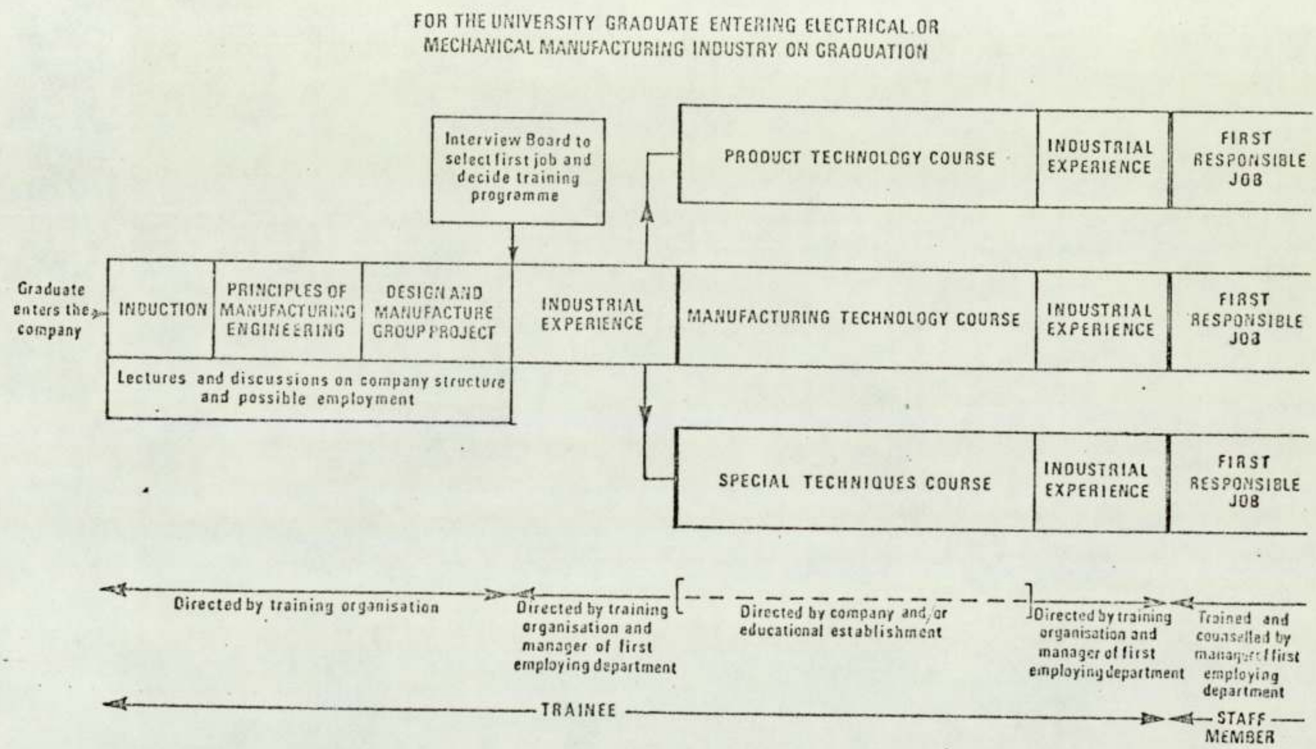
The working party was mainly concerned with the formulation of guide lines for a "matching section" for graduates in the interim period between leaving university and entering industry. The scope of the recommendation, it was stated is not restricted, however, to post-graduate courses.

The need to establish courses in Product and Manufacturing technology was recognised in the light of the Swann Report (73) which stressed the need to increase the flow of scientists, engineers and technologists into industry, and in view of the dramatic reduction of school leavers taking part-time studies and receiving on-the-job training.

It had been noted that as a result of the latter events industry has experienced some difficulties in attracting graduate scientists and technologists in manufacturing activities, and it was felt tht this situation was created by the inability of traditional university courses to inject into students sufficient enthusiasm towards manufacturing activities and to promote adequate abilities for these vital industrial tasks.

The framework which has been suggested by the working party to correct these deficiencies is shown below (fig. 4.2.6).

Fig. 4.2.6



To obtain evidence and an assessment of the value of the proposed scheme, discussions were held with employers, educationalists and graduates. Recent graduates emphasized that manufacturing technology/engineering could be dealt with at undergraduate level and could replace the less useful subjects generally taught.

The working party emphasised, however, that a much closer and more detailed examination of specific needs should be carried out before translating these recommendations into a formal course*. Furthermore it was also recognised that it may be too difficult to devise a single course which would fulfil the needs of all industries concerned and that adjustments would have to be made to suit more specific needs.

4.5.1 The scope of manufacturing technology

The key characteristics of manufacturing technology were expressed in the following definition:

> "The manipulation of materials in an optimum way in order to obtain the desired shapes and physical properties".

The main components to be found in the study of manufacturing technology were seen to contain both static and dynamic elements, the static components being the processes, materials and organisational structures involved, whereas the dynamic aspects comprise process optimization, measurements etc. In other words, it was concluded that the theme of a course in manufacturing technology should be developed around Processes and Systems.

Processes consist of processing elements and processing stations or factories, whereas systems are concerned with the suprastructure elements of an enterprise, e.g. measurements, control, communication, human factors etc.

Three groups of process elements were identified:

(i) Those which impose a definite geometry on a material or several connected materials.

(ii) Those which produce desired properties in the body or surface of the material, e.g. heat treatments, finishing etc.

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* Ø 35, p.15.

(iii) Those which impose a controlled environment around or within the material, e.g. protective coatings, printing etc.

The processing stations or factories were regarded as relatively self-contained man-machine units with an in-flow and out-flow of materials, services and information.

Both processes and factories must work under optimum conditions, hence there is an interaction of processes and system components which involves, therefore, substantial management functions.

The abilities which a course in manufacturing technology should develop were stated as follows:

(a) The ability to identify objectives and environments, which involves knowledge and understanding of the environment, perception of objectives, and judgement to establish priorities.

(b) The ability to create and implement the means of achievement, which involves the creation of a favourable climate for achievement of the objectives, and knowledge and understanding of the uses of resources available.

(c) The ability to measure the extent and efficiency of the achievement.

In the interim report issued in 1966, some specific outlines of the aims and contents of courses in manufacturing technology/engineering were given. The main aim which was envisaged was:

> "To acquaint the student with the problems of turning ideas into hardware, with the processes and techniques for doing this - their advantages and limitations; with materials at his disposal - their properties and performances; and with the way in which the requirements of design, manufacturing and cost interact".

The recommended course content was to be based on materials science and technology with emphasis on methods and processes and/or materials properties. The foundation unit of such a course would be concerned with studies of materials behaviour from the general point of view of solid state physics. The main body of the course, on the other hand, would consider processes in relation to materials properties, using non-metallic materials examples whenever possible.

CHAPTER 5

TRANSLATION OF INDUSTRIAL NEEDS INTO CURRICULAR STRUCTURES LEADING TO POLYMER TECHNOLOGY QUALIFICATIONS

5.1 Inferences on the general tasks of polymer technologists in industry

The existence of substantial proportion of firms in U.K. (20 - 35%) involved with polymeric materials, revealed by one of the questionnaire surveys and implied by authoritative statements of senior industrialists and statutory organisations, such as the National Economic Development Office, clearly indicates that industry is heavily dependent on the flow of communication and expertise in polymer technology.

The increasing investments forecast for the processing sector and for those manufacturing concerns using polymeric materials, e.g. furniture, car components manufacturers etc., suggest that polymer technologists will play an increasing role in development, production and marketing functions within a much broader range of industries.

The evaluation of industrial needs was carried out at various levels of specificity. At the most general level the activities of industry as a whole were examined to identify the extent of involvement with polymeric materials and the type of main academic background of the technologists;employed to deal with these materials. At the most specific level, information was obtained from individual graduates within those sectors of industry dealing with polymeric materials; and research associations and other Government Laboratories.

The responses recorded were mainly in the cognitive domain and were classified at various levels of abstraction, i.e. the respondents were asked to make both judgement on general abilities required in their jobs and to provide factual information on specific matters. Some response was also obtained in the affective domains since certain questions involved elements in the "receiving" and "valuing" categories of Bloom's taxonomy. In one of the questions, for instance, the respondent was required to indicate whether he would have liked to receive further instruction on the topics specified. In another survey, the respondent was asked to make judgement as to whether he felt that a broader understanding of materials, acquired through formal education, would improve prospects in industry.

From the results of these surveys carried out it can be inferred that polymer technologists are more associated with functions concerning the utilisation of polymeric materials than with polymerization, synthesis of additives, design of plants, fabrication equipment and designing structures or components from polymeric materials. The majority of polymer technologists cannot be considered to be employed as specialists since they are appreciably involved in all three major industrial functions, i.e. development, production and marketing, and their work is essentially multi-disciplinary. Therefore, in order to be able to derive general educational aims, it is worth considering the types of tasks that they are likely to perform in industry.

The range of industries concerned and the likely functions of polymer technologists may be represented as follows:

Fig. 4.27

Industrial Sectors	Likely functions of polymer technologists
Additives and auxiliary materials manufacturers	Marketing
Materials producers	Materials development, marketing
Processors and fabricators	Process development, production supervision
Manufacturing industry	Product and process development, production supervision
Machinery manufacturers	Process development, marketing

From discussions held with several industrialists, a specification of tasks for the three main industrial functions was derived, i.e.:

Development functions:

The term development is used here in the context of the definition given by Ward (68). It is understood that research to study the causalities of the behaviour of polymeric materials in a given situation is implicit in such a definition. Development functions include:

(i) Studying needs for experimentation and formulating objectives

(ii) Acquisition of background information

(iii) Planning and performing experiments

(iv) Technical/economic assessment of experimental results and their implication for commercial exploitation.

(vi) Liaison with marketing and production departments

(v) Report writing and verbal communication

(vii) Supervision and training of assistants

(viii) Laboratory administration

It will be noticed that in development functions:

a) actions are mostly programmed,

b) decisions are taken on the basis of acquired evidences,

c) knowledge of specifics is not as important as the ability to codify and retrieve information.

Marketing functions

Marketing functions comprise all the interface activities between development, production and customers and the role of technologists involved is to expedite the flow of information and courses of action. The main tasks in marketing functions can be subdivided as follows:

(i) Assessing and developing markets for new products.

(ii) Providing an up-to-date assessment of competitor products.

(iii) Customer liaison on technical/economic matters and providing assistance on product/process development .

(iv) Trouble shooting of customer problems.

(v) Preparing tenders and organising distribution of products.

(vi) Liaison with development and production departments.

(vii) Report writing and verbal communications.

In marketing functions it would seem that:

a) actions are mostly unprogrammable,

b) knowledge of specific facts is very important,

c) many decisions have to be taken on insufficient evidence.

Production functions

These functions comprise the following activities:

(i) Product/process control and development of suitable inspection procedures

(ii) Assessing specifications and allocating manufacturing programmes to specific plants, machineries etc.

(iii) Evaluation of manufacturing implications of new products.

(iv) Process evaluation, organising and assisting production trials.

(v) Organising maintenance of equipment and making recommendations for the acquisition of new components, plants, etc.

(vi) Assessing costs of production and organising incentive schemes to increase productivity.

(vii) Liaison with customers, marketing and development departments within the company

(viii) Training of assistants and unskilled personnel.

(ix) Report writing and verbal communications.

It could be inferred that in production activities:

a) there are both programmed and unprogrammed actions to be taken,

b) the majority of day-to-day decisions are taken on the basis of past experience, and

c) both knowledge of specifics and ability to codify and retrieve information are important.

Many of the activities specified for the three main functions are obviously related to one another and therefore they could be clustered into a generalised hierarchy of activities. Vice versa, other subsumed activities could be included in the list produced. For instance "the evaluation of manufacture implications of new products" would include the following subsumed tasks:

a) Assessing the supply position of raw materials.

b) Assessing machinery/plant capacity and labour requirements.

c) Assessing suitability of component design or product specification in relation to machinery/plant capabilities.

Similarly in development functions, the activity associated with "studying the needs of experimentation and formulating objectives" would subsume the "task of assessing the implications from patents, market requirements, production capacity etc.

It is unlikely, however, that it will be necessary to make a detailed breakdown of tasks within these functions, since at this level of specificity one is mainly seeking to derive a general classification of underlying abilities to be translated into educational objectives rather than an intensive training programme, nor can it be presumed that such a detailed analysis would be free of inaccuracies.

5.2 Inferences on the level of competences in polymer technology

Within the fabric of activities specified in the foregoing section, there is a need for manpower possessing various levels of competences. For the purpose of this investigation, as already stated in p 43, it will be assumed that there are three levels of competences or job grades required, i.e.:

Technicians	or Industrial assistants
Graduates	or Junior technologists
and Professionals	or Mature technologists.

These three designations are synonomous with the present qualification levels of the Institute of the Rubber Industry and the Plastics Institute. The general level of competences for technicians can be inferred directly from the description of responsibilities for a design draughtsman given by Kaufman (72), i.e.

a) to discuss with customers specifications and/or drawings for moulds and ancillary equipment;

b) to produce drawings for moulds;

c) to issue drawings for inspection department;

d) to modify designs to customer requirements.

The above can be translated into a generalised specification of level of competences for a technician as follows:

> "To execute courses of actions involving routine procedures on matters related to specific aspeds of the technology of polymeric materials".

The characteristics of graduates have been stated in several different ways; the description given by Buley (74) will be used here, however, as a basis for the specification of the level of competences of a graduate or junior technologist grade.

> Buley writes: "a graduate is someone who, by undertaking an intellectually demanding study of one or more bodies of organised knowledge, principles, hypotheses and ideas, has acquired certain fundamental intellectual qualities, including the ability to learn and to apply learning in new and unfamiliar situations".

Clearly the above description does not portray adequately the responsibilities of a graduate employed in the industrial functions discussed in the previous section. The interpretation of "ability to apply learning" is not sufficiently specific in behavioural terms, hence the following specification of competences of a graduate working with polymeric materials will be adapted for the purpose of this investigation:

> "To investigate in a disciplined manner problems associated with the utilization of polymeric materials and to create means of achieving predetermined objectives".

Finally, for the specification of competences of professional or mature technologists, use will be made of Schein's criteria (75). Although the majority of the criteria analysed by Schein appeared to fit best the traditional or "learned" professions of medicine, law and divinity, there are a few which appear to be applicable to the case in question. These are:

a) the professional possesses a specialised body of knowledge and skills that are acquired through a long period of education and training.

b) The professional makes decisions on behalf of a client in terms of general principles, theories and propositions which he applies to the particular case under consideration.

c) The professional's services to the client are assumed to be based on the objective needs of the client.

The client is any person or organisation from whom the professional derives his main source of income.

Although the direct client of a fully employed, salaried professional in industry, civil service or education is his employing organisation, in the definition of client must be included the community which the professional serves through his organisation. Since in such a situation it would be difficult to specify precise ethical codes, it will be assumed that the professional technologist recognises and accepts his moral responsibility to society at large in performing his duties.

A specification of competences and code of ethics for a professional or mature polymer technologist can be stated as follows:

"To propose suitable courses of action and take appropriate decisions on matters concerning the utilization of polymeric materials, and to exert his influence in decisions and courses of action taken by others in order to ensure that both natural and human resources are used for the social and material benefit of the community at large".

It is to be noticed that the specifications of competences given for a graduate and a professional respectively fit well the description of duties for a "scientist grade" of a processing company which the writer visited, i.e.

a) To further the commercial objectives of the company by applying scientific and technological expertise to the attainment of agreed technical targets.

b) To create new areas of commercial opportunity by seeking, finding, recognising and promoting technical innovations.

It is understood that competence specifications for technicians, graduates and professionals must not be interpreted too rigorously. In practice a technician may well be required to perform certain tasks which may fit the description of a graduate, while the latter may have to perform duties which overlap with those falling within the realm of responsibilities of a professional. In other words, there may well be more than one level of competence for each category, e.g. juniors and seniors, forming a continuous spectrum in the hierarchical structure of an organization rather than a subdivision in steps. Consequently, the subdivision of responsibilities into technicians, graduates and professionals is used here merely as a means of categorizing various levels of behaviours required in performing industrial tasks.

In addition to the level of competences described respectively for professional, graduates and technicians, it is necessary to formulate a framework for the types of competences or, more specifically, the areas of knowledge on which the activities specified are used.

This necessitates taking into consideration the demands of industry and the views expressed by practitioners. At present for development functions, industry seems to demand a larger proportion of graduates with a chemical background than engineers, whereas the reverse applies for production functions. In marketing functions, technical service in particular, the type of background is determined mostly by the nature of the market to be served, varying therefore from chemistry for sales to producers of raw polymers and compositions to engineering for sales to processors and manufacturing industry. From discussions held with industrialists and from the results of the surveys carried out, it can be inferred that by and large, except for design, plant installation and servicing (engineering functions) and polymer synthesis activities (chemical functions) in which polymer technologists have a negligible involvement, the subject bias of graduates and professionals cannot be easily identified. The majority, however, have associated their work with manufacturing technology and material science, and neither the more theoretical concepts of polymer science (polymer chemistry in particular) nor the typical subject matter of chemistry and chemical engineering degree courses were considered to be relevant. The range of activities performed by mechanical and production engineers appeared to be appreciably narrower than that of the bulk of the population examined. The range of subject matter, normally associated with the study of polymer technology, was also much more restrictive for the latter category of respondents. Consequently, since the bulk of the work of polymer technologists does not fall to a substantial extent within the realm of traditional degree courses, it would seem appropriate to use, instead, the theme suggested by the Bosworth Committee as a basis for the development of suitable curricular structures.

This conjecture is also supported by the views of metallurgists and by the implications conveyed in the examination of the subdivision of responsibility in a materials laboratory of a typical manufacturing industry (Fig. 4.17) which the writer visited.

As it has already been indicated, this does not at all imply that graduates in traditional disciplines such as chemistry, physics, mechanical engineering, etc., have no place in those industries producing and handling polymeric compositions. It merely points out that the bulk of the work carried out in these industries falls outside the areas of chemical synthesis and chemical characterization on one hand, and it is not so much concerned with theoretical design of equipment or components on the other.

Therefore chemical synthesis and equipment design activities may be regarded as specialistic functions, for which a strong background in single disciplines is more adequate than the more general, multidisciplinary training required for polymer technologists. In assessing needs in terms of training required for polymer technologists, the following observations must not pass unnoticed:

a) Graduates formally educated in the science and technology of polymers made strong criticisms of the excessive chemical contents of existing courses and urged to increase the emphasis on technological aspects, especially with regard to the production aspects of processing and the range of polymeric materials included in the curriculum. However, both the results of the survey on relevance of topics of study to industrial situations, fig. 4.24, and the manpower demands for the period 1972-1973, clearly indicate that a chemistry background is required to deal with polymer technology problems met with in industry.

b) Although there are several topics pertaining to polymer science (as it is known at present) that are not considered relevant, their technological implications must not be overlooked. For instance, the topic "solution thermodynamics" received a very low score in all cases and the frequency of the "some relevance" designation reached a maximum of 33% only for the case of research chemists. On the other hand, the subject "technological aspects of additives", in which the basic principle for predicting polymer/additive compatability is a thermodynamic one, has received an appreciably high score.

c) Technologists do not make appreciable use of mathematics in their work because they find it convenient to present their ideas and results in a descriptive manner or graphical/tabular form. It may well be, however, that the real reason is that technologists lack the confidence and skills required in approaching a novel problem in a quantitative analytical manner.

d) For the many topics which received a low score of "relevance", the practitioners indicated that a broad knowledge is nevertheless required.

Fig. 4.27

Typical subdivision responsibilities in an R & D laboratory of a manufacturing industry

CENTRAL PROCESS AND MATERIALS LABORATORY

ASSISTANT CHIEF MATERIALS ENGINEER

MATERIALS ENGINEERING

(1) Plastics, Standards, Design Process Data.
(2) Competitors Products, (3) Product Analysis

(1) Adhesives Consultancy (2) Plastic Foam
(3) Insulation Materials (4) Surface coating materials
(5) Non-metallic standards (6) Encapsulation materials
(7) Design Liaison (8) Toxic materials
(9) Effluent (10) Oils

(1) Design Liaison (2) Metallic Standards
(3) International Metallic Standards
(4) Alternative Metallic Materials
(5) Production Tooling (6) Service Failure Analysis
(7) Photography
(8) Advanced Examinations
(9) Material Quality Control Methods
(10) Branch Factory:-Trouble Shooting
(11) Evaluation of Magnetic Properties
(12) Evaluation of Work Hardening: Characteristics of Mild Steel
(13) Property Evaluation (14) Computer Application
(15) Special Test Apparatus - Construction and Design

PROCESS ENGINEERING

JOINING PROCESSES
(1) Brazing, Soldering and Welding
(2) Arc and Gas Techniques
(3) Mechanical Fastening
(4) Joining of Plastics
(5) Application of Adhesives
(6) Fabrication and Manufacturing techniques
(7) Specifications, Standards and Design liaison

HEAT TREATMENT
(1) Case Hardening and Direct Hardening
(2) Induction Treatments
(3) Salt Bath Treatment
(4) Annealing and Stress relieving
(5) Heat Treatment of Tool Steels
(6) Control of Furnace Atmosphere
(7) Instrument Control
(8) Specifications, Standard and Design Liaison

ORGANIC FINISHING
(1) Phosphating and Painting
(2) Lacquering and Aluminising
(3) Powder Coating (Fluidised Bed)
(4) Corrosion Testing
(5) Specifications, Standards and Design Liaison

ELECTROPLATING
(1) Cleaning and Pretreatments
(2) Electroplating (3) Electroless Plating
(4) Anodising (5) Chromate Passivation
(6) Corrosion Testing (7) Design Liaison
(8) Varnishing and Impregnating (9) Effluent control

NEW TECHNOLOGIES

(1) High Speed Plating
(2) Electroforming
(3) Electrolytic recovery of metals
(4) Plating Circuits
(5) Automatic Material and Process

(1) Electroplating Plastics
(2) Chemical pre-treatment of Plastics
(3) Selective Plating

(1) Vacuum Brazing
(2) Vacuum heat treatment
(3) Anti-Wear Treatments
(4) Protective Treatments for Tools
(5) Non-Destructive Testing

(1) Flow Forming Plastics
(2) Plastics Joining Consultancy
(3) Friction Welding

5.3 Derivation of curricular structures for courses leading to graduate and professional qualifications

In chapter 2 it was stated that for the translation of needs into a curricular structure and educational objectives, it is necessary to begin with an elucidation of global aims which the educational programme seeks to achieve.

The extensive involvement of the manufacturing industry (see table 4.1, for instance) and the substantial demand for polymer technology experts (see fig. 4.4) confirms that the community is in need of qualified manpower capable of tackling problems associated with polymeric materials and products. Furthermore, they are required to perform a wide range of tasks (see figs. 4.15, 4.16 and pp 155-158). Consequently an educational institution which intends to meet such needs could state its global aims as follows:

1) To prepare students for an active participation in development, marketing and production functions of these sectors of industry concerned with the production and utilization of polymeric materials.

2) To develop in students those intellectual abilities and associated practical skills which will provide them with the maximum opportunity for self-realization during their subsequent life in the community.

There is a strong indication, however, that many technologists may be required to work with materials other than polymeric compositions (see survey of metallurgists, p 75 and the implications of the NEDO report, p 67). Therefore, there is a need for broader courses which on the basis of the inferences drawn in section 5.2, should adopt the general theme of "materials and manufacturing technology". Such a broad approach to studies of polymeric materials seems to be justified also on the basis of the educational principles outlined in chapter 2, i.e.

a) A broad knowledge of the behaviour of a wide range of materials, especially if it can be integrated through common principles is more conducive to the development of novel composite microscopic structures and increases understanding of materials interfacial problems, as in processing, cables, surface coatings etc. and especially the wide range of applications where polymeric compositions are used as auxiliaries, e.g. binders etc.

The experience gained from studies in one class of materials, e.g. metallography, fracture phenomena etc. may be transferred more easily to different materials if the worker has the confidence to search for information from sources outside his main area.

In his paper on nucleation of glasses to form ceramics, Stookey (Corning Glass Works), in fact, wrote (77):

> "In any field of investigation we find it helpful sometimes to back off and look at problems from new angles to see if there are other ways of attacking them, and once in a while workers in entirely different fields discover facts that suggest new ideas and techniques".

It can be fairly safely assumed that such a confidence is more easily acquired if the worker has been exposed during the course of his education to a large variety of problem-solving exercises. It is to be emphasised, however, that although many academics would suggest that the above conditions would be satisfied by studies in two or three pure disciplines (chemistry, physics and mathematics, in particular) without involving the student in technological problems during his formal education, it is the difficulty of converging the highly structured knowledge and mode of thinking acquired through studies of pure disciplines to particular life-problems which creates so much insistence by the professions and educationalists (76) for clinic- or life-orientated curricula.

Since many life-problems cannot be fitted within the limits of any one discipline, studies of the actual problems provide the only means of learning the thought processes required for their solution. In support of this statement one can add Taba's (78) remarks on the effectiveness of applied subjects and problem-oriented topics in developing intellectual abilities:

> "If the means can be found for the application of basic principles, then the applied fields might offer special opportunities for completing the 'acts of thought' by requiring the use of basic principles and concepts in an entirely new context".

There are, however, practical difficulties which would prevent the complete amalgamation of studies of polymeric materials within a general curriculum centred around the whole field of materials and manufacturing technology, which must not be overlooked even if this was desirable on the basis of the structure of the underlying knowledge. First and foremost, there are severe restrictions on duration of courses which may prevent the achievement of the level of competences required for the fulfilment of some important industrial tasks within the realm of individual classes of materials, and second, there is a lack of resources, staff and facilities, to enable all the educational insititutions concerned to carry out such a programme. Consequently, there is also a strong case for curricula based on studies of single classes of materials or more specific technologies, albeit some broadening experiences may be included to enhance the transfer of knowledge where it is deemed to be most appropriate.

On the basis of the above discussions, it would seem, therefore, that for the selection of appropriate curricular structures, there are several possibilities open:

5.3.1 Polymer technology in a vocational curriculum

A vocational approach to the teaching of polymer technology, that is one which commits the student to a career within the polymer-based industries, is already widely used at both secondary and tertiary level in courses leading to the Plastics Institute and the Institution of Rubber Industry qualifications.

Although there are also schemes which enable students to acquire the three levels of qualifications specified in consecutive steps, a technician qualification is normally considered to be a terminal level of competence and only some students proceed to take graduateship or associateship courses.

Since practitioners in the polymer-based industries, whose qualifications were at least equivalent to degree standard, have unequivocally indicated that "knowledge of methods and practical skills" are very important elements in their job, it can be inferred that a cumulative experience beginning with the acquisition of technician skills is highly desirable for degree and professional courses. (This was the normal practice for engineering professional courses in this country until the mid 60s).

If it is accepted that both analytical skills and abilities to propose hypotheses, formulating models etc., are also necessary attributes for professionals in their role of proposers of courses of action and decision makers, then it would seem appropriate that the three types of competences required for technicians, graduates and professionals respectively should be acquired in successive stages. Since such a curriculum is occupation orientated it would seem that it is more appropriate to organize studies around polymeric materials and manufacturing processes:

The first stage curriculum would be designed around specific technologies or specific aspects of the technology of polymeric materials, i.e. either rubbers, plastics, surface coatings and adhesives.

The second stage would seek to treat all polymeric materials in an integrated manner, and possibly allow also some broadening experiences by means of comparisons (see writer's comments in p. 13).

The third and final stage of the course would be designed exclusively in a manner which would lead to professional qualifications of one of the established Institutes, i.e. The Plastics Institute or Institution of the Rubber Industries, allowing for specialization but not necessarily on single classes of materials, e.g. rubbers, plastics.

Such a scheme would obviously have the advantage of meeting the needs of industry for the three levels of manpower competences specified but at the same time would provide for breadth in the graduateship stage of the course and could have sufficient flexibility to allow students to take up a final professional route whose specialization is different from the one taken in the first stage.

This would also provide a mechanism for the professional Institutes to control the intake of members to a profession according to the demands for a particular type of specialization.
The scheme would, furthermore, satisfy the criteria of relevance, generality and articulation adopted by American professional education curricula. (80)

Such a programme would be best carried out on a sandwich or part-time basis in order to allow sufficient time to elapse between the three stages so that the student can decide at which level he wishes to terminate his studies, even if only temporarily, and industry can derive sufficient benefit from the student's education in terms of services which he provides.

The part-time or sandwich scheme would be particularly attractive to the 'eclectic' educator, who accepts that the maturity gained by the student over a prolonged experience, both inside and outside college, provides a more meaningful education than the intrinsic knowledge which may be more easily acquired through intensive academic studies. Furthermore, it is doubtful whether a professional technologist can be sufficiently prepared without real life experience of the industry and community in which he is to serve as a practitioner, unless the college establishes special "teaching clinics"* to enable the student to come into frequent contacts with real-life problems. It cannot be over-emphasised, therefore, that since the

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* A "teaching clinic" denotes a centre through which the educational institution concerned provides services to the community for the purpose of utilizing available resources and to expose students to "real" professional experiences.

fundamental concept of a vocational curriculum is that all areas of study or units of a course are committed to develop those skills that the student will need to have in his subsequent professional (or vocational) services, educational objectives have to be stated in terms of levels and types of competences that current practitioners are expected to possess. Hence the reason why the writer has left the question of relevance of subject matter to the judgement of practitioners.

5.32 Polymer technology in a curriculum resembling Dressel's "dewy-eyed", "outreach" and "theme" models: the "Thematic" curriculum

These three models are very similar in nature, hence the reason for their being clustered together. They have as common bases the following:

a) knowledge is worthwhile only if it can be used to solve problems.

b) Education is a preparation for life and the curriculum must contain, therefore, experiences similar to life.

c) Practical and theoretical experience must be balanced and the student decides after his practical experience whether he needs any further formal education.

d) Areas of study must be selected to provide themes related to the needs of the community and the disciplines have to define their roles in respect to the theme.

These concepts do not appear to differ appreciably from those of a vocational curriculum, especially if in the latter are included broadening experiences as suggested in the preceding section. The thematic curriculum, however, does not commit the student to any specific occupation or profession, hence the curricular structure cannot be divided in stages and the level of competences that can be achieved would be synonymous to those described for a graduate. Contrary to the case of a vocational curriculum the general theme of the course would be "materials and manufacturing technology" and the role of the polymer technology units would be to provide problem-solving examples in the utilization of natural resources and materials. The course could contain additional or complementary units to broaden further the life-oriented experiences of students, (e.g. combined Honours courses in current use in British universities and polytechnics), but care must be exercised in the selection of additional units to avoid running the risk of crossing too many frontiers of knowledge and making it, therefore, impossible for the student to acquire sufficient in-depth experiences, especially in those fields of study where the entry competences are minimal.

Complementary units for such a course could use themes based on current events, such as "Economics of raw materials and energy utilization", which would have the role of promoting in the student an awareness of the problems facing society in making decisions on vital long range issues. Polymeric materials would be relevant to such an issue and considerations of the relative value of 'oil' as a source of materials and energy would provide the integrating threads with the polymer technology units.

The similarity in educational philosophy with the vocational curriculum makes it necessary for the course to operate on a sandwich or part-time basis, unless the college has "teaching clinic" facilities.

The question which naturally arises in this respect is whether polymer technology can be studied in a thematic curriculum in isolation from or only with some reference to the technology of other materials. It would seem that such an approach would be too restrictive in scope in so far as it would not provide the non-committeed student with sufficient opportunity to establish the role of polymeric compositions in the manufacturing industry in relation to other materials.

Therefore, only if there are severe limitations on the duration of the course should one consider narrowing its scope but without sacrificing on the theme of polymeric compositions as materials for the manufacturing industry. In other words, polymer technology would become the central theme for in-depth experiences, out of which would stem broadening experiences for studies on other materials.

5.3.3 Polymer technology in a curriculum resembling the "pedantic pattern" and the "saintly" conception. The single discipline curriculum.

Educators who adopt these curricula assume that:

a) Education is for an intellectual élite and its aims are to develop the mind through dialectic on areas of study which deal with the truth and values discovered by the great minds of the past.

b) The major disciplines represent the best effort of man to date to organise knowledge and systematize the task of seeking new knowledge.

c) Since no one can master all knowledge, one or two disciplines are chosen for intensive studies and only after a discipline has been mastered should one consider its practical implications and applications.

The lack of concern on the part of academics who adopt such a philosophy for the fate of students on completion of their studies and for life-problems has frequently been criticised by both industrialists (81) and modern educators (82). The best that can be assumed to result from this approach is the development of intellectual abilities which will enable the student to become a useful member of the community, but it does not satisfy the first criterion stipulated by curriculum development theory, i.e. that a curriculum should be designed around well defined needs and educational objectives. However inappropriate such an educational philosophy may be, it is highly unlikely that it will ever cease to be adopted nor can there be any convincing arguments in support of polymer technology for such curricula, in spite of the attempts which have been made to include at least some elements of technology in engineering science curricula (83, 84)

5.3.4 Polymer technology in a curriculum which changes character through various stages

As already pointed out in Chapter 1, the majority of existing courses containing polymer technology units adopt at least two types of curriculum models, i.e. study of single disciplines followed by vocational studies in polymer technology. This approach is founded partly on the general belief that fundamental principles have to be mastered first before areas of technology are dealt with, and partly for practical reasons (see comments in Chapter 1, pp 10-12)

Not only is there no educational justification for using this approach, but experience in professional studies, medicine in particular (85), has shown that exposing the student to real problems right from the beginning increases the inner motivation for learning. It is also well accepted in the teaching of languages that exposing the students to rigid syntax rules at the beginning of a course normally causes a loss of interest in the subject which inhibits the learning process. Learning some basic skills first, i.e. to use a few conversational sentences, on the other hand, provides a much better climate for cumulative learning and for a better grasp of syntax rules in later stages.

Schein (86) argues that instead of debating whether clinical or basic science work should come first, schools should develop curricula which permit basic science, applied science and clinical modes to be taught in an integrated fashion, i.e. a vertical type of integration.

But even if it is accepted that basic science should be taught before dealing with technological aspects, this can only influence the sequencing process and not the choice of contents of a curriculum.

For the case in question, two types of curriculum transformation seem to be applicable: one in which the curriculum changes from a thematic to a vocational type, and one where the thematic curriculum is preceded by studies of single disciplines.

It is unlikely that any course whose ultimate objective is to produce professional polymer technologists can operate successfully on the direct transformation from the "single discipline" approach to a vocational curriculum. It would be too difficult for the students quickly to adjust their divergent and abstract thinking mode acquired in the study of single disciplines to a convergent and practical approach required in the professional stages of the curriculum.

It is also unlikely that the student can readily accept the new mode of thinking that conclusions can be reached, and that in many cases have to be reached, on insufficient scientific evidence and even by defying the rigid rules of the discipline. This can be inferred from the intrinsic nature of technological reasoning which is often hypothetical and difficult to validate empirically and, therefore, technology diverges from science, in this respect, and approaches philosophy(*).

A further detrimental consequence of such a brusque transition may be inferred from the observations made by the writer with respect to the attitude of academics at the pedantic stage of the curriculum towards the subsequent vocational stage. The latter is frequently considered a specialization of the main discipline which, therefore tends to make the students refrain from taking a course based on polymer studies when these are offered as an alternative to the continuation of studies in the main discipline.

5.3.4.1 A three-stage course leading to professional qualifications in polymer technology

In those cases where a vocational approach is only used in the final stage of the course, it would be necessary that each preceding stage adopt

(*) Pope J.A., "Technology; a technique or a philosophy". Convocation - Annual general meeting, University of Aston, 27th February 1970.

objectives compatible with those in the successive stages. In other words, the aims of the final vocational stage determine the major types and levels of objectives to be achieved in preceding stages in order to provide continuity and cumulative learning.

This implies, for instance, that the pedantic approach in the first stage would aim at developing in students "scientific conversancy" and not "matery of knowledge in a specific discipline". In other words, the first stage would concentrate on the study of those areas of science which are basic to the technological studies in the subsequent stages.

The thematic model adopted for the second stage would be based on the general theme of materials and manufacturing technology and only in the final vocational stage there will be any deliberate bias towards one or more of possible professional routes, i.e. metallurgy, ceramics and plastics technology, rubber technology etc. Both stages 2 and 3 of such a course would have to operate on a sandwich or part-time basis or through frequent learning experiences in teaching clinics.

5.3.4.2 A two-stage course leading to professional qualifications in polymer technology

The curricular structure of such a course would differ from the three-stage model in so far as in the first and second stage the underlying principles would have to be treated as an integral part of the technology units, although additional separate units in basic disciplines could be included but in a subordinate role to the technology units.

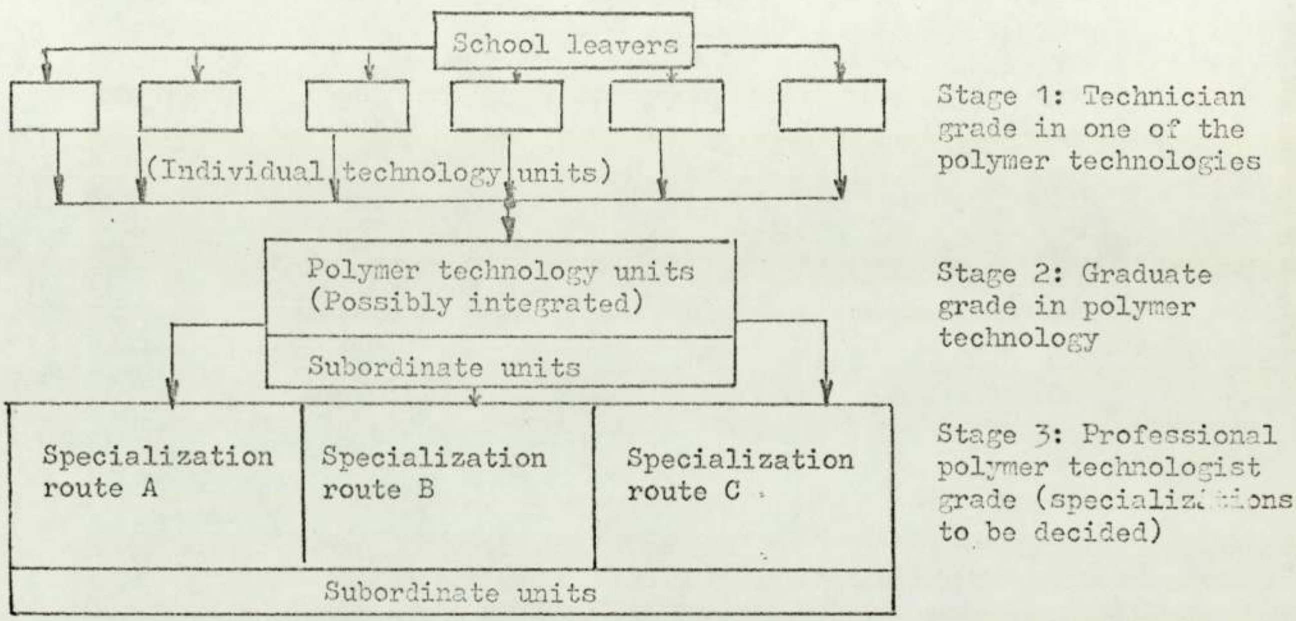
As for the previous case, however, there seems to be little scope in such a curricular structure for providing a route leading to technician qualifications.

5.4 Summary of the appraisal of suitable curricula schemes

From a consideration of the implications of each curriculum model discussed in p 6 and from an analysis of the needs of industry, it is inferred that the most likely scheme to be adopted for such courses would be either a "fully vocational curriculum" or one which changes character in stages.

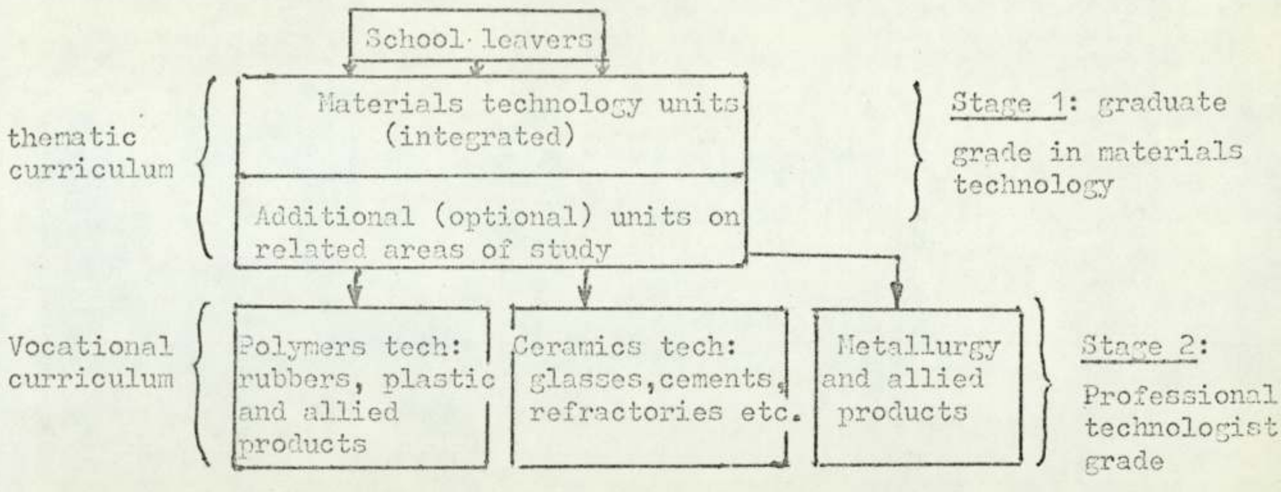
Each of the schemes proposed can be represented diagrammatically as follows:

(i) <u>The fully vocational curriculum</u>

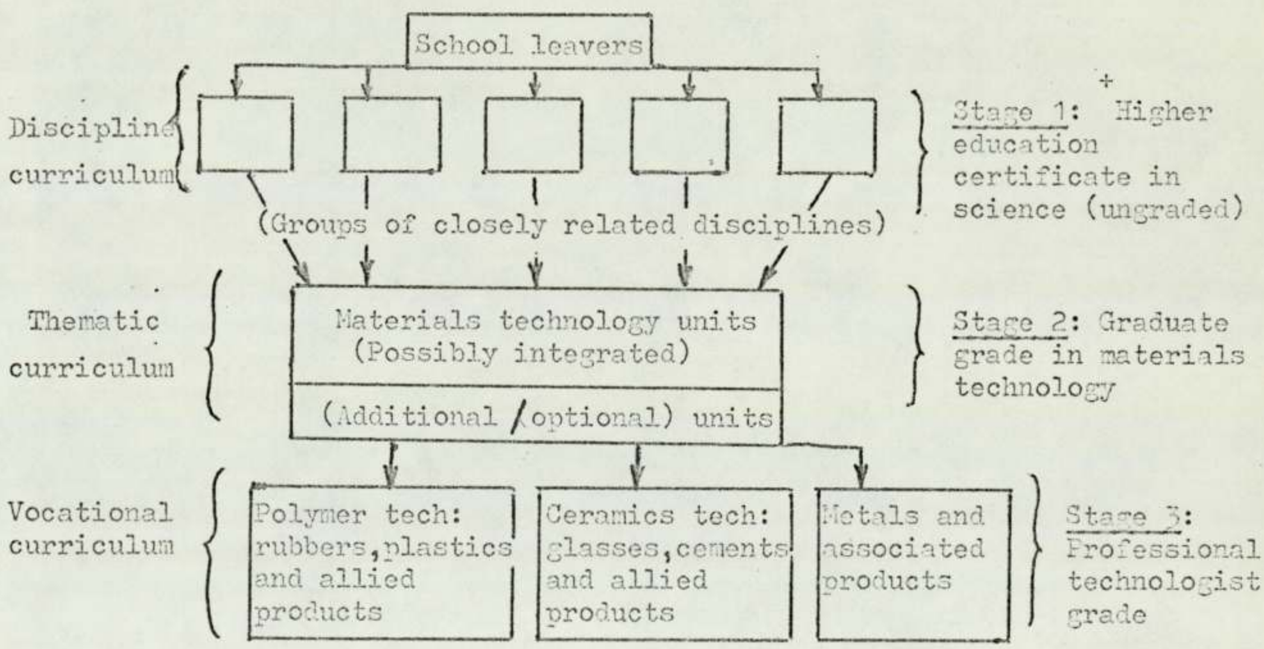


Note: A grade denotes the attainment of competences directly related to the needs or activities of industry and commerce.
and

(ii) The thematic → vocational curriculum



(iii) The discipline → thematic → vocational curriculum



Note: + denotes qualifying certificate to stage 2.

As it can be inferred from the examination of industrial needs, the types of expected behaviours for each stage of the courses specified, i.e. knowledge of specifics and practical skills for technicians, analytical abilities for graduates and powers of judgement and abilities to take decisions for professionals, are not mutually exclusive. Consequently even in the first stage of a fully vocational course structure the type A behaviours (i.e. ability to evaluate and decide) are not precluded, but the complexity of behaviour is at the lowest level. For instance, if we consider a subject area such as "the fracture resistance of plastics", a student who achieves the technician grade is expected to be able to carry out the necessary tests as dictated by specifications, standard test methods etc., but at the same time he must be able to express judgement as to the number of tests that may be required to obtain a realistic assessment of a particular property in question. At the end of stage 2, the student is expected to be able to analyse and identify the relative merits of established or newly proposed test methods in a novel situation, but he must be able also to express judgement as to the relative suitability of the types of specimens and test procedure for the evaluation of the particular material in question. On the other hand, at the end of stage 3 the student is expected to be able to make firm decisions as to which type of tests have to be carried out and to be able to devise suitable testing procedures in novel circumstances. In other words, he must be able to solve more complex problems than at stage 2, e.g. he must take into account time and cost elements and decide whether it is necessary to devise elaborate procedures to obtain a more accurate estimate of the property in question.

In the thematic stage of the curriculum the student is not committed yet to any specific profession, not even to those to which the contents are related, therefore it would be essential to develop these more critical affective behaviours which provide motivation for learning. The student would have to develop awareness and interest in the subject (affective behaviours equivalent to response and valuing in Bloom's taxonomy). This affective behaviour would at the same time provide continuity for the subsequent development of professional commitments necessary in the subsequent vocational stage.

In the cognitive domains learning continuity would be provided by broad objectives such as "to learn to discover concepts of materials technology", followed by "to learn to make disciplined enquiries about materials". The scheme in which the curriculum changes from a discipline-oriented curriculum to a vocational type through an intermediate thematic stage would resemble to some extent the structure of American professional engineering education (87).

Since the level of student competences in the first stage is to "become conversant in a series of relevant disciplines", the curriculum would, therefore, be concerned with developing basic skills in selected areas of science. Since it will not be possible to cover the contents of the underlying sciences, nor is it a necessary pre-requisite to achieve transferability of knowledge (87), it would be essential to deduce the basic principles and concepts from a full hierarchy of behavioural objectives for the subsequent technology units of the course. The basic principles would then be used as the criteria for sampling, rather than covering the more specific aspects necessary to develop them.

Objectives in the affective domains, therefore, would include "to become aware of the implications of science to the technology of utilization of materials", which will be more easily achieved if relevant examples from areas of study in subsequent units are taken. It can be anticipated that, irrespective of the type of curricular structure adopted, the terminal behaviours of students at the professional stage and, to a large extent, also at the graduate stage, must be identical. Therefore, the three course structures outlined would differ from one another only with respect to the selection and organization of both contents and learning experiences which are required at each stage.

Finally, it must be emphasized that although in the schemes proposed it was deemed necessary to introduce a professional stage following the graduation stage in order best to fulfil industrial needs, this does not preclude the existence of a need and the practical feasibility for alternative schemes. For instance, it could be argued that in parallel to the professional stage which would commit the student to a career in industry, a small number of alternative routes could be introduced specifically for those intending to become specialists in interdisciplinary research work, chemical synthesis, engineering design, etc., or take up teaching posts, technical journalism etc. The alternative routes would, in this case, consist of either advanced studies in specific areas of the technology of materials and associated sciences by course work and/or collaborative industry/university research through schemes similar to the I.H.D. of the University of Aston, or conversion training courses leading to related professions.

CHAPTER 6

SYNTHESIS OF EDUCATIONAL OBJECTIVES

Bloom suggests that the following questions should be asked in the formulation of objectives:

a) What are the activities that individuals are expected to perform?

b) What are the problems that they are likely to encounter?

c) What are the opportunities they are likely to have for service and self-realization?

Krathwohl, Stones et al. and others (27, 32, 35) stress that objectives must be formulated at various levels of specificity after having established the overall aims that the educational programme seeks to achieve.

Therefore, the synthesis of educational objectives rests on the matching of types and levels of expected competences with the types and level of educational objectives as stipulated by Stones and Anderson. To these ends an analysis was carried out, in order to arrive at a specification of competences to be achieved in the final professional stage. From these a hierarchy of subsumed objectives for the lower stages was then derived. As a first approximation, the relationship between the activities of professional technologists and educational objectives was drawn up using Bloom's taxonomy, as shown in fig. 6.1. At the most general level, educational objectives transcend the contents of a particular course, and may be considered to be equivalent, therefore, to category 'A' attributes postulated by Buley in his analysis of the aims of higher education (74). In other words, the global aims of a course are to bring about certain fundamental changes in the student, which are not specific to any particular areas of study. Hence the reason why knowledge has been omitted in fig. 6.1.

Each activity and those closely related to one another were first examined in order to derive an inference of the global aims of the courses considered. The scope of polymer technology studies was then defined in terms of the most appropriate areas of study, which were derived from a consideration of th topics contained in fig. 4.2.3. For each of these areas of study a specification of objectives was made on the basis of expected competences, taking into account the results of the surveys carried out.

6.1 Global aims of professional education in polymer technology

On the basis of what has been said above, a statement of global aims can be made as follows:

a) Aims related to the development of abilities applicable to all functions

These abilities include:

(1) Ability to appraise the technical, economic and social implications of data and experimental results in a highly competitive commercial situation. This ability can yield a general educational (affective) objective stated as:

"To develop in students a commitment always to consider data, whether obtained through experimentation or other sources, in terms of technical, economic and social aspects".

This carries the implication that the most acceptable product is not necessarily the one with the highest sales appeal or technical performance, but one which causes no ill effects on the personnel involved in its manufacture and to the consumer.

Fig. 6.1

Inference of educational aims related to the professional activities of polymer technologists

Professional activities related to development, marketing and production functions	Educational aims: Cognitive domains (related to professional tasks)					Affective domains (related to professional ethics)				
	(a) comprehension	(b) application	(c) analysis	(d) synthesis	(e) evaluation	(f) receiving	(g) responding	(h) valuing	(j) organisation	(k) characterization
(×) Studying needs and formulating objectives			V		V		V	V		
(×) Acquisition of background information	V		V		V	V				
(×) Planning and performing experiments		V		V			V			
(o) Assessing and developing new markets			V	V	V		V	V	V	
(o) Preparing tenders and organising distribution	V		V	V			V	V		
(•) Controlling products/processes and developing inspection procedures		V		V	V		V	V	V	
(•) Assessing specifications and allocating manufacture schedules to specified plants/machinery	V			V		V	V	V		
(•) Evaluating new processes and production methods			V		V		V			
(•) Organising maintenance of equipment and recommending purchase of new plant/machinery			V		V	V	V	V		
(•) Assessing costs of production and organising incentive schemes			V	V	V			V		
(/) Technical/economic assessment of data	V		V		V			V		
(/) Liaison with other departments & customers	V	V	V	V	V	V	V	V		
(/) Supervising and training assistants		V						V	V	V
(/) Trouble shooting			V	V	V	V	V			
(/) Report writing and verbal communication				V					V	V
(/) Assessing manufacture implications of new products			V		V		V	V		

Notes:

Typical activities:

(×) activities connected with devlopment functions
(o) typical marketing activities
(•) typical production activities
(/) activities applicable to all thr functions

Interpretation of aims in the cognitive and affective domains

(a) Interpretation and translation of a communication
(b) Transferring data or principles to new situations
(c) Breaking down a situation into its constitutive elements
(d) Systematise principles or data
(e) Making judgements on appropriateness of ideas
(f) Awareness of the existence of data, principles, etc.
(g) Willingness to take necessary actions
(h) Commitment to company objectives and social responsibilities
(j) Judging a situation in terms of purposes rather than egotistic motives
(k) Developing a code of behaviour based on ethical principles consistent with democratic ideals

(2) Ability to assess the manufacturing implications of a new product

The interdepartmental participation in dealing with the manufacture of new products is illustrated by Giragosian (89) with reference to the chemical industry (Fig. 6.2, below).

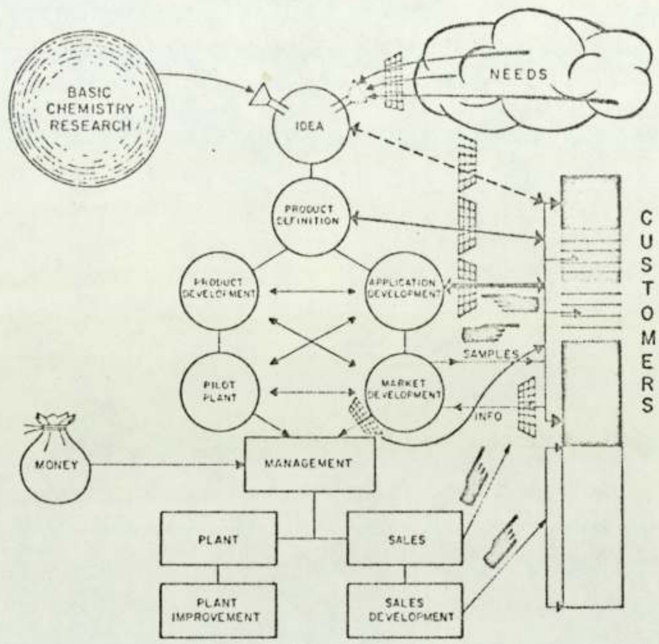


Fig. 6.2 Feeding the idea generators with needs of various industries from the universe of possibilities (the white cloud implying a large number of such industries).

Giragosian proposes that several factors will have to be considered by the departments concerned, as for instance:

Marketing Department:

(i) Would the product fit logically into existing lines of products?

(ii) How long would it take competition to copy or imitate the new product?

(iii) Does the company have the manpower available to develop manufacture and introduce the product?

(iv) What would the development cost be?

Manufacturing and Engineering Department:

(i) Can the product be manufactured from easily obtainable materials? Are these materials in common use by the company?

(ii) What effect will the introduction of the product have on existing production schedules?

Finance and Planning Department:

(i) What is the estimated return on the investment?

(ii) Is the company financially able to develop and introduce the product?

The above illustrates that manufacturing new products involves mental operations which transcend the type of product. Hence the development of mental discipline to deal with "the assessment of the manufacturing implications of new products" may be considered in itself a general educational objective.

(3) Trouble shooting abilities

Trouble shooting is an activity which involves mostly analytical, synthetic and evaluative abilities. The most prominent feature of a trouble shooting task is that the time element is short, usually conclusions have to be reached on insufficient evidence and decisions have to be made under conditions of high risk. Several solutions may be possible but only one or a few must be proposed. A general educational objective to develop trouble shooting skills may be stated as follows:

"To develop problem solving abilities under high risk conditions and from a limited amount of background information".

(4) Liaison with members of a team and clients

The role of a technologist as an effective member of a team and clients has already been illustrated when dealing with activities associated with "assessment of manufacturing implications of new products".

The activity stated here is meant to be more general in so far as it covers liaison work of all kinds. A general educational objective for the development of liaison abilities may be stated in terms of Dressel's fourth specification of student competences, i.e.

> "The student should develop the ability to cooperate and collaborate with others in studying analysing and formulating solutions to problems and in taking action on them" (10).

(5) Abilities to supervise and train assistants

An effective educational objective which is related to the first element of this activity may be stated as follows:

> The student should develop a commitment to pass on to others his knowledge and skills.

The training element, on the other hand, would also involve objectives in the cognitive domains, but the attainment of such abilities would fall outside the scope of a polymer technology unit.

(6) Report writing and verbal communication abilities:

These activities can also be related directly to one of Dressel's student competences, but slightly more elaborated to include specifically report writing abilities, i.e.

> "The student should have a high level of mastery of the skills of communication and should be able to make a constructive synthesis of information and data acquired from lectures, private studies, laboratory assignments, field studies etc."

b) Aims related to the development of abilities applicable specifically to development functions.

Development activities include:

(1) Studying needs for generating knowledge and formulating objectives. Obviously one has to distinguish between long-term and short-term projects. Here one is more concerned with the latter since long-term policies are decided by the higher level management of an organization. The professional technologist must be able, however, to interpret, translate and implement long-term policies by formulating clear objectives for new projects and proposing suitable courses of action.

It is difficult to decide upon a general educational objective to develop appropriate competences for this activity and, perhaps, the most commendable objective may be stated in terms of affective behaviours, i.e.

> "The student should appreciate the costly burden of development work and become committed to establish needs and to formulate objectives clearly before embarking on new projects".

(2) Acquisition of background information.
This activity denotes the possession of abilities equivalent to Dressel's first student competences, i.e.

> "The student should know how to acquire knowledge and how to use it"

which can be elaborated into a more precise statement:

> "The student should have the ability to collect, organise and restate information acquired through reading etc. He should be able to analyse the information and identify its relevance and applicability to the solution of a given problem".

(3) Planning and performing experiments
This is a major activity in development functions, in fact a polymer

compounding and processing company which the writer visited gave the following subdivision of duties for a technologist engaged in development work:

Written reports, acquisition of information etc.	25%
Planning and direction of work programmes, including consultations with Section Head	35%
Experimentation, design and plant work	25%
External and interdepartmental liaison	15%

The resources available were stated as follows:

Junior scientific staff.

Colleagues and senior staff in own and other departments.

Laboratory and plant facilities.

Information and other ancillary services in own and other departments.

External organisations (e.g. suppliers, independent laboratories etc.).

Furthermore, the respondents of the survey of polymer technologists in industry recorded a very high score to "Technological methods of experimental design". Hence an educational objective for this activity can be stated in quite specific terms, e.g

> "The student should be proficient in the use of methods of experimental design and be able to formulate clear programmes of work"

c) Abilities applicable to marketing functions

Marketing functions represent the interface activities between development, production and customers and the role of the technologists involved is to expedite the flow of information and courses of action.

The four characteristic activities in marketing were identified as:

(i) To prepare tenders and organise distribution of products

(ii) To provide an up-to-date assessment of competitors' products

(iii) To assess and develop new markets

(iv) To trouble-shoot and service existing markets.

The extent of direct participation of a polymer technologist in the first activity is, probably, rather small and would be limited to providing data on materials and processes. But even if the profession demánded a high level of competences in this activity from its members, the development of associated abilities would fall outside the scope of the polymer technology units of a curriculum.

There is little doubt, however, as to the immense involvement of polymer technologists in the latter three activities and, since the types of products, processes and markets fall well within the scope of the areas of knowledge of the profession, the responsibility for the development of underlying competences would be the direct concern of the polymer technology units. Abilities associated with trouble shooting activities have already been discussed and, similarly, those related to the "assessment of competitor products" can be considered to be equivalent to the "ability to appraise the technical, economic and social implication of data and experimental results in a highly competitive commercial situation" and to the "ability to assess the manufacturing implications of new products". The role and abilities of a polymer technologist for market development, on the other hand, can be best defined using the prescription proposed by Kinsinger with respect to product innovation in the chemical industry (90). Referring to the reasons for the lack of success of industry to meet market needs, he states that a major barrier lies in the fact that product innovators in chemical research usually think in terms of chemistry rather than functional performance. What is required, he claims, is the development of a discipline to translate functional needs into products. Kinsinger, therefore, implies that the synthesis of a chemical product requires the same discipline as for engineering design, and that the role of a polymer technologist in market development functions is to provide specifications for products and processes.

To do this he must consider the theoretical and practical feasibility to meet these specifications. Consequently in relation to the previously specified activity, "to assess the manufacturing implications of a new product", market development deals with the conception stage, development is concerned with the preliminary appraisal and small scale evaluations, and production is involved in large scale trials.

Market development functions require both convergent and divergent thinking abilities. Hence a general educational objective in this area could be simply stated in terms of developing problem solving skills, and especially the ability to translate and extrapolate ideas, concepts etc.

d) Abilities applicable to production functions

The disciplines required in the organisation and control of production have special characteristics and the production engineering profession is also well established. Consequently polymer technologists in production functions are employed mainly in capacities to deal with specific problems associated with materials and processes rather than with production systems. Once more, even if the polymer technology profession demanded competences in production systems from its members, the attainment of these would fall outside the scope of a polymer technology unit. It is difficult, therefore, to formulate global aims in the cognitive domain which would differ from those already specified in respect of other activities.

However, it may be appropriate to formulate a global aim in the affective domain, i.e.

"The student should appreciate that high productivity is necessary in competitive commercial situations."

6.2 General objectives for a professional education curriculum in polymer technology (cognitive domains)

On the basis of Stones and Anderson (92) recommendations, the broad areas of study for the polymer technology units of the courses set out in Chapter 5 were determined, using as a guideline the data contained in figs. 4.19 and 4.24. Particular attention has been given to those topic areas which fell under the designation of materials science and manufacturing technology, while the least importance has been attached to those connected only with the activities of research chemists, research physicists and development engineers. It is worth noting that in the case of research chemists, the only topic which did not fall into the realm of material science and manufacturing technology was "polymerization mechanisms", whereas for the case of development engineers, the topic which did not feature in the above designation was "engineering design with polymers". This is concordant with differences and relationships between technologists and engineers outlined in Chapter 1.

The selection of areas of studies was made on the basis of clusters of associated topics in figs. 4.19 and 4.24. The following clusters were identified: Cluster 1: General and specific aspects of polymeric compositions; mechanisms and technological aspect of additives; reinforcement and composites; compounding. These can therefore form the basis for an area of study carrying the title of "The Constitution and production of polymeric compositions".

Cluster 2: Mechanisms and technological aspects of degradation and cross-linking reactions; technological aspects of rheology; thermal behaviour of polymers; technological and production aspects of rubbers and plastics processing; moulds, machines, dies, etc. These can form a basis for an area of study bearing the title of "The processibility and process technology of polymeric compositions".

Cluster 3: Standard test methods; structure/properties relationships; fracture and large deformations; engineering principles; technological aspects of rubber elasticity; technological aspects of viscoelasticity; surface and interfacial properties; engineering design with polymers. These can, therefore, form a basis for an area of study bearing the title of "The properties and serviceability of polymeric compositions".

It is also useful to identify the range of contents or basic concepts, principles, facts etc., for each area of study in order to facilitate the formulation of educational objectives, i.e.

(i) The constitution and production of polymeric compositions

a) Production and availability of raw polymers and resinous materials; sources of raw materials and economics of polymer synthesis; general classifications, etc.

b) Use of additives; principles of selection; interactions; legislations; economics, classifications etc.

c) Compounding of polymers and resins with additives; factors affecting dispersion, miscibility, dissolutions; compounding methods and comminution processes; economics; efficiency etc.

(ii) The properties and serviceability of polymeric compositions

a) Deformational characteristics; significance in the design of components; effects of additives, morphology, molecular parameters etc; cost/effectiveness considerations.

b) Fracture and yield phenomena; significance in design of components; effects of additives, morphology, molecular networks etc.

c) Reinforcement, toughness enhancement and plasticization of polymeric materials; mechanistic interpretations; prediction of properties from basic constituents; economics of property modification by incorporation of additives etc.

d) Surface and interfacial characteristics of polymeric compositions; frictional behaviour and wear, effects of additives, morphology etc; modification of surface behaviour by lubricants, adhesive promoters etc.

e) Environmental behaviour of polymeric compositions; weathering, ageing; effects of chemicals and biochemical agents; protection of polymeric compositions against environmental agents etc.

f) Dielectric, thermal and optical properties; effects of molecular and microstructual parameters; modifications by means of additives; significance in engineering etc.

(iii) The processability and process technology of polymeric compositions

a) Mechanisms of large deformations; relationship to molecular and microstructual parameters; influence of additives, temperature, solvent environments, polymer reactivity etc; relationship between basic material parameters, applied stresses and geometrical factors of the deformations.

b) Manufacturing processes; classifications; interaction of materials and process variables, and their effects on output and product quality; process selection and production economics, etc.

c) Finishing processes; post-processing treatments; factors affecting performance etc.

d) Quality control procedures; production management, stocking, dispatching etc.

For the purpose of this investigation, objectives for each of the three areas of study can be adequately determined only at two levels since a specification of lower level objectives would require a detailed task analysis, which can only effectively be carried out by a team of research workers.

Even so, the problem arises as to the criterion to be used in deciding the space intervals of behaviours involved and consequently the accuracy of the specification may be open to questions. It is unlikely, however, that such a problem may be resolved without detailed task analysis on a wide range of activities taken from real-life examples and carried out by a team competent in both polymer technology and behavioural studies. Therefore, for the purpose of this investigation, the writer was compelled to develop a sequence of objectives purely on the basis of personal judgement. To test their general validity, however, a task analysis was carried out for three specific assignments. One example was taken to represent a typical research and development project, one corresponding to a trouble shooting task and associated product improvement, and, finally, one assignment was selected to represent an activity related to the function of a polymer technologist in a production environment and connected with the task of "assessing the manufacturing implications of a new product". The details of the analysis are shown in the discussion of objectives for the discipline stage of a graduate curriculum (section 6.6) In specifying objectives for each area of study considered, a statement has been made, first, of the general aims which a teaching unit of the particular area of study seeks to achieve. These aims are more specific than the global aims discussed in the foregoing section in that their achievement entails the possession of some specific areas of knowledge.

No difference is made between the various types of polymeric compositions involved, i.e. whether plastics, rubbers, surface coatings or adhesives, as it is presumed that the best means of achieving integration of subject matter is through a specification of common objectives. It may be, however, that the most complex objectives (i.e. those at level 1) in the professional stage may not be achievable in practice as they may encompass a too vast area of knowledge (a situation which frequently arises in professional studies). Therefore, it may be necessary in practice to introduce several specializations by stipulating, for instance, that such objectives should be achieved only in one selected area of study.

This can only be established at the evaluation stage of the curriculum development programme, after the selection and organisation of both subject contents and learning experiences have been adjusted to produce maximum achievement of the proposed objectives. Furthermore, it must be remembered that objectives are also the means by which a discipline (i.e. the universally accepted process of dealing with related problems) may be developed and the underlying knowledge structured, and therefore unified objectives should not be dismissed merely on the basis of existing specialization and fragmentations of contents of the areas of study involved.

Finally, it must be borne in mind that in developing educational objectives, although attempts have been made to encompass the whole range of situations with respect to both types of polymeric compositions and their underlying technology, it may be possible to discern an inevitable bias towards plastics technology, owing to the greater association of the writer's experience with plastics materials than other forms of polymeric products.

6.2.1 <u>Specification of objectives for the area of study "The constitution and production of polymeric compositions"</u>

The aims of this area of study in a professional polymer technology curriculum can be stated as follows:

> "To develop those skills* required by polymer technologists in the making of decisions associated with a) the production of high quality compositions (at the most economic rate) in servicing existing markets and developing new ones, and b) liaison with engineers involved in the design and development of compounding equipment".

This aim illustrates also the role of technologists in relation to engineers, as discussed in Chapter 1.

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* Bloom, in his taxonomy of educational objectives, gives the following definition: skills = knowledge + abilities.

Level 1 objectives: (highest level of generality)

Type A: (1) Propose suitable schemes for the preparation of polymeric compositions in a novel situation using data obtained either from laboratory evaluations or from materials suppliers.

(2) Propose procedures for the evaluation of polymeric compositions and raw materials, which may be used for quality control of novel compounding line.

Type B: (1) Identify the key characteristics of raw polymers or resins, additives and compounding procedures in a novel situation, which would affect the ease of compounding and the quality of polymeric compositions.

(2) Analyse the general features of current and newly proposed quality control procedures and rate them on the basis of functioning reliability, economics and validity of data provided in relation to application specifications/ engineering design.

Type C: (1) Recall the principles or rules which may be used as guidance to predict the compounding characteristics and product quality of polymeric compositions from established practice.

(2) Recall the theoretical interpretations of the parameters to be controlled in the production of polymeric compositions and the principles of quality control test procedures.

Level 2 objectives

Type A: (1) Decide which material parameters in mixtures of polymers or resins and additives are likely to exert the greatest influence on the degree of mixing in a given compounding line.

(2) Decide which machinery variables must be critically adjusted and controlled to produce optimum performance in

a given polymeric composition.

(3) Decide which of the data obtained from experimental evaluations are likely to provide a reliable guidance in the prediction of the compounding performance of a given polymeric composition on a given compounding line.

(4) Decide which test methods will give the most reproducible results in controlling the critical raw material parameters in the compounding of novel polymeric compositions.

(5) Decide which test methods will give the most reproducible and meaningful results in the quality control of a novel polymeric composition.

(6) Decide on the minimum number of tests necessary to control the overall compounding operation for the production of a novel polymeric composition.

Type B: (1) Identify all the materials parameters which affect the degree of mixing of polymers or resins and additives mixtures and distinguish between major and secondary effects.

(2) Identify all the machinery variables in a novel compounding line which affect the degree of mixing, differentiate between major and secondary variables.

(3) Identify the various relationships which exist between laboratory evaluation procedures and full scale compounding operations.

(4) Analyse the details of a given test procedure recommended for the evaluation of raw materials and identify any source of errors which may arise from variability of operation or intrinsic inadequacy to evaluate specific materials.

(5) Analyse the procedures recommended for the evaluation of polymeric compositions and distinguish between those which give results directly useful for application specifications or design purpose and those which merely provide information on the consistency of a given product.

Type C: (1) Translate the formulation features of a novel polymeric composition into a generalised set in which each constituent is clearly characterised in terms of its function and physico/chemical properties.

(2) Translate the features of a novel compounding line into a general scheme suitable for the compounding of a given polymeric composition.

(3) Recall the general features of laboratory types and full scale compounding procedures and, for the case of a novel compounding scheme, make suitable interpretations as to the type of relationships which may exist between laboratory and full scale compounding operations.

(4) List all the material parameters and testing procedures which may be used to control the compounding of a novel polymeric composition.

(5) Translate the details of given evaluation procedures for the raw materials of polymeric compositions into general set of applicable principles or rules of testing.

(6) Recall the basic parameters of a given polymeric composition needed in general specifications and design with polymeric materials.

No doubt, at each level, one could include other objectives, such as those orientated towards distribution, production planning etc.

6.2.2 Specification of objectives for the area of study "The properties and serviceability of polymeric compositions"

The overall aims of this area of study can be stated as follows: "To develop those decision-making skills required by polymer technologists in liaison with engineers and chemists, (respectively involved in design and development of components, structures etc. and in synthesis of raw polymers, resins and auxiliary additives) and in formulating novel polymeric compositions".

Level 1 objectives

Type A: (1) Given a specific, novel application, make precise recommendations as to the most suitable polymeric compositions which will meet all the requirements specified.

(2) Given a situation where a given number of polymers, resins and additives is available determine the range of polymeric compositions that may be economically produced to meet general markets requirements.

Type B: (1) Analyse the performance requirements specified for a given application (excluding processing considerations) and identify the structural features of several alternative polymeric compositions which contribute most to the relevant properties.

(2) Classify the general market requirements of the manufacturing industry on the basis of property range and economic tolerances likely to be met by polymeric compositions based on currently available raw polymers, resins or additives.

Type C: Recall the major structural features of common polymeric compositions and interpret both the manner in which these influence their properties and the criteria used to predict their performance.

Level 2 objectives

Type A: (1) Decide whether a given specification is adequate for or applicable to polymeric compositions.

(2) Decide whether existing compositions are likely to meet the performance demanded or whether modifications may be necessary.

(3) Decide whether the performance required in a given application can be predicted from laboratory evaluations or whether field trials may be necessary.

(4) Decide on the most desirable properties and service performance that may be achievable with a combination of formulation components available.

(5) Decide on the most likely levels of incorporation that may be required and the highest levels that may be tolerated for both economic reasons and likely side effects which may result.

(6) Decide whether recycling would be possible in situations of high wastage rates, disposal difficulties and objectional ecological effects.

Type B: (1) Analyse the data of a specification for a given application and distinguish between those applicable and those not applicable (if any) to polymeric compositions.

(2) Given a specific application analyse the characteristics of the common components of a selected range of polymeric composition and identify those features (if any) which may give rise to material failure in service.

(3) Analyse the current criteria available for the prediction of a specific performance and identify intrinsic inadequacies (if any) or deficiencies arising from experimental errors or materials variability.

(4) Identify the function of the components of several classes or types of polymeric compositions currently available, and characterize them on the basis of the manner in which they exert their function, estimated cost/ effectiveness etc.

(5) Identify the types of constituents normally used in a given class or range of polymeric compositions and discern those factors which may limit their maximum level of addition.

(6) Trace the likely fate of a class or range of polymeric compositions in their common applications and identify those factors which may create waste problems and recycyling difficulties.

Type C: (1) Recall the basic parameters needed to be included in the specification of performance of polymeric compositions.

(2) Recall those features which give rise to sporadic service failures in the use of polymeric compositions, and the theoretical interpretations put forward to explain such failures.

(3) Recall the major criteria used to predict the performance of polymeric compositions.

(4) Recall the basic formulation parameters that can be manipulated in common polymeric compositions to modify their performance.

(5) Recall the basic factors which govern the maximum level of additive incorporation in common polymeric compositions.

(6) Recall the factors which cause excessive waste and recycling problems in the use of polymeric compositions.

6.2.3 Specification of objectives for the area of study "The processability and process technology of polymeric compositions

The aims of this area of study can be stated as follows:
"To develop those decision-making skills required by technologists a) in processing, fabrication and conversion of polymeric compositions, b) in the formulation of compositions for optimum processing and product performance, and c) in liaison with engineers and chemists (respectively involved in the synthesis of raw polymers, resins and additives, and in the design and development of processing machinery and auxiliary equipment)"

Level 1 objectives

Type A: (1) Propose suitable grades of polymeric compositions, including special features (e.g. maximum allowable levels of recycle, in-house modifications of purchased raw materials etc.) for a given processing line, which are likely to yield the optimum balance of product quality and processing economies.

(2) Propose a detailed processing schedule, including special recommendations on critical equipment features (e.g. gating channels, die-lips configurations etc.) for the production of a novel component using a given polymeric composition, which are likely to yield the optimum balance of product quality and processing economics.

Type B: (1) Analyse each stage of a given processing line; identify all the factors which may affect the processing behaviour of a given class of polymeric compositions and discern any special formulation feature which may assist or impair the ease of processing.

(2) Analyse the features of a novel component to be manufactured from a given polymeric composition; identify all the suitable processing methods and, for each case, discern

any special equipment feature which may assist or impair the ease of processing.

Type C: (1) Recall the main propositions concerning the effects of formulation parameters and processing method on product quality and production economics for the manufacture of components from (or applications of) commonly available polymeric compositions.

(2) Interpret the features of a novel component (or application), in terms of generalised sets of rules governing the choice of several alternative processing features and processing conditions, to achieve the optimum balance of product quality and production rate.

Level 2 objectives

Type A: (1) Decide on the parameters of several suitable alternative materials which would give the best product quality for each stage of a given processing line.

(2) Decide on the parameters of several suitable alternative materials which must be critically controlled or adjusted to ensure an overall maximum rate of production in a given processing line.

(3) Decide on the minimum levels of acceptable quality production rates and re-work, for the processing of alternative polymeric compositions in a given processing line.

(4) Decide on the processing operations which would be most adaptable to changes in supply of grades of polymeric compositions.

(5) Decide on the processing operations for each stage of a given processing line which would give the most economic rate of production.

(6) Decide on the type of special features for alternative processing methods which would give the optimum balance of product quality and output.

Type B: (1) Examine the (main)components of several alternative polymeric compositions and identify those physical/chemical parameters which are likely to affect the product quality at each stage of a given manufacturing line.

(2) Examine the (main) components of several alternative polymeric compositions and identify those physical/chemical parameters which are likely to affect the output at each stage of a given manufacturing line.

(3) Examine the main features of a given component and those alternative polymeric compositions which may be used for its production, and identify those characteristics which may be affected by excessive use of rework and from abuses in outputs.

(4) Analyse the features of alternative process operations of a manufacturing line and identify those factors which are likely to be influenced by changes in the grades of polymeric composition used.

(5) Analyse the features of each stage of a manufacturing line and identify those factors which are likely to have the greatest effects on the overall rate of production.

Type C: (1) Recall the main physical/chemical interactions of the components of common polymeric compositions and the manner in which they affect product quality during processing.

(2) Recall the main physical/chemical interactions of the common components of polymeric compositions and the manner in which they affect processing rates.

(3) Interpret the basic principles related to the behaviour of polymeric compositions in mixtures with recycled materials in common processing situations.

(4) Interpret the basic principles related to the effects of alterations of polymeric features or types of additives in common processing situations.

(5) Recall the rationale for the operations required in the manufacture of common components from (or application of) polymeric compositions.

(6) Recall the special features of common processing operations, which can be suitably altered to increase output and processing rate.

6.3 General objectives for a graduate curriculum in polymer technology: (cognitive domains)

The difference between a graduate and a professional was expressed in terms of their roles in industry. The professional was portrayed as a "decision maker and proposer of courses of actions", whereas the traits of a graduate were described in terms of his skills as "an investigator who creates the means for the making of decisions and achievement of objectives". It is conceivable, therefore, that an arbitrary dividing line between the professional stage and the graduate stage of the course structures proposed in Chapter 5 could be drawn at some level of specificity in the hierarchy of objectives to set the transition between the two stages in question. As a first approximation one could take the two levels of objectives specified in the earlier section as a convenient point at which to draw the dividing line.

For the case of a fully vocational curriculum it would seem appropriate to make a further subdivision until a level of specificity is reached, which would set the limits of objectives for the technician stage of the course.

Such a procedure for determining objectives for the lower stages of a course carries the corollary that in each subsequent stage the student would acquire an increasingly greater capacity to deal with complex problems, (i.e. problems which are broader in context and therefore require taking into consideration a larger number of interacting factors for their solution and to solve a wider range of problems.

Consequently, in the professional stage to any given area of study can be added subordinate and complementary units or topics to enable the student to tackle problems thoroughly.

In other words, the professional stage of the curriculum seeks to develop those skills necessary to look at a problem in all its dimensions. For instance, in the production of polymeric compositions, the problem is not just restricted to the actual compounding operation or units of a compounding line, but would include considerations varying from the supply of raw materials to the delivery of polymeric compositions to the manufacturing industry, or even to clients subsequent to processing.

The full hierarchy of objectives for the three areas of study specified previously and the interdependence of objectives between the professional and graduate stages are shown in tables 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9. The reasoning used to determine the objectives for the graduate stage is similar to that put forward by Stone and Anderson and is illustrated by the examples shown below.

6.3.1 Examples of derivation of objectives for the graduate stage of a polymer technology curriculum (vocational and thematic .)

The aims of the three areas of study for the graduate stage of a fully vocational curriculum can be stated as follows: "To develop those skills required in the investigation of problems associated with the production and utilization of polymeric compositions and in establishing suitable bases for improving productivity, working conditions, etc."

For the case of a thematic curriculum, the aims can be stated as follows:

(1) "To develop an overall view of contemporary polymer technology which is consistent with that of practitioners"

(2) "To emphasize the major concepts and principles of polymer technology as a means of promoting problem solving abilities required for development production and utilization of materials and processes".

The first aim suggests that, by and large, the objectives for the vocational and the thematic curricula respectively should be identical except at some highly specific level, i.e. dealings with specific techniques. Such specific skills, however, in the case of a fully vocational course are acquired in the initial stage (i.e. the technician stage) and therefore do not need to be specified in the graduate stage. The second aim, on the other hand, implies that only examples are to be taken in the areas of polymer technology for in-depth studies.
In other words, it is recognised that in practice all the objectives specified for the vocational curriculum cannot be achieved for the case of a thematic curriculum, since the latter may seek to achieve a broader range of objectives and include areas of study outside those deemed to be necessary by the professiona concerned. Therefore, in the case of a thematic curriculum one would select objectives at each level of the kierarchy of objectives given for the vocational curriculum.

The traits of a graduate, therefore, are portrayed in terms of his inherent skills in formulating suitable hypotheses for the occurrence of certain events and in devising suitable investigation procedures to test these hypotheses.

Consequently, by taking each objective at level 2 of the professional stage of the curriculum, the subordinate objectives at level 1 of the graduate stage can be derived through an examination of the related concepts, giving due regard to the tasks likely to be performed by graduates in industry in the situation considered.

Thus for the area of study: "The constitution and production of polymeric compositions": a) Level 2; type A, objective 1 of the professional stage yields the following level 1; type A objectives for the graduate stage:

(1) Propose suitable hypotheses relating materials parameters of a polymeric composition to the degree of mixing and side effects in a given compounding line.

(2) Propose suitable procedures for the verification of the effects of materials parameters to the degree of mixing and side effects in a given compounding line.

b) Level 2; type B, objective 1 of the professional stage yields the following level 1; type B objectives for the graduate stage:

(1) Identify the constituents of known polymeric compositions and their intrinsic physico/chemical characteristics, and discern those which are likely to give rise to associations or other forms of interactions.

(2) Analyse the features of a given compounding operation or units of a compounding line and discern those factors which are likely to exert the greatest influence on critical mixing parameters (e.g. shear stresses, shearing rates, turbulence, heat build-up, lubrication etc.)

c) Level 2; type C, objective 1 of the professional stage yields the following level 1, type C objectives for the graduate stage:

(1) Recall the physico/chemical characteristics of the constituents of common polymeric compositions,

the reason for their use and the desirability function methods to determine optimum levels.

(2) Recall the factors which affect the mixing parameters (e.g. shear rates etc.) in a given compounding equipment and

the reasons why a particular geometry of the mixing rotors or blades isbeing used.

6.4 Affective domains objectives for the professional and graduate stages of a polymer technology curriculum (vocational and thematic)

An indication of the affective behaviours required in the main industrial activities of polymer technologists has been given in fig. 6.1 and the corresponding global objectives have been elucidated in section 6.1. At more specific levels it should be possible to devise a classification of affective objectives similar to Stone and Anderson taxonomy of cognitive objectives. The most complex affective behaviours would be classified as type A objectives and would correspond to Bloom's concepts of "organisation and characterization". Type B objectives would correspond to "valuing" and type C objectives would be equivalent to "receiving and responding".

Therefore, one could make a provision for the inclusion of affective objectives by qualifying the cognitive terms used with others denoting the equivalent affective behaviours.

The addition of affective objectives would modify the evaluation of objectives given in tables 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8 and 6.9 in the manner shown below:

Type A objectives: Proposes..... and manifests a commitment to his proposals...........

Type B objectives: Analyses...... and shows satisfaction in deriving conclusions.....

Type C objectives: Recalls...... and voluntarily enquires about alternatives.........

6.5 General objectives for technician courses in polymer technology (cognitive domains)

The role of technicians in the main industrial functions was interpreted in terms of providing assistance to graduates and professionals by executing courses of action requiring routine procedures.

In other words the difference between graduates, professional, and technicians is not so much in the matter of their work as it is in the novelty of the situation in which they find themselves in performing tasks and in the number of factors to consider in solving problems. This implies that courses for technicians, graduates and professionals would comprise essentially the same subject matter or theme, but the objectives and the underlying contents and learning experiences would differ with respect to the relative complexity of behaviours involved. Therefore objectives for the technician stage of the vocational curriculum in polymer technology can be derived from those stated for the graduate stage using Gagne's classification (93) of behaviour categories as a guidance.

In Gagne's classification, various capabilities depend on previous learning of some other simpler ones. Hence strategies and problem-solving require pre-learning of principles, which depend on previous grasp of concepts. Concepts, on the other hand, require pre-learning of associations, which in turn rely on the pre-acquisition of chains of responses. Consequently for a given area of study the technician stage of the course would be concerned mostly with the lower learning categories, i.e. chains of responses, concepts and basic principles.

By the very nature of their work, however, technicians must be specialists either in terms of types of products that they handle (e.g. plastics, surface coatings, etc.) and/or job elements involved (e.g. polymer processing, physical testing etc.) so that they may perform, efficiently and reliably, their tasks.

In order to maintain continuity in the hierarchy of educational objectives it is assumed that three types of technicians are required, one for each of the three areas of study considered.

In this investigation, however, the specification of objectives was restricted to only one area of study since the major concern of this enquiry is for the graduate and professional stages of the curriculum (see Chapter 1). The area of study which was selected for this purpose is the processability and process technology of polymeric compositions, for which the main aims can be stated as follows:

> "To develop those skills necessary to interpret and translate into suitable courses of action instructions concerning manipulations of established processing techniques, and to execute without supervision routine evaluations of the processing performance of polymeric compositions".

Although objectives for technician courses normally fall within four domains, instead of two, i.e. cognitive, affective, psychomotor and perceptual domains (94), only those pertaining to the cognitive domains were considered. For the sake of consistency, once more, only two levels of objectives have been taken into account (table 6.10).

Table 6.1
Type A objectives and their interdependence for the professional and graduate stages of a polymer technology curriculum

Area of study: The constitution and production of polymeric compositions

Professional stage: level 1; objective 1	**Professional stage: level 1; objective 2**
1) Propose suitable schemes for the preparation of polymeric compositions in a novel situation using data obtained either from laboratory evaluations or from materials suppliers	2)Propose suitable procedures for the evaluation of polymeric compositions and raw materials, which may be used for quality control of a novel compounding line
Professional stage: level 2; objectives 3,4,5	**Professional stage: level 2; objectives 6.7.8**
3)Decide which material parameters in mixtures of polymers/resins and additives are likely to exert the greatest influence on the degree of mixing in a given compounding line 4)Decide which machinery variables must be critically adjusted and controlled to produce optimum performance in a given polymeric composition 5)Decide which of the data obtained from laboratory scale evaluations are likely to provide a reliable guidance in the prediction of the compounding performance of a given polymeric composition	6)Decide which test methods will give the most reproducible results in controlling the critical raw material parameters in the compounding of a novel polymeric composition 7)Decide which test methods will give the most reproducible and meaningful results in the quality control of a novel polymeric composition 8)Decide on the minimum number of tests necessary to control the overall compounding operation for the production of a novel polymeric composition
Graduate stage: level 1; objectives 9,10	**Graduate Stage: level 1; objectives 11,12**
9)Propose suitable hypotheses relating materials parameters of a polymeric composition to the degree of mixing and side effects in a given compounding line 10)Propose suitable procedures for the verification of the effects of materials parameters of a polymeric composition to the degree of mixing and side effects in a given compounding line	11)Propose suitable hypotheses for the setting up of test procedures to be used as quality control evaluation of raw materials for a given polymeric composition 12)Propose suitable adaptations to any existing standard test method used for quality control of polymeric compositions to enhance its suitability in a novel situation
Graduate stage: level 2; objectives 13,14,15	**Graduate stage: level 2; objectives 16,17,18**
13)Postulate probable mechanisms for the manner with which additives disperse in a novel polymeric composition 14)Predict the probable effects of compounding conditions on some postulated dispersion mechanisms 15)Postulate probable mechanisms for side effects which may arise in the compounding of a novel polymeric composition	16)Appraise the relative testing difficulties and meaningfulness of results in evaluating the components of a novel formulation individually against evaluations carried out in combination with other additives 17)Appraise the relative merits and deficiencies of some existing standard test methods for the evaluation of a particular polymeric composition 18)Appraise the relative merits and deficiencies of existing test methods in relation to the expected performance of a novel polymeric composition

Table 6.2

Type B objectives, and their interdependence, for the professional and graduate stages of a polymer technology curriculum
Area of study: The constitution and production of polymeric compositions

Professional stage: level 1; objective 1

1) Identify the key characteristics of raw polymers or resins, additives and compounding procedures in a novel situation, which would affect the ease of compounding and the quality of polymeric compositions

Professional stage: level 2; objectives 3,4,5

3)Identify all the material parameters(levels of addition, physico/chemical characteristics etc) which affect the degree of mixing of the components of a given polymeric composition	4)Identify all the machinery variables in a novel compounding line which affect the degree of mixing,and differentiate between major and secondary variables	5)Identify the various relationships which exist between laboratory evaluation procedures and full scale compounding operations

Graduate stage: level 1; objectives 9,10

9)Identify the constituents of known polymeric compositions and their intrinsic physico/chemical characteristics,and discern those which are likely to give rise to associations or other forms of interactions	10)Analyse the features of a given compounding operation or units of a compounding line and discern those factors which are likely to exert the greatest influence on critical mixing parameters (e.g. shear stresses, shearing rates, turbulence, heat build up etc)

Graduate stage: level 2; objectives 13,14,15

13)Classify the constituents of a given polymeric composition on the basis of their roles and chemical or physical characteristics (e.g. compatability,reactivity, surface activity,packing arrangements etc.)	14)Classify compounding operations on the basis of the mixing action which they exert on a polymeric composition base or premix (e.g. vortex types,roll mills, extrusion etc.)	15)Classify the types of side effects which are likely to result from results of interactions between the components of a polymeric composition and with compounding equipment (e.g.plate-out, mechano-degradation, sweating etc.)

Professional stage: level 1, objective 2

2) Analyse the general features of current and newly proposed quality control procedures and rate them on the basis of their functioning reliability, economics and validity of data provided in relation to application specifications/engineering design

Professional stage: level 2; objectives 6,7,8

6)Analyse the details of a given test procedure recommended for the evaluation of raw materials and identify any source of errors which may arise from variability of operation or intrinsic inadequacy of the test	7) Analyse the procedures recommended for the evaluation of polymeric compositions and distinguish between those which give results directly useful for application specifications or design purpose and those which merely provide information on consistency of production	8)Study the characteristics of a given polymeric composition and distinguish between those parameters which are of importance to their application and those which may be used only as a guidance to monitor their consistency

Graduate stage: level 1; objectives 11,12

11)Distinguish between errors arising from sampling instrumentation and limitations of underlying theories in the testing of a given polymeric composition	12)Distinguish between functional and incidental properties of a given polymeric composition

Objectives subsumed from those at level 1 above, either would be too specific in terms of tasks involved or would impinge too heavily in the areas of physical sciences. Therefore they would not apply to this case but would be more suitable for the preceding technician stage or the pedantic stage as outlined in p

Table 6.3

Type C objectives, and their interdependence, for the professional and graduate stages of a polymer technology curriculum
Area of study: The constitution and production of polymeric compositions

<table>
<tr><td colspan="3">Professional stage: level 1, objective 1</td><td colspan="3">Professional stage: level 1, objective 2</td></tr>
<tr><td colspan="3">1) Recall the key principles and rules which may be used as a guidance to predict the compounding characteristics and product quality of polymeric compositions</td><td colspan="3">2) Recall the current propositions regarding the control of variability of common polymeric compositions during compounding operations</td></tr>
<tr><td colspan="3">Professional stage: level 2; objectives 3,4,5</td><td colspan="3">Professional stage: level 2; objectives 6,7,8</td></tr>
<tr><td>3)Translate the formulation features of a novel polymeric composition into a generalised set in which each constituent is clearly characterised in terms of its function and physico/chemical properties</td><td>4)Translate the features of a novel compounding line into a general scheme suitable for the compounding of a given polymeric composition</td><td>5)Recall the general features of laboratory types and full scale compounding procedures and, for the case of a novel compounding scheme, make suitable interpretations as to the types of relationships which may exist between laboratory and full scale compounding operations.</td><td>6)List all the material parameters and testing procedures which may be used to control the compounding of a novel polymeric composition</td><td>7)Translate the details of a given evaluation procedure for the raw materials of polymeric compositions into general sets of applicable rules and principles of testing</td><td>8)Recall the basic parameters of a given polymeric composition needed in general specifications and design with polymeric materials</td></tr>
<tr><td colspan="3">Graduate stage: level 1; objectives 9,10</td><td colspan="3">Graduate stage: level 1; objectives 11, 12</td></tr>
<tr><td colspan="2">9) Recall the physico/chemical characteristics of the constituents of common polymeric compositions [illegible] the reason for their use and the desirability-function methods to determine optimum levels</td><td>10)Recall the principal factors which affect the mixing efficiencies of common compounding equipment and [illegible] the functions of a particular geometry of mixing rotors or blades being used</td><td colspan="2">11)Recall the basic principles of quality control and reliability which may be, applied to compounding of polymeric compositions</td><td>12)Recall the basic rules governing the acceptability of quality control test procedures in high output production systems</td></tr>
<tr><td colspan="3">Graduate stage: level 2; objectives 13,14,15</td><td colspan="3" rowspan="2">Objectives subsumed from those at level 1 above either would be too specific in terms of tasks involved or would impinge too heavily in the areas of physical sciences. Therefore they would not apply to this case but would be more suitable for the preceding technician stage or the pedantic stage as outlined in p 244</td></tr>
<tr><td>13)Recall the basic principles underlying the physical and chemical interactions likely to occur between potential components of polymeric compositions (e.g. compatability,packing factors, reactivity, etc)</td><td>14)Recall the basic physical principles underlying the motion mechanisms of suspensions,aggregates, solutions,melts,etc., and the effects of geometrical constraints of potential compounding components</td><td>15)Recall the effects of size of constitu ents and volume of a mix on temperature rise, shear rates developed etc.</td></tr>
</table>

Table 6.4

Type A objectives and their interdependence for the professional and graduate stages of a polymer technology curriculum
Area of study: The properties and serviceability of polymeric compositions

<table>
<tr><td colspan="3">Professional stage: level 1, objective 1</td><td colspan="3">Professional stage: level 1, objective 2</td></tr>
<tr><td colspan="3">1) Given a specific novel application make precise recommendations as to the most suitable polymeric compositions which are likely to meet all the requirements specified</td><td colspan="3">2) Given a situation where a given number of polymers, resins and additives is available determine the range of polymeric compositions that may be economically produced to meet general market requirements</td></tr>
<tr><td colspan="3">Professional stage: level 2, objectives 3,4,5</td><td colspan="3">Professional stage: level 2; objectives 6,7,8</td></tr>
<tr><td>3)Decide whether a given specification is adequate for or applicable to polymeric compositions</td><td>4)Decide whether existing compositions are likely to meet the performance demanded or whether modifications may be necessary</td><td>5)Decide whether the performance required in a given application can be predicted from laboratory evaluations or whether field trials may be necessary</td><td>6)Decide on the most desirable properties and service performance that may be achieveable with a combination of formulation components available</td><td>7)Decide on the most likely levels of incorporation that may be required and the highest levels that may be tolerated for both economic reasons and likely side effects which may result</td><td>8)Decide whether recycling would be possible in situations of high wastage, disposal difficulties and objectionable ecological impacts</td></tr>
<tr><td colspan="3">Graduate stage: level 1; objectives 9,10</td><td colspan="3">Graduate stage: level 1; objectives 11,12</td></tr>
<tr><td>9)Propose suitable hypotheses which relate the fundamental physical properties of a polymeric composition to a specific service performance</td><td colspan="2">10)Propose suitable labotatory evaluation procedures from which a specific service performance of a given polymeric composition may be predicted</td><td colspan="2">11)Propose suitable hypotheses relating the charaderistics of formulation parameters to a specific performance of a given polymeric composition</td><td>12)Propose suitable hypotheses for the likelihood of interactions of formulation components with service environment, which may lead to objectionable side effects or recycling difficulties</td></tr>
<tr><td colspan="3">Graduate stage: level 2; objectives 13,14,15</td><td colspan="3">Graduate stage: level 2; objectives 16,17,18</td></tr>
<tr><td>13)Specify the optimum conditions for which some fundamental physical property can be related to a specific service performance</td><td>14)Specify the optimum conditions for the measurement of some physical properties which can be related to a specific service performance</td><td>15)Specify the type of indirect observations which can be used to monitor a specific service performance of polymeric compositions</td><td>16)Postulate probable mechanisms by which a certain component of a novel polymeric composition either exerts its primary function or affects some major property</td><td>17)Postulate probable mechanisms by which a given component of a novel polymeric composition can interact with environmental agents in a given situation to produce objectionable side effects</td><td>18)Predict all the likely service situations which are likely to affect the functioning of a given component of a polymeric composition</td></tr>
</table>

Table 6.5

Type B objectives and their interdependence for the professional and graduate stages of a polymer technology curriculum

Area of study: The properties and serviceability of polymeric compositions

Professional stage: level 1, objective 1
1) Analyse the performance requirements specified for a given application (excluding processing considerations) and identify the structural features of several alternative polymeric compositions which contribute most to the relevant properties

Professional stage: level 1, objective 2
2) Classify the general market requirements of the manufacturing industry on the basis of property range and economic tolerances likely to be met by polymeric compositions based on currently available raw polymers, resins or additives

Professional stage: level 2, objectives 3,4,5		
3)Analyse the data of a specification for a given application and distinguish between those applicable and those not applicable (if any) to polymeric compositions	4)Given a specific application analyse the characteristics of the common components of a selected range of polymeric materials and identify those features (if any)which may give rise to material failure in service	5)Analyse the current criteria available for the prediction of a specific performance and identify intrinsic inadequacies (if any) or deficiencies arising from experimental errors or materials variability.

Professional stage: level 2, objectives 6,7,8		
6)Identify the function of the components of several classes or types of polymeric compositions currently available, and characterise them on the basis of the way they function, estimated cost/effectiveness etc.	7)Identify the types of constituents normally used in a given class or range of polymeric compositions and discern those factors which may limit their maximum level of addition	8)Trace the likely fate of a class or range of polymeric compositions in their common applications and identify those factors which may create waste problems and recycling difficulties

Graduate stage: level 1; objectives 9,10	
9)Classify the properties of polymeric compositions on the basis of likely performance requirements and identify both the fundamental physical properties and structural features to which their serviceability is likely to be related	10)Analyse the basic relationship between relevant fundamental properties and some specific environmental conditions, and identify the different types of experimental procedures which may be used to predict service performances.

Graduate stage: level 1, objectives 11,12	
11)Analyse the mechanisms or relationships proposed for the functioning of additives and their interactions with polymer or resin matrix for some specific composition and examine their validity or applicability to more general situations	12)Identify the key factors in several classes of polymeric compositions which are likely to produce permanent and deleterious changes during general processing or subsequent service life

Graduate stage: level 2; objectives 13,14,15		
13)Classify the effects of major structural parameters of common polymeric compositions on their fundamental properties and service performance	14)For a novel application identify the physical characteristics of a polymeric composition which can be more reliably assessed by simulating service conditions than by measuring some intrinsic fundamental properties	15)For a novel application distinguish those materials characteristics which can be more readily assessed by indirect observations from those which need to be assessed directly and within the bounds of scientific principles

Graduate stage: level 2, objectives 16,17,18		
16)Classify the key features of additives, resins and polymers used in common polymeric compositions according to a logical chemical and physical scheme of classification	17)Classify the types of physical and chemical interactions which may occur between additives, resins and polymers commonly used in polymeric compositions	18)Classify the types of interactions which may occur between the components of polymeric compositions and environmental agents

Table 6.6

Type C objectives and their interdependance for the professional and graduate stages of a polymer technology curriculum

Area of study: The properties and serviceability of polymeric compositions

Professional stage: level 1; objective 1			Professional stage: level 1, objective 2		
1) Recall the major structural features of common polymeric compositions and interpret both the manner in which these influence their properties and the criteria used to predict their performance			2) Recall the range of performance likely to be achieved with polymeric compositions and interpret the costs likely to be incurred in achieving such performance		
Professional stage: level 2; objectives 3,4,5			Professional stage: level 2; objectives 6,7,8		
3)Recall the basic parameters needed to be included in the specification of performance of polymeric compositions	4)Recall the features which give rise to sporadic service failures in the use of polymeric compositions, and the theoretical interpretations put forward to explain such failures	5)Recall the major criteria used to predict the performance of polymeric compositions	6)Recall the basic formulation parameters that can be manipulated in common polymeric compositions to modify their performance	7)Recall the basic factors which govern the maximum level of additive incorporation in common polymeric compositions	8)Recall the factors which cause excessive waste and recycling problems in the use of polymeric compositions
Graduate stage: level 1, objectives 9,10			Graduate stage: level 1; objectives 11,12		
9)Reconstruct the relationship between molecular and morphological features of the major components of polymeric compositions on the fundamental properties of these	10)Recall the well established experimental procedures which may be used to predict the performance of polymeric compositions from accelerated laboratory tests		11)Reconstruct those well established mechanisms governing the interactions of additives with polymers and resins and the manner in which they may affect the performance of polymeric compositions	12)Recall the well established interactions of environmental agents with polymeric compositions and state how these can give rise to waste and recycling problems	
Graduate stage: level 2; objectives			Graduate stage: level 2 objectives		
The more specific levels of objectives in this area of study would be determined by subdividing it into various subjects dealing with (say) groups of properties, e.g. bulk mechanical properties, surface and interfacial properties etc. and relate these to the characteristics and structure of polymeric compositions, e.g. polyolefins, polyamides, phenolic resins etc. and to functions of additives, e.g. mechanical properties modifiers, protection against environmental agents etc.					

Table 6.7
Type A objectives and their interdependence for the professional and graduate stages of a polymer technology curriculum

Area of study; The processability and process technology of polymeric compositions

Professional stage: level 1; objective 1	Professional stage: level 1, objective 2
1)Propose suitable grades of polymeric compositions, including special features, (e.g. maximum allowable levels of recycle, in-house modifications of purchased raw materials etc) for a given processing line, which are likely to yield the optimum balance of product quality and processing economics	2) Propose a detailed processing schedule, including special recommendations on critical equipment features (e.g. gating channels, die lip configuration etc) for the production of a novel component using a given polymeric composition which are likely to yieldthe optimum balance of product quality and processing economics

Professional stage: level 2, objectives 3,4,5			Professional stage: level 2; objectives 6,7,8		
3)Decide on the parameters of several suitable alternative materials which would give the best product quality for each stage of a given processing line	4)Decide on the parameters of several suitable alternative materials which must be critically controlled or adjusted to ensure an overall maximum rate of production in a given processing line	5)Decide in the minimum levels of acceptable quality production rates and re-work, for the processing of alternative polymeric compositions in a given processing line	6)Decide on the processing operations which would be most adaptable to changes in supply of grades of polymeric compositions	7)Decide on the processing operations for each stage of a processing line which would give the most economic rate of production	8)Decide on the type of special features for alternative processing methods which would give the optimum balance of product quality and output

Graduate stage: level 1, objectives 9,10		Graduate stage: level 1; objectives 11,12	
9)Propose suitable hypotheses relating the processing rate and product quality of a novel polymeric composition to formulation parameters in a given processing line	10)Propose suitable experimental procedures for the assessment of the influence of formulation parameters on the processing rate and product quality of a novel polymeric composition	11)Propose suitable hypotheses relating processing conditions and special equipment features to product quality and output of a novel process using a given polymeric composition	12)Propose suitable experimental procedures for the assessment of special equipment features and processing conditions on the product quality and processing rate of a given polymeric composition

Graduate stage: level 2, objectives 13,14,15			Graduate stage: level 2; objectives 16,17,18		
13)Postulate mechanisms for the manner in which the physical/chemical parameters of a novel polymeric composition interact with themselves and the surface of processing equipment under various conditions and influences the ease of processing, processing rate and product quality	14)Propose simple analytical relationships which may be used as a guidance for a quantitative estimate of the effects of physical/chemical parameters of a novel polymeric composition on the ease of processing, processing rate and product quality	15)Postulate suitable mechanisms for the manner in which the physical/chemical formulation parameters of a novel polymeric composition would interact during processing and cause decomposition or otherwise affect its reprocessability	16)Postulate suitable mechanisms for the effect of some special equipment features (e.g. those which can be easily modified) and processing conditions on the ease of processing, processing rate and product quality	17)Propose simple analytical relationships which may be used as a guidance for a quantitative estimate of the effects of special features of processing equipment and processing conditions on the ease of processing,processing rate and product quality	18)Propose suitable experimental procedures for the monitoring of product quality and production rate in a novel processing line

Table 6.8
Type 3 objectives and their interdependence for the professional and graduate stages of a polymer technology curriculum
Area of study: The processability and process technology of polymeric compositions

Professional stage: level 1; objective 1
1) Analyse each stage of a given processing line; identify all the factors which may affect the processing behaviour of a given class of polymeric compositions and discern any special formulation feature which may assist or impair the ease of processing

Professional stage: level 1, objective 2
2) Analyse the features of a novel component to be manufactured from a given polymeric composition; identify all the suitable processing methods and, for each one, discern any special equipment feature which may assist or impair the ease of processing

Professional stage: level 2, objectives 3,4,5		
3) Examine the (main) components of several alternative polymeric compositions and identify those physical/chemical parameters which are likely to affect the product quality at each stage of a given manufacturing line	4) Examine the (main) components of several alternative polymeric compositions and identify those physical/chemical parameters which are likely to affect the output at each stage of a given manufacturing line	5) Examine the main features of a given component and those of alternative polymeric compositions which may be used for its production, and identify those characteristics which may be affected by excessive use of rework and from abuses in outputs

Professional stage: level 2; objectives 6,7,8		
6) Analyse the features of alternative process operations of a manufacturing line and identify those factors which are likely to be influenced by changes in the grades of polymeric compositions used	7) Analyse the features of each stage of a manufacturing line and identify those factors which are likely to have the greatest effects on the overall rate of production	8) Identify any special feature of a given process operation of a manufacturing line which could be suitably altered to increase output and/or product quality

Graduate stage: level 1; objectives 9,10	
9) Classify the components of a polymeric composition according to their effects on processing and identify those formulation parameters for a novel polymeric composition likely to affect its rate of processing and product quality	10) Classify the experimental procedure used for the evaluation of the processing performance of polymeric compositions according to a coherent scheme and identify those features which are likely to provide the most relevant information on the effects of formulation parameters

Graduate stage: level 1; objectives 11,12	
11) Given a novel processing line identify those processing variables and any special equipment feature which are likely to have appreciable effects on output and product quality, and classify these effects according to a coherent scheme	12) Analyse the processing variables and any special feature of a novel processing line, and identify the laboratory experimental procedures (if available) which may be used to assess their effects on product quality and processing rate

Graduate stage: level 2; objectives 13,14,15		
13) Classify the interactions of the chemical/physical parameters of the components of polymeric compositions in processing situations on mechanistic bases in relation to the possible effects which they may have on deformation flow rates and morphological microscopic features	14) Classify the analytical relationships for the influence of formulation parameters and environmental conditions on deformation/flow rates and morphological/microstructural features of polymeric compositions according to a coherent scheme	15) Classify the interactions of physical/chemical parameters of the components of polymeric compositions according to mechanisms ledding to decomposition and cross-linking reactions

Graduate stage: level 2; objectives 16,17,18		
16) Classify (on a mechanistic basis) the behaviour of suspensions, melts and viscous solutions in relation to the geometry of container, channels and environmental conditions according to the type of flow of deformations imposed and the resulting morphological/microscopic features of the resulting products	17) Analyse the basic analytical relationships governing the behaviour of suspensions, melts and viscous solutions in relation to the geometry of the container, channels and environmental conditions and identify those which may provide suitable predictions on deformation/flow rates and the resulting microscopic features of the resulting products	18) Classify the experimental procedures used to monitor the behaviour of suspensions, melts etc. according to the type of information which they may provide in relation to the processing of polymeric compositions

Table 6.9

Type C objectives and their interdependence for the professional and graduate stages of a polymer technology curriculum

Area of study: The processability and process technology of polymeric compositions

Professional stage: level 1; objective 1			Professional stage: level 1; objective 2		
1) Recall the main propositions concerning the effects of formulation parameters and processing method on product quality and production economics for the manufacture of components from or applications of commonly available polymeric compositions			2) Interpret the features of a novel component or application in terms of generalised sets of rules governing the choice of several alternative processing features and processing conditions to achieve the optimum balance of product quality and production rate.		
Professional stage: level 2; objectives 3,4,5			Professional stage: level 2; objectives 6.7.8		
3)Recall the main physical/ chemical interactions of the components of common polymeric compositions and the manner in which they affect product quality during processing	4)Recall the main physical/ chemical interactions of the components of common polymeric compositions and the manner in which they affect processing rates	5)Interpret the basic principles related to the behaviour of polymeric compositions in mixtures with recycled materials in common processing situations	6)Interpret the basic principles related to the effects of alterations of polymer features or types of additives in common processing situations	7)Recall the rationale for the operations required in the manufacture of common components from (or applications of) polymeric compositions	8)Recall the special features of common processing operations which can be suitably altered to increase output and processing rate
Graduate stage: level 1; objectives 9,10			Graduate stage: level 1; objectives 11,12		
9)Recall the main underlying principles governing the relationships between the behaviour of formulation components of common polymeric compositions and their rate of processing and product quality	10)Recall the main procedures and underlying principles for the evaluation of the ease of processing of common polymeric compositions		11)Recall the major processing variables and special equipment features of common processing methods and interpret the principles governing their effects on processing rate and product quality	12)Recall the main experimental procedures and underlying principles for the assessment of processing variables and special equipment features on output and product quality for common processes	
Graduate stage: level 2; objectives 12,13,14			Graduate stage: level 2; objectives 15,16,17		
12)Recall the main mechanisms underlying the deformational behaviour of organic macro-molecular compounds over a wide range of temperatures and the manner in which such a behaviour may be modified through chemical/ physical interactions with other chemicals or additives	14)Recall thebasic analytical relationships which describe the behaviour of organic macromolecular systems under conditions leading to large deformations and flow	15)Recall the major mechanisms for the interaction of organic macromolecular systems with potential processing environments (e.g. additives, high temperature,oxygen,UVradiation etc.)	16)Recall the basic mechanisms of large deformation and flow of visco-elastic solids, melts, suspensions and solutions under a variety of geomet-rical constraints	17)Recall the basic analytical relationships which describe large deformations and flow of viscoelastic solids,melts suspensions and solutions under a variety of geometric-al constraints	18)Recall the major experimental procedures used for the characterization and interpretation of large deformations and flow of viscoelastic solids,melts suspensions and solutions

Objectives for the technician stage of a vocational curriculum in polymer technology

Area of Study: The processability and process technology of polymeric compositions

Type A Objectives: level 1	Type B objectives: level 1	Type C objectives: level 1
1. Deduce which processing method would most adequately impart the required type of deformation in the processing of a given polymeric composition 2. In a novel processing situation, deduce which component of a polymeric composition may be responsible for any observed effects on processing rate and product quality. 3. Deduce from a set of experimental data the most appropriate processing conditions and the type of special equipment features (e.g. gate design for a mould etc.) which would produce the highest output and the best product quality.	1. In a novel processing situation, identify the type of deformation to which a common polymeric composition is subjected during processing. 2. For a novel polymeric composition, identify those components which are likely to affect the processing rate and product quality. 3. In a novel processing situation, distinguish between those effects on processing rate and product quality arising from alterations in processing conditions from those due to special features of the processing method used. 4. Analyse the procedure details of a novel standard test method recommended for the monitoring of the processing characteristics of polymeric compositions and identify those key features (if any) which may differ substantially from those of established test methods.	1. Recall the qualitative relationships between large strain deformational behaviour of polymeric materials and types of processing methods used commercially. 2. Recall the basic concepts which underly the relationships between processing rate and product quality to the characteristics of the components of polymeric compositions. 3. Recall the basic concepts which underly the relationships between processing rate and product quality to processing conditions and special features of equipment used in the processing of common polymeric compositions. 4. Recall the main features of standard experimental procedures which are currently used to monitor the processing characteristics of polymeric compositions.
Type A objectives: level 2	**Type B objectives: level 2**	**Type C objectives: level 2**
1. Deduce whether a given polymeric composition undergoes predominantly an orientational type of deformation when subjected to a novel stressing situation in a certain temperature range. 2. Deduce whether a given experimental procedure would enable one to distinguish qualitatively the effects of additives from those due to polymer/resin constitution. 3. Deduce whether certain morphological and microstructural features in a component manufactured from or application of a polymeric composition have been brought about by additives or variations in processing conditions. 4. Deduce which parameters may be used to characterize the product quality of components manufactured from or applications of polymeric composition at the manufacturing stage. 5. Deduce whether a new or modified process is likely to affect the deformational behaviour, morphological and microstructure features of a resulting component. 6. Decide on the necessary conditions for novel test methods to provide reliable information on the effects of deformation rate and on microstructure of components manufactured from or applications of polymeric compositions.	1. Observe the manner in which a novel polymeric composition deforms flow and recovers when subjected to stresses and describe its behaviour using the appropriate scientific/technological nomenclature. 2. Analyse the stress/strain - straining rate curves for a common polymeric composition and distinguish those effects brought about by additives from those caused by modifications of the polymer/resin constitution. 3. Analyse various microstructural features of a novel component manufactured from or application of a common polymeric composition and distinguish those features brought about by additives from those due to alterations in processing conditions. 4. Observe the manner in which a given component manufactured from or an application of polymeric compositions is being used in service and identify those parameters which may be used to monitor the product quality at the manufacturing stage. 5. Analyse the components, operation sequences and variables of a novel processing equipment and identify those features which differ substantially from established processes. 6. Identify the features of novel test methods which may provide relevant information on deformational rates and on microstructure of components manufactured from or applications of polymeric compositions.	1. Recall the various sequences of events which take place when polymers and resins are subjected to large deformations under various conditions of temperature and stressing rates. 2. Recall the manner in which the basic structural features of polymers, resins and additives affect the large strain deformational behaviour of polymeric compositions. 3. Recall the manner in which the basic structural features of polymers and resins and the presence of additives affect the morphology and microstructure of common polymeric compositions in various processing situations. 4. Recall the basic parameters which may be used to characterise the product quality of components manufactured from or applications of polymeric compositions. 5. Recall the manner in which the variables of common processes may be manipulated to alter or control the deformational behaviour and microstructural organisation of polymeric compositions. 6. Recall the main equipment components and sequences of operations which may be used to monitor the deformation/flow rate and the microstructure of polymeric compositions.

6.6 Educational objectives for the discipline stage of a graduate curriculum in polymer technology

The aims of the discipline stage of a graduate curriculum in polymer technology may be stated as follows:

"To develop the necessary competences in basic sciences and associated mathematics (i.e. a scientific literacy) which will enable the student to carry out scientific enquiries and to apply the fundamentals of science (i.e. the basic concepts and principles) to the studies of polymer technology".

The objectives which the above aims subsume would have to be deduced from an analysis of the objectives stipulated in the graduate stage. A full hierarchy of objectives for the three areas of study in polymer technology is not available however, and consequently it is only possible to identify the broad contents of science and mathematics on which to base appropriate learning experiences.

These broad areas of relevant fundamental knowledge can be inferred from the contents of each of the three areas of study specified, i.e.

Areas of study pertaining to physical sciences

1. Bonding and interactions of atoms and molecules
2. Mechanisms, kinetics and energetic considerations of chemical reactions.
3. The structure of molecules and their characterization .
4. Atomic and molecular organization of the solid state.
5. Physico/chemical concepts of surface activity and interfacial phenomena.
6. Thermodynamics of transitions and associated relaxation.
7. Diffusion of gases and liquids in solids.
8. Mechanics of solids and interfaces.
9. Thermal and electrical conduction in solids.
10. Interactions of electrical and electromagnetic radiations in solids.
11. Momentum, energy and mass transfer processes.

Areas of study pertaining to social sciences

1. Economic theory of supply and demand.
2. Pricing mechanisms and costing.
3. Marketing and distribution.
4. Sources of finance
5. Management principles
6. Industrial law
7. Trade Unions and industrial relations
8. Social interactions

Areas of study pertaining to mathematics

1. Differentiation and differential equations
2. Integration and multiple integrals
3. Series
4. Polynomials and expansions
5. Complex numbers
6. Trigonometric functions
7. Matrices
8. Probability theory, statistics and experimental design.

The instructors would find it impossible to formulate objectives for these areas of studies without any clarification of the expected competences required in the subsequent stages of the course. They would also be equally embarassed if a "fully" pedantic instead of a pseudo-pedantic treatment of all the areas of studies listed was expected (see p. 201).

6.6.1 Identification of the areas of knowledge and abilities required by a graduate to comprehend the backfround information and to seek solutions to problems in polymer technology

To illustrate how educational objectives for this stage of the course may be inferred from the expected terminal behaviours of a graduate on completion of the course, a task analysis on three assignments was carried out.

6.6.1.1 Task analysis on a "Research and Development" project

(i) Identification of the underlying areas of knowledge

The project under exzmination concerns an investigation into the mechanisms by which "low profile and low shrinkage additives" eliminate surface roughness and reduce the moulding shrinkage in "SMC" compositions. The graduate is required to determine what are the ideal characteristics of those additives in terms of their molecular structure and particle geometry. This carries the implication that there should be no adverse effects on the ease of compounding and moulding, and on the service performance of manufactured components.

In order to be able to analyse the problem mentioned in the foregoing section and put forward suitable experimental propositions, the graduate must first be able to recall and interpret some pre-acquired information. The background information which the graduate received from a professional polymer technologist in the industry concerned, was stated as follows:

"It has been found empirically that by the incorporation of certain thermoplastics polymer powders, low shrinkage and profile additives, components manufactured from SMC's can display, under appropriate moulding conditions, zero-shrinkage and superior surface finish. Some undesirable side effects, such as the formation of white-speck blemishes, are brought about, however, when certain pigments are used".

The graduate would have to recall, or quickly retrieve, more relevant information on the problem. It is likely that he would subdivide the underlying areas of knowledge into:

a) composition parameters

b) compounding parameters

c) moulding parameters, and

d) service performance,

and recall, or obtain from the trade literature, the following type of information :

a) Composition parameters

An SMC consists of the following components:

Inhibited unsaturated polyester resin/thermoplastic polymer solution	30% w/w
Glass-fibres chopped strand rovings	30% "
Magnesium oxide powder (thixotropic agent)	5% "
Peroxide catalyst	0.3% "
Thermoplastic polymer powder (low profile additive)	2-5% "
Finely ground limestone filler	30% "
Pigment mixtures	1-3% "

1. An unsaturated polyester resin is a solution of low molecular weight unsaturated polyester in a liquid cross-linking monomer, containing very small amounts (the correct concentration is determined empirically for each specific type of resin) of a benzoquinone type inhibitor. For the purpose of reducing shrinkage to the resin solution is added a thermoplastic polymer; the mechanism is, however, unknown. Although there are several variants to the chemical constitution of unsaturated polyesters and cross-linking monomers, most widely used commercially are based on ortho-phthalic anhydride/ propylene glycol/maleic anhydride polyesters and styrene as the cross-linking monomer.

To be able to interpret and translate the above statements, it is necessary for the graduate (a) to be aware of the existence of such resins, (b) to know the terminology and concepts of the various chemical components involved, (c) to know the basic principle of acid/alcohol condensation and free-radical reactions, (d) to be aware of the concepts by which such reactions may be initiated, retarded and inhibited by external agents, and (e) to be familiar with the basic concepts of solubility of non-electrolites (table 6.2, objectives 9, 13; table 6.3, objectives 9, 13).

2. The glass-fibres chopped strand rovings are available in either soda glass- or alkali-free glass-fibres held in position by means of "size" coatings. The alkali-free glass fibres, also known as E-glass fibres are those most widely used commercially and the size formulations are based, normally, on vinyl acetate polymers. It is required that the sizes dissolve, or at least swell, in polyester resins. The sizes also contain a silane coupling-agent which is reactive towards both the surface of glass f ibres and the resin and therefore improves the interfacial adhesion between these two components of the composition. The surface of fibres is coated with a cationic lubricant in order to reduce interfibre friction and abrasion, which in conjunction with an auxiliary "anti-static agent" used to prevent the accumulation of surface charges, improves the handling characteristics of the fibres during their manufacture.

To comprehend the above information, it would require pre-learning of (a) the basic chemical concepts and attributes of glasses and surface activity of solids, (b) the basic concepts of solubility of electrolites and non-electrolites. (In addition, the student must be familiar with the basic concepts of electrostatic charge generation on surfaces and resistivity of solids. (Supporting objectives for objectives 9 and 13 of tables 6.2 and 6.3, hence suitable for the discipline stage).

3. The finely divided ground limestone filler is essentially calcium carbonate, normally containing a stearate coating, which reduces interparticle friction and enhances its free-flowing characteristics. The stearate coating renders the surface of the calcium carbonate somewhat hydrophobic and minimises the tendency of the particles to agglomerate, hence improving their dispersability in the liquid resin.

To comprehend the above statement it is, once more, necessary to be able to recall the basic concepts of surface activity and their association with dispersion of solid particles in liquids, in addition to chemical structure of the surface of minerals. (Suitable for the formulation of supporting objectives in the discipline- stage).

4. The very fine magnesium hydroxide powder is used to impart to the resin system thixotropic properties, i.e. to increase its viscosity for short shearing periods. This statement would be nonsensical without a recollection of (a) the basic concepts of shear stress and shear rate, and the manner in which they are related to the viscosity of liquids, and (b) the basic associations of surface activity of solid particles to their dispersion in liquids. (Suitable as supporting objectives for the discipline stage).

5. The pigments are used to impart the required colour to the composition. Normally, they are complex mixtures of inorganic oxides or salts with organic and organometallic compounds.

To decipher such a highly generalised communication, it is necessary that the graduate is familiar with the phenomena of light absorption and light diffraction on surfaces. (Suitable as supporting objectives for objective 9 in table 6.6).

6. The peroxide "catalyst" is used to initiate and increase the reactions between the cross-linking monomer and the polyester component. Both "gellation" time and rate of reactions are proportional to the concentration and type of peroxide used.

To interpret this statement, it is necessary that the graduate (a) knows the terminology, (b) is familiar with the chemical structure of peroxides and their ability to form free-radicals, (c) is aware of the properties of free radicals to react with unsaturated compounds and (d) has developed a sense of curiosity to enquire into the causes and mechanisms of "gellation". (Suitable as supporting objectives for objectives 9 and 13 in tables 6.2 and 6.3).

b) Compounding parameters

Compounding of SMC materials presents considerable problems in so far as the mechanical work necessary for efficient dispersive mixing cannot be performed on these materials owing to the need to preserve the length of the glass fibres. Consequently, special equipment and mixing procedures have to be used which vary from one manufacturer to another. A small amount of "low temperature" peroxide (i.e. one which can initiate curing of the resin at room temperature) could be used, perhaps,to "partially gell" the resin so that a "tack-free", easily handled, composition may be produced. It is feasible that to achieve this a small amount of tetrafunctional cross-linking monomer, such as diallyl phthlate is also used in addition to the difunctional styrene monomer.

Obviously, the interpretation of the above statement requires that the graduate is familiar with (a) the common compounding procedures used in the production of polymeric compositions, (b) the principles relating functionality and extent of reactions to "gel point" of thermosetting systems, and the implications of this in terms of flow properties of resins.

Furthermore, it is expected that the graduate is also familiar with the principles of dispersive mixing in order to interpret the functioning of the novel mixing procedure and relate it to the dispersion of the components of an SMC. (Objectives 10, 14 and 15 in tables 6.2 and 6.3).

c) Moulding parameters

Moulding of SMC materials is carried out in compression presses using matched-metal moulds. The temperature of the mould is maintained at the highest possible level in order to minimize the cycle time. The upper temperature limit, the pressure and the rate at which the pressure is applied is dictated by (a) the deformation characteristics of the composition, (b) by the volatility of the cross-linking monomer, (c) the concentration and type of peroxide and on the deformational constraints whichthe cavity geometry imposes on the deformation of the composition.

During curing the resin undergoes a volumetric shrinkage of approximately 7 - 8%, which causes the moulded components to assume dimensions smaller than the mould cavity. Additional shrinkage takes place when the component is allowed to cool to ambient temperature. In the absence of suitable low profile and low shrinkage additives, the moulded components display a surface roughness (a profile) and a "poor" control of the dimension tolerances. Variations in the moulding procedure and conditions, and in the geometrical features of the components give rise to sporadic results in the quality of surface finish of components, and in measurements of their toughness.

To interpret this information, it is necessary that the graduate:

a) has a basic knowledge of the elements of compression moulding processes (i.e. equipment features and process variables);

b) has a basic knowledge of the relationships between deformation rates and shear stresses for highly concentrated suspensions and is aware of the influence of cylindrical fillers and of the effects of geometrical constraints imposed on the deformations;

c) has a basic knowledge of the concepts of vapour pressure of liquids and solids and an awareness of the diffusion concepts through solids and porous media;

d) is aware of the effects of chemical structure and temperature on the decomposition rate of peroxides and the rate of initiation and propagation of free radical reactions;

e) has a basic knowledge of the concepts of free volumes in liquids and solids and the manner in which these are influenced by transitions and associated molecular relaxations.

f) is familiar with the concepts of toughness of materials and the implications for practical measurement of toughness.

(Items a) and b correspond to objectives 11, 16 and 17 in tables 6.8 and 6.9; items c, d, e and f are suitable as supporting objectives for the discipline stage).

d) Service performance parameters

The potential applications of SMC products are likely to demand the following performance:

i) High stiffness, strength and toughness and retention of these properties on ageing and in pressure of environmental agents.

ii) High surface gloss and freedom from aesthetically objectionable blemishes, and retention of gloss on ageing.

iii) Dimensional accuracy and dimensional stability of the components at elevated temperatures, on ageing and in contact with environmental agents.

iv) High electric strength and resistivity, and retention of these properties on ageing.

The above statements are meaningless, without a knowledge of:

a) the basic concepts of stress, strain, modulus, strain energy, fracture and yield stress, work or energy of fracture, and the underlying relationships between molecular structure and mechanical properties of solids;

b) the basic concepts of light diffraction on the surfaces of solids;

c) the basic concepts of conduction in covalently bonded materials;

d) the concepts of thermal and photoxidation of alkane structures and hydrolitic decomposition of esters.

Furthermore, it will be necessary that the graduate is aware of:

e) the limitations of standard test methods to predict the service performance of plastics compositions;

f) the effects of elevated temperatures, ageing and environmental agents on the mechanical properties of plastics compositions;

g) the factors which contribute to dimensional changes and warpage of plastics components.

(Items a,b,c and d are suitable as bases for formulating objectives for the discipline stage. Items e,f and g correspond to objectives 9 and 13 in table 6.5, objectives 9 and those at highest level in table 6.6, and objectives 17 and 18 in table 1).

(ii) <u>Identification of abilities</u>

In an industrial situation, after having interpreted the background communication on a specific problem, the graduate would be expected to gain practical experience (if not already available) of the compounding, moulding and product evaluation in order to familiarise himself with the procedures involved in actual full scale production. In this exercise he will make observations and measurements and will then make an analysis of the more specific information acquired through both personal experience and study of the relevant literature, so that he can define more precisely the nature of the problem and ways of finding appropriate solutions. In this analysis the graduate begins to engage in the process of scientific enquiry, which according to Bloom et al. (95) falls into four major categories (see table 6.11), i.e.

I Observing and measuring .

II Seeing a problem and seeking ways to solve it.

III Interpreting data and formulating generalisations.

IV Building, testing and revising a theoretical model.

In those circumstances, where there are too many constraints (economic and technical) on the number of variables that may be manipulated, e.g. production or technical service situations, the literature and experimentation on production scale equipment and materials are the only means by which the graduate would investigate the problem. In development functions, on the other hand, there are fewer constraints and, therefore, after discerning the most prominent features of the problem, the graduate would devise experimental procedures by which specific aspects of the problem can be evaluated in isolation, i.e. away from the production environment, so that a direct evidence of any formulated hypotheses can be obtained.

For the investigation outlined above, therefore, the following abilities may be identified:

Abilities required for investigations on production scale

(c.f. production development and trouble shooting)

A graduate may be asked to study the inter-relationships between all four production operations discussed earlier, i.e. formulation, compounding, moulding and product performance.

The most likely hypotheses that may be put forward here are:

a) The reduction in surface roughness is caused by migration of the low profile additive to the surface of the component, which results from phase separation of the thermoplastic polymer component as the resin cross-links, filling the depressions produced by the shrinkage of the resin.

As a corollary to the above hypothesis, the shear rate imposed on the composition during moulding (i.e. the rate of application of pressure) and curing rate of the resin (i.e. type and level of peroxide used in the formulation) should have a significant effect on the efficiency of low profile additives to reduce surface roughness (objectives 9 and 13 in table 6.7).

b) The reduction in shrinkage is caused by the thermal expansion of the "low shrinkage additive" which precipitates out of the resin during curing and counteracts its shrinkage. Hence mould temperature, type and level of peroxide used should have a significant effect on the efficiency with which low shrinkage additives reduce the mould shrinkage. (Objectives 9 and 13 in table 6.7).

c) The major effects of low profile and low shrinkage additives on the service performance of SMC components are:

α) an increase in toughness of components resulting from a reduction in residual stresses at the matrix/filler interfaces, and possibly also from an additional crack stopping mechanism which they provide;

β) an increase in diffusion rates of liquids and gases as a result of the formation of a greater incidence of microcracks, causing a more rapid deterioration in strength and toughness of components on ageing.

(Objectives 11 and 16 in table 6.4).

d) The efficiency of low profile and low shrinkage additives and their effects on service performance may be optimised by adjustments in the level and types of low profile additives and appropriate compounding and moulding conditions.

This hypothesis is at the highest level of abstraction and complexity, hence it is likely that it would be made more on the basis of logic reasoning than by fundamental considerations of the multitude of interactions likely to take place. It therefore represents the empirical element of the scientific enquiry in the solution of technological problems (see definition of technology in p 19) (This behaviour is not covered by objectives in tables 6.1....6.9, and therefore it would be necessary to add further objectives for those behaviours requiring transfer of learning across the three areas of study).

The testing of the above hypothesis would require carrying out a large number of experiments where many material variables interactions are likely to take place; therefore it would be necessary to set up the logic sequences of experiment by experimental design procedures (note the very high score accorded to experimental design by practising technologists).

The instruments and methodology for the evaluation of these hypotheses would involve procedures stipulated by appropriate "standards authorities", such as BSI, ASTM, ISO etc., unless appropriate test methods are not available owing to the short history of the compositions in question. Therefore, the graduate would be required to exert judgement as to whether any procedures stipulated for the testing of other materials and processes may be applied directly or by introducing some modifications. (Objectives subsuming the above behaviour are quite specific, hence they do not feature in tables 6.1....6.9).

The process of formulating and testing the above hypotheses would require that:

1) The graduate has a basic knowledge of the concepts of flow of suspensions and the ability to extrapolate these concepts to situations completely different and more complex than those in which they were originally derived. The literature survey can aid such a transfer

of basic concepts to more complex situations provided that the graduate has the capacity <u>either</u> to break down a complex communication, say a mathematical theoretical model, into its essential elements and select the useful and reject the irrelevant (analytical skills), <u>and/or</u> synthesize from a set of empirical data a congruent communication containing the essential basic scientific concepts. (Suitable objective for the discipline stage).

2) The graduate is aware of the thermodynamic transitions in thermoplastic polymers and structural rearrangements which take place during cross-linking of thermosets. Furthermore, he has to be aware of the effects of catalyst concentration and temperature on rates of free-radical reactions and be able to translate data from the literature, expressed in terms of activation energy, and rates constants. (Suitable as basis for the formulation of objectives for the discipline stage).

3) The graduate has to be aware of the phenomena of differential contraction or expansion between adjoining surfaces and the significance of these with respect to both stresses set up and conditions for crack propogation. Furthermore, he has to have a knowledge of the concepts of stress intensity and associated strain energy at the tip of cracks during fracture, and be able to interpret the manner in which stored strain energy may be reduced by promoting plastic deformations. He must be able <u>either</u> to break down a complex communication (a mathematical model) into its essential elements, select the useful and reject the irrelevant <u>and/or</u> synthesise from a set of empirical data (impact strength) a congruent communication containing the essential basic scientific concepts (i.e. stress concentrations, energy release rates etc.) (Suitable objectives for the discipline stage).

4) a) The graduate must be aware of the basic concepts of diffusion of gases and liquids and their adsorption on to solids, and must know the basic principles of hydrolisis of organic compounds.

b) He must know the basic principles relating interfacial bonding and matrix properties to strength and toughness of composite materials.

c) The graduate must be able to interpret and translate both the results of practical evaluation and theoretical elucidations on rates of diffusions, mechanisms of polymer decomposition reactions and interfacial phenomena in composites (a) and (possibly) b) suitable as objectives for the discipline stage. c) corresponds to objective 11 in table 6.5).

5) The graduate must have practical skills in manipulation of physical testing and engineering equipment (note the high importance attached to these by practitioners).

6) The graduate must be able: (i) to translate specific experimental data into conceptual parameters, (e.g. transforming pressure/deformation/time data into straining rate, stressing rate etc.), (ii) to present results concisely in graphical and tabulated formate (e.g. contour diagrams, statistical tests of significance etc.) (Behaviours 5 and 6 are quite specific, hence not featuring in tables 6.1....6.9).

7) The graduate must be able to evaluate the relative economic and technical significance of the data obtained and be able to deduce the conditions which produce the optimum balance of properties or produce the most desirable effects. (This corresponds to general aim in p. 210 + objective 9 in table 6.3).

<u>Abilities required for small scale investigations away from the production environment</u> (c.f. materials development)

It was said earlier that to carry out development work the graduate may be required to study mechanisms of low profile and low shrinkage additives under more controllable conditions than those obtainable in production so that direct observations and measurements may be made. In this case, one is ultimately interested in obtaining a definition for "the ideal low shrinkage and low profile additive", in terms of its physical characteristics and molecular structure, and compounding and moulding procedures. It is likely, therefore, that to try to achieve this objective, the graduate would probably consider the setting up of the following experiments in order to test the previously stated hypotheses:

Test of hypothesis (a):

- Measuring the speed at which thermoplastics powders rise to the surface at each stage of the curing process of the resin, and determine the influence of the thixotropic agent and of the particulate and fibrous fillers in the composition.

- Measuring the solubility characteristics of low shrinkage additives at different curing stages of the resin, by monitoring the rate of precipitation and observing any phase inversion phenomena.

- Measuring the relative segragation characteristics of filler particles and polymer particles under the influence of a low shear rate field at each stage of the curing process.

All these procedures would involve the use of standard techniques and equipment, but the graduate would have to devise a methodology by which the migration of particles may be followed. (These imply skills in laboratory techniques, hence suitable for the discipline stage).

Test of hypothesis (b):

This would involve first, an attempt to calculate what levels of additive would be necessary to counteract the shrinkage of polyesters, by several definite amounts, from a knowledge of the thermal expansion characteristics of the polymer powders and volumetric shrinkage of the resin. If the data are not available, they would have to be measured experimentally, and comparison would be made with the calculated values. (This implies general computation abilities, hence suitable as a basis for formulating objectives for the discipline stage).

Test of hypothesis (c):

Increasing toughness in engineering materials is always desirable and, therefore, if existing additives do not appear to produce such beneficial effects, this hypothesis would have to be reformulated in the light of novel experimental results aimed at discovering those factors which interfere with the proposed toughening mechanisms.

This would make it necessary to measure the effects of thermoplastic powders, the fracture toughness of resin/particulate filler, resin/fibrous filler/particulate filler systems, and to examine by direct observations the operating mechanisms. This would involve, of course, various other important considerations, such as the effects on interfacial bonding, geometrical shapes of polymer particles and their bulk mechanical properties (i.e. rubbery, capable of yielding under triaxial stress fields, etc. (The above implies the possession of scientific enquiry ability, hence suitable as basis for objectives in the discipline stage.

On the assumption that the more rapid deterioration in toughness resulting from ageing in degradent environments is unacceptable, (a decision which would be reached by the professional technologist rather than the graduate) it would be necessary to verify the hypothesis that this is connected with the increased diffusion rates of the degradent agents. A thorough investigation would involve locating the micro-cracks and establish their features in a moulded component (i.e. whether occurring in the bulk of the matrix or in the interfacial regions), and determine whether the deterioration is due to resulting modifications of interfacial properties or to chemical decomposition of the resin. The latter can be measured directly by means of established chemical analysis techniques, whereas the former would have to be inferred by indirect deduction, unless highly specialised and expansive isotope labelling and counting techniques are available and/or justifiable economically. (Scientific enquiry abilities).

Test of hypothesis (d):

This hypothesis would be verified by a deduction reasoning involving the analysis of trends in all the behaviours examined and by applying suitable statistical optimization tests.

Obviously in an industrial situation, the whole process of hypothesis testing and associated experimental measurements depend on resources available and on the value of the knowledge obtained to the company, in terms of sales prospects etc. Although such a decision falls outside the range of responsibilities of a graduate, it is nevertheless important that the graduate should appreciate the economic constraints and, whenever applicable, the social implication of his work (see general objectives in the affective domain, p 185). Hence the graduate often faces the arduous task of having to select and test only a few hypotheses and propose solutions to a problem on insufficient direct evidence. This ability represents an additional dimension for the process of scientific enquiry, discussed earlier, in technological work.

For the purpose of identifying suitable objectives for the discipline stage of the curriculum, however, it is important to note the following points:

1) To formulate and test hypothesis (a) the graduate requires to have a basic knowledge of the implications of Stoke's law in situations where there are several constraints to its direct application, i.e. the presence of many particles would reduce their net velocity by mutual collisions. Furthermore, the graduate must be able to extrapolate the basic principles of the velocity of a "free" flowing sphere in a stationary liquid to one where the fluid is subject to "drag" flow.

Such considerations would enable the graduate to reject the first part of hypothesis (a) in favour of the third and, therefore, avoiding setting up wasteful experiments. To formulate and evaluate the worth of the second part of hypothesis (a), the graduate requires to know the concepts of solubility of polymers in solvents, so that he will be able to distinguish between potentially efficient low shrinkage additives from those which are not. He must, finally, be able to select or devise suitable experimental procedures which give the most realistic results in terms of actual compounding and moulding conditions used on production scale.

2) To formulate hypothesis (b) the graduate needs to be familiar with the concepts of thermodynamic transitions in macromolecular systems and associate these concepts with molecular relaxations and changes in "free volumes", brought about by chemical cross-linking reactions and variations in temperature.

Furthermore, he must be able to manipulate algebraic expressions and, possibly, perform simple computations involving partial differentiations.

3) To formulate and test hypothesis (c), firstly the graduate must know the basic concepts of fracture mechanics and, secondly, he must be able to translate and extrapolate the mechanisms put forward in relation to nucleation and growth of cracks in materials. Finally, he must be able to apply standard test method procedures to measure the toughness of composite materials and interpret the data obtained in terms of their potential service performance.

6.6.1.2 Task analysis on a "Trouble Shooting" assignment

This analysis considers the actions which had to be taken by the writer, while working in industry as a graduate, in response to a problem associated with fire-retardant grades of polypropylene. There were basically two major problems associated with the use of these materials:

a) there were recurring discolourations on the mouldings produced, and

b) the mouldings were losing the self-extinghishing characteristics after relatively short exposures (3 to 6 months) in the temperature range of 60 - 80°C.

The graduate was, therefore, required to examine the causes and to provide fairly quickly a solution by devising alternative formulations.

(i) Identification of the underlying areas of knowledge

The graduate had to retrieve the relevant information on the problem by searching into the details of the formulations, compounding procedures and moulding conditions used. The considerations on the underlying areas of knowledge are similar to those made for the case of the SMC project and, therefore, any difference between the two projects would be revealed at more specific levels than those shown in tables 6.1.....6.9. This is illustrated below:

(a) Considerations on formulation parameters

A fire retardant polypropylene formulation is based on a mixture containing raw polymers, halogenated hydrocarbons, antimony oxide and normal auxiliary ingredients, such as stabilisers, pigments etc. The records would show the nature and proportion of each ingredient, and (possibly) the reports on the experiments carried out to arrive at the given formulation.

To be able to interpret these data, it is necessary that the graduate knows:

(a) the nomenclature for all chemical constitutents,

(b) the principles by which fire retardancy is achieved, and

(c) the basic principles underlying the functioning of the auxiliary ingredients

(tables 6.2 and 6.3, objectives 9 and 13 - similar to SMC project). These in turn subsume a knowledge of the basic mechanisms and rates of chemical reactions, concepts of solubility of non-electrolites and behaviour of solids (e.g. melting, sublimation etc.) and, therefore, constitute a suitable basis for objectives in the discipline stage.

(b) and (c) Considerations on compounding and moulding parameters

The areas of knowledge at both general and specific levels can be inferred directly from the considerations made on the SMC project.

(ii) Identification of analytical abilities

In such a situation, the graduate is likely to put forward the following hypotheses and test these either by setting up rapid experiments or by direct inferences from the records on such materials, i.e.

I. Discolouration problems

(a) The discolourations in the mouldings are due to either:

(α) decomposition of the polymer, (β) decomposition of the fire retardant additive, and (γ) chemical interactions with the pigments used in the formulations.

(b) Discolourations may be due to material decomposition during compounding and subsequent moulding.

(c) Rates of decomposition are dependent on temperature.

In order to make such generalised hypotheses, the graduate must have reached the objectives 9, 10 and 15 in table 6.1; objectives 9 and 15 in tables 6.2 and 6.3; objective 15 in tables 6.7, 6.8 and 6.9; objectives 11 and 12, 16 and 17, table 6.5. Once more the graduate is engaged in a process of scientific enquiry (see p259) and, therefore, the educational process for the development of such abilities can be initiated in the discipline stage of the course.

II. Loss of fire retardancy on ageing

(a) Fire retardant properties are lost by virtue of further decompositions occurring on ageing, which would be accompanied, therefore, by increasingly more pronounced discolourations.

(b) Fire retardancy is lost by volatilization of the fire-retardant components, either directly or as a result of interactions.

In order to be able to formulate and verify such hypotheses, the graduate must have reached objectives 10, 14, 15, 16, 17 and 18 in table 6.5.

(iii) Identification of abilities related to synthesis and evaluation in Bloom's taxonomy

The graduate at this stage would have established that the causes of discolourations are due to the decomposition of the halogenated hydrocarbon component in the formulation, whereas the loss of fire-retardancy is due to sublimation of the same component. In this situation, after having established the causes of the problems, the graduate had to provide a short term solution to the problem and had to explore the means of achieving a permanent solution.

A short term solution on discolourations was found by using a co-polymer which could be processed at lower temperatures and by addition of suitable processing stabilizing agents. The only short term solution to the loss of fire-retardancy that could be found was to establish the minimum level of fire-retardant agent which would meet the specifications provided and estimate the initial levels required in order to maintain the fire-retardant properties during the expected service-life of the components.

To obtain a more permanent solution, it was required to search for a much more stable and less volatile halogenated compound. This involved having discussions with the various suppliers and selecting from the multitude of alternatives a few compounds likely to give the required performance.

Furthermore, it was deemed necessary to explore the possibility of using co-additives to produce synergistic effects and, therefore, reducing the levels of additions so that formulation cost would have been reduced and a less severe deterioration of mechanical properties would have resulted from the incorporation of additives. In such studies, considerable transfer of knowledge was required in so far as the situation did not allow for extensive experimentation to investigate into mechanisms, etc. These had to be inferred directly from other fields by means of analogies and extrapolations. The graduate had to devise rapid and reliable procedures to monitor the effects of the modifications considered and experimental design procedures had to be invoked, in order to reduce to a minimum the number of variables investigated.

It would seem that as far as the manipulation of data and knowledge is concerned, all the elements contained in this analysis have already been accounted for in the analysis of the SMC project: the only difference being with respect to specific items (e.g. injection moulding instead of compression moulding) and with regard to the time element, which is always shorter in trouble shooting situations (see general educational objective in p.213).

6.6.1.3 <u>Task analysis of a "Production Situation" in which the polymer technologists is required to assess the manufacturing implications of a new product</u>

This analysis considers the involvement of the writer (polymer technologist) in assisting a trade moulder (design and production engineers) in the selection of suitable plastics materials for the production of a given component.

The firm in question was considering the replacement of cast aluminium with a high performance plastics material as a joining member for metal frames in the construction of shelves and display scaffolding. The key features of such components were(i) a locking mechanism to prevent the square tubular frames from sliding out; (ii) a cubical geometry of the corner pieces and (iii) heavy cross sections of the connecting rods to ensure that the structure was sufficiently rigid.

The polymer technologist was required to analyse the existing metal component, suggest qualitative modifications in order to enable the component to be manufactured from plastics materials and to supply the required data on a few selected plastics materials so that the designer of the component and associated moulds could make more exacting estimates of the geometry and dimensions (see the relationship between technologists and engineers in p. 19 and educational aims in p.227).

(i) Identification of the underlying areas of knowledge

To interpret the above information, it was necessary for the graduate to be aware of some basic engineering principles, e.g. shear stresses developed by twisting or torque actions, etc. (note the inclusion of this topic area in fig. 4.24, hence suitable as a basis for objectives in the discipline stage).

In order to assess the implications of the suggestions made it was necessary to have a knowledge of the factors which govern the deformational behaviour of plastics (level 2 objectives for the graduate stage in table 6.6) and of the factors which affect their mouldability (objectives 9, 11, 12, 14, 16 and 17 in table 6.4).

(ii) Identification of the abilities required

In the analysis of the features of the component in question, the polymer technologist had to identify all the factors which would limit the use of plastics materials with respect to service performance and manufacturing processes available. Thermoplastics were the preferred choice of materials in view of their superior toughness, but there was some concern regarding the dimensions of the cross-section of the component which might have made it difficult to control the tolerances. It may have produced also internal defects and surface depressions and may have given rise to long production cycles.

It was felt that many of such difficulties could be overcome by altering the profile of the connecting rods and by selecting materials which display both a low shrinkage and a reduction in surface depressions during moulding. The problem of stress relaxation and creep exhibited by thermoplastics was recognised and the need to estimate the magnitude of these effects within the expected service life of the component was established.

Nylon 6, nylon 6.6, acetals and the respective glass-reinforced grades were selected on the basis of their high static strength, high modulus and low stress relaxation and creep rates. Two prototypes differing from each other only with respect to cross-section dimensions were machined from standard-rod stocks and both the load to fracture or yield and the locking torque were measured under simulated service conditions. A standard formula was then used to calculate the shear stress corresponding to the measured torque and the extent of stress relaxation was estimated using creep curves. The data on the glass filled grades were available only for the nylon 6.6 material and, therefore, the remainder had to be inferred from the curves for the unfilled materials.

The force required to pull-out the frame from the joining member, subsequent to the expected stress relaxation process, was estimated. From these results it was concluded that the best performance was to be expected from the use of nylon 6, but in view of the manufacturing difficulties outlined previously, the corresponding glass reinforced grade would also have to be considered, and that the final decision could only be reached after a more rigorous design analysis and on the basis of experiments carried out on the actual moulded prototypes. This analysis illustrates not only the close relationship which may exist between polymer technologist and engineers, but also that between graduates and professionals. Furthermore, it provides tangible evidence for the statement made in p. 202 that in technology many conclusions have to be reached on insufficient data.

In order to be able to carry out the above task, a polymer technologist would have reached: objectives 3, 4, 5, 9, 13, 14 and 15 in table 6.5; objectives 1, 3, 5, 9, 10, 11, 13 and 18 in table 6.4; objectives 3, 4, 6, 8, 9 and 11 in table 6.8 and objectives 3, 9 and 16 in table 6.7.

This analysis seems to indicate also that there well may be advantages to be gained from a broader approach in the study of materials for the development of abilities related to material replacement problems or to situations where a wide range of materials and processes may have to be considered.

It can easily be inferred from the three "tasks" analysed above that the objectives in tables 6.1....6.9 are still not sufficiently specific to enable an instructor to deduce directly the behaviours entailed in performing the tasks described. It seems also that these analyses may be used as a basis for inferring the more specific objectives, as it is illustrated below.

6.6.2 Translation of abilities required to investigate specific problems in polymer technology into educational objectives

The tasks analysed in the preceding section fall within the realm of all three areas of study specified in the graduate stage of a polymer technology curriculum, and in some instances they merge with the objectives specified for the professional stage.

The analysis also illustrate well the wide range of basic science subjects on which the graduate has to draw in order to make a disciplined enquiry, and confirms the appropriateness of "Materials and manufacturing technology" as the focal theme for polymer technology curricula. By means of this analysis, it is possible to continue the hierarchy of educational objectives for the polymer technology units by adding more specific ones. One of the type B objectives, at level 2, for the area of study "the processability and process technology of polymeric compositions" was:

"Classify the experimental procedures used to monitor the behaviour of suspensions, melts etc., according to the type of information which they may provide in relation to the processing of polymeric compositions".

This can be followed by lower level (more specific) objectives, such as:

level 3: Distinguish those moulding characteristics of a novel polymeric composition which may be directly evaluated on production scale equipment from those which require model equipment operating under controllable and/or steady state conditions.

level 4: Analyse the geometrical details of the cavity of a compression mould and identify those features which may give rise to variations in shear rates, temperature rises, turbulence, fibre breakdown, etc., in the moulding of long fibres random composites.

level 5: Identify the conditions under which a polymeric composition containing a mixture of high density fillers, fibrous and particulate, and low density filler particles, give rise to separation of components.

It must be noticed that although all three objectives stated above have been developed in relation to one specific task analysed, they apply equally well to a wide range of other polymeric compositions, e.g. phenolics, amino moulding powders, fire retardant thermoplastics composites, reinforced rubber compositions etc.. Furthermore, apart from the second objective stated above, they apply equally well to most paint compositions.

A further increase in level of specificity would produce objectives whose achievement does not depend on taking specific polymer technology examples, and consequently would be suitable for the discipline stage. The next objective in the above hierarchy, therefore, could be stated as follows:

"Analyse the range of predictions which can be made by the application of Stoke's law and identify those features which may limit its direct applicability in the case where there are a large number of particles present".

Alternatively, for the purpose of deriving suitable objectives for the discipline stage, it is possible to adopt the scheme devised by Bloom, Hastings and Madaus (97). In this scheme, a matrix is used in which the columns specify the range of behaviours and the rows contain the areas and topics of basic science to be used as central focus for the achievement of educational objectives. On the basis of this scheme the behaviours and areas of science revealed by the task analysis, carried out in the preceding section, were identified and listed in table 6.11.

An examination of table 6.11 reveals the wide range of behaviours and science concepts and principles encompassed by areas of study in polymer technology, and suggests that a full hierarchy of objectives can be derived even on a fairly small range of investigations likely to be carried out by graduates in industrial situations.

The scheme outlined, in which behaviours are expressed in general terms and are directly related to subject matter (or contents), is more in line with the doctrines of a "pedantic type" curriculum than one in which objectives are expressed in terms of specific behaviours, such as those specified in tables 6.3, 6.4....6.10.

However, as already explained (p.203 and p.207), the wide range of "disciplines" which such units would encompass will certainly limit the level and extent of coverage of subject matter and therefore it is essential to draw appropriate inferences from the objectives specified in the subsequent polymer technology units.

It is understood that whereas the acquisition of knowledge of basic concepts and principles is the prime objective of the discipline stage of the curriculum, it is equally important to develop analytical abilities to enable the student to break down a theoretical model into its essential elements and to identify its applicability to a novel situation. It is also important that the student should develop the ability to synthesize from a set of empirical data a congruent communication containing the essential basic concepts (e.g. ability to interpret impact strength data in terms of fracture mechanics concepts). It is, therefore, in this respect that the discipline stage would differ from a "pedantic/saintly conception" approach.

TABLE 6.11 Specification of educational objectives in the "pedantic" stage of a polymer technology curriculum, as inferred from task analysis on a specific investigation (95)

Areas of study for the pseudo-pedantic stage	A 0 Knowledge and comprehension	A 1 Knowledge of specific facts	A 2 Knowledge of scientific terminology	A 3 Knowledge of concepts of science	A 4 Knowledge of conventions	A 5 Knowledge of trends and sequences	A 6 Knowledge of classifications, categories and criteria	A 7 Knowledge of scientific techniques and procedures	A 8 Knowledge of scientific principles and laws	A 9 Knowledge of theories or major conceptual themes	A 10 Identification of knowledge in a new context	A 11 Translation of knowledge from one symbolic form to another	B 0 Processes of scientific inquiry I: Observing and measuring	B 1 Observation of objects and phenomena	B 2 Description of observations using appropriate language	B 3 Measurement of objects and changes	B 4 Selection of appropriate measuring instruments	B 5 Estimation of measurements and recognition of limits in accuracy	C 0 Processes of scientific inquiry II: Seeing problems and seeking ways to solve them	C 1 Recognition of a problem	C 2 Formulation of a working hypothesis	C 3
1. Physical Sciences																						
1.1 Bonding of atoms & molecules																						
1.1.1 covalent, ionic & metall.			V	V		V					V				V					V		
1.2 Mech. & kin. energy of chem. reactions																						
1.2.1 Free radicals & photoch.		V	V	V		V	V		V		V			V	V	V				V	V	V
1.2.2 Esterification & hydrolisis		V		V							V									V		
1.2.3																						
1.3 The struc. of molec. & charact.																						
1.3.1 Spectroscopy				V				V							V							
1.3.2 Molecular dimensions & shapes				V		V	V				V					V	V					
1.4 Atomic & molec. organ. in solids																						
1.4.1 Configurations of cov.bonded molecules		V	V	V							V									V	V	
1.4.2 Amorphous & crystalline states		V	V	V		V	V	V	V		V			V	V	V	V	V		V	V	V
1.4.3 Nature and interactions of atoms & molecules at surfaces and surface changes		V	V	V			V	V	V	V	V			V	V	V	V	V		V	V	V
1.5 Thermodynamics of transitions																						
1.5.1 Relaxation phenomena and influence of molec. structure		V	V	V		V					V			V		V	V					V
1.5.2 Solutions of electrolites and non-electrolites		V	V	V				V	V		V			V	V	V	V			V	V	V
1.6 Diffusion processes of ions and molecular species		V	V	V				V			V			V	V	V				V		
1.7 Mechanics of solids and interfaces																						
1.7.1 Concepts of stress, strain, modulus, strength, toughness		V	V	V				V			V			V	V	V	V	V		V	V	V
1.7.2 Relationship between structure of solids and modulus, strength and toughness				V							V				V	V	V	V			V	V
1.7.3 Principles of reinforcement and optimization of strength and toughness				V				V			V				V	V	V	V		V	V	V
1.8 Momentum energy and mass transfer																						
1.8.1 Rheology																						
1.8.1.1 Basic shear stress/shear rate relationships for Newtonian and non-Newtonian fluids		V	V	V	V			V	V		V			V	V	V	V	V		V	V	V
1.8.1.2 Dispersive mixing			V	V		V					V			V	V	V	V			V	V	V

																			D 0 Processes of scientific inquiry III: Interpreting data and formulating generalizations
	✓	✓	✓		✓		✓		✓	✓									D 1 Processing of experimental data
	✓	✓	✓	✓	✓		✓		✓	✓									D 2 Presentation of data in the form of functional relationships
	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓		✓			D 3 Interpretation of experimental data and observations
	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓		D 4 Extrapolation and interpolation
			✓						✓			✓	✓				✓		D 5 Evaluation of a hypothesis under test in the light of data obtained
	✓	✓	✓	✓					✓										D 6 Formulation of generalizations warranted by relationships found
																			E 0 Process of scientific inquiry IV: Building, testing and revising a theoretical model
	✓		✓		✓		✓		✓	✓	✓				✓	✓	✓		E 1 Recognition of the need for a theoretical model
			✓						✓	✓		✓	✓						E 2 Formulation of a theoretical model to accommodate knowledge
																✓	✓		E 3 Specification of relationships satisfied by a model
	✓		✓	✓	✓				✓	✓		✓	✓		✓	✓	✓		E 4 Deduction of new hypotheses from a theoretical model
	✓																		E 5 Interpretation and evaluation of tests of a model
																			E 6 Formulation of a revised, refined or extended model
																			F 0 Application of scientific knowledge and methods
															✓	✓	✓		F 1 Application to new problems in the same field of science
																	✓		F 2 Application to new problems in a different field of science
	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		F 3 Application to problems outside of science (including technology)
																			G 0 Manual skills
	✓	✓	✓		✓	✓			✓	✓									G 1 Development of skills in using common laboratory equipment
		✓	✓		✓	✓			✓	✓									G 2 Performance of common laboratory techniques with care and safety
																			G 3
																			H 0 Attitudes and interests
					✓	✓			✓	✓		✓	✓	✓					H 1 Manifestation of favorable attitudes toward science and scientists
			✓						✓	✓									H 2 Acceptance of scientific inquiry as a way of thought
										✓									H 3 Adoption of "scientific attitudes"
			✓	✓	✓				✓	✓		✓	✓	✓					H 4 Enjoyment of science learning experiences
				✓	✓	✓	✓	✓		✓		✓	✓	✓	✓		✓		H 5 Development of interest in pursuing a career in science
																			I 0 Orientation
		✓															✓		I 1 Relationships among various types of statements in science
	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓				I 2 Recognition of the philosophical limitations and influence of scientific inquiry
																			I 3 Historical perspective recognition of the background of science
																			I 4 Realisation of the relationships among science, technology and economics
			✓	✓	✓				✓										I 5 Awareness of the social and moral implications of scientific inquiry and its results

CHAPTER 7

STUDY OF THE FEASIBILITY OF INTEGRATING POLYMER TECHNOLOGY IN THE GRADUATE STAGE OF A CURRICULUM.

The desirability of integrating studies of the technology of various polymeric products and of extending the integration process to studies of other materials, in order to provide a broader based education and to better satisfy industrial needs, was indicated in the first chapter, and confirmed by the survey of practising technologists.

Model curricular structures leading to professional qualifications were consequently developed (Chapter 5) with such integration in mind, although reservations were made with regard to the practical feasibility of eliminating completely a bias towards or emphasis on a particular class of materials, even through a thematic approach in the graduate stage.

In the development of objectives, it was shown that a vertical integration of basic science with technology is made feasible by sub-dividing levels of objectives in ascending order of specificity of behaviours involved. It was demonstrated, in fact, that by this procedure a highly specific type B objective pertaining to the area of study "the processability and process technology of polymeric compositions", such as:

"Classify the experimental procedures used to monitor the behaviour of suspensions, melts, etc., according to the type of information which they may provide in relation to the processing of polymeric compositions"
would produce an even more specific objective, such as:
"Analyse the features of a given experimental procedure for the measurement of the viscosity of fluids and identify the factors which may have to be controlled to obtain accurate estimates of the shear rate"
which falls clearly in the realm of basic science.

The integration of underlying polymer science with polymer technology is also implicit, of course, in this approach, as it can be exemplified by the type C objective for the area of study: "The constitution and production of polymeric compositions":

"Recall the basic principles underlying the physical and chemical interactions likely to occur between potential components of polymeric compositions".

In this objective is implicit the possession of a knowledge of the concepts of free-radical polymerization reactions, which are normally associated with studies of polymer science, but the manner in which the objective is stated forces the instructor to integrate concepts of free radical polymerization (c.f. cross-linking of thermosetting systems) with those of free radical decomposition. These two aspects are normally treated separately, often by different instructors, with the inevitable repetition of concepts of peroxides, decompositions and reaction steps.

The advantage of integrating the science concepts with the technology of controlling such reactions is apparent, therefore, not only in terms of added meaning to the learning process, but also with respect to the efficiency of utilization of a very important resource, i.e. time. In other words, by vertical integration of science and technology in this context is meant that process which brings about continuity and sequence of learning experiences in a curriculum through a divergence of basic science into technological areas or by focussing related scientific principles on to practical problems.

7.1 Horizontal integration of the technologies of polymeric compositions in a graduate curriculum

It was said in p. 59 that the feasibility of horizontal integration has to be judged on evidence that concepts and procedures for one product technology can be applied to others without "distorting" the original concepts and/or questioning the validity of established procedures.

The objectives in table 6.3, 6.4....6.9 were expressed in sufficiently general terms to ensure that they would apply to all types of polymeric compositions, irrespective of the details involved at more specific levels and were derived purely on the basis of the writer's experience and knowledge. Therefore, the applicability of such objectives to problems associated with development, trouble shooting and other activities involving other classes of polymeric compositions, e.g. adhesives, surface coatings, etc., can only be ascertained by appropriate task analysis exercises carried out by specialists in these fields.

If the underlying concepts, principles etc., however, (as already mentioned in Chapter 3, p. 59) are applicable to the technology of all polymeric compositions, then it is quite likely that the mental operations involved in the manipulation of these to the solution of practical problems are also transferable. It is, therefore, the purpose of this section to analyse the areas of knowledge underlying the technology of plastics, rubbers, adhesives and surface coatings and, to a lesser extent, also the basic concepts and principles in the field of ceramics and metals, in order to identify possible integrative threads.

The production of fibres and associated weaving and knitting technologies are excluded a priori from this analysis, owing to the uniqueness of the procedures involved and the geometry of the products. The same arguments apply as regards other highly specialised technologies where the polymeric materials are either used as additives, auxiliaries, e.g. binders for papers, concrete etc., or they consist of traditional natural products, which are not associated with the materials producing branch of industry, (i.e. timber, plywood, leathers etc.).

It is not implied, of course, that the technology of these materials should not be integrated within the framework of polymer technology, but it is merely pointed out that because of their highly specialized nature, they would only feature in a few objectives and that their omission in the analysis is made in order to render the task more manageable.

In the analysis, the objectives (at level 1) specified for the graduate stage were used as the basis for the identification of common elements underlying the technology of the various classes of materials in question.

Recall objectives were selected for the analysis instead of transfer objectives (i.e. types B and A) since the achievement of the latter is less dependent on the underlying knowledge. In other words, as implied earlier, if type C objectives may be integrated, then integration of objectives type B and A would follow automatiaally. A thorough analysis of all the aspects of the technology of materials is obviously a too great task to be carried out by any single individual, since much of the technological knowledge has been acquired on highly specific lines. Therefore, such a study would have to be carried out through detailed studies of publications and the information contained would have to be restructured along some unified lines. For the purpose of this investigation, only a test of the feasibility of integration has been attempted and consultation of the literature has been restricted to basic textbooks.

In figs. 7.1, 7.2 and 7.3 are shown both the methodology used in this analysis and the inferences derived. The common elements of the technology were clustered together and the basic concepts which have to be manipulated for the interpretation of such technological elements were identified.

7.1.1 Inferences on the feasibility of unifying the knowledge underlying "The constitution and production of polymeric compositions"

The analysis of level 1 recall-objectives for this area of study (fig. 7.1) revealed the following:

(i) Integration of the four major classes of polymeric compositions into a unified polymer technology frame work is highly feasible.

Practically all polymers and additives available commercially are used in all four classes of polymeric compositions, Admittedly, the different property requirements for various product applications would demand considerable tailor-making of structure and levels of basic polymer structure and additives, c.f. pigment content in surface coatings and plastics.

Furthermore, some highly specific elements of the technology of certain polymeric compositions, e.g. the use of sulphur and associated accelerators and activators exclusively used for the cross-linking of polydiene rubbers, could also appear as obstacles to the total process of integration.

(ii) Unification of the constitution of polymeric and ceramic compositions is only partly feasible at some specific objective levels, i.e. those involving the recalling of basic underlying scientific concepts. For instance, in discussing the constitution of polymers used in the production of polymeric compositions, it would be possible to compare the effects of size and polarity of comonomer units in organic polymers with the relative size and screening power of metal oxide ions in inorganic (ceramic) polymeric structures (98). Greater possibilities of integration exist, on the other hand, in the interpretation of the constitution of ceramics and metal alloy compositions since their formation is based, in both cases, on well established concepts and principles of phase diagrams. Although it could be argued that these concepts are also applicable to polymer/additive mixtures in the production of polymeric compositions, there are only a few examples which could be used to provide the unifying threads, i.e. possibly plasticization and internal/external lubrication concepts.

Such a forced style of integration, however, could have more detrimental than beneficial effects on the transfer of learning, since it could convey to the student the impression that the examples given constititute the major methods by which the composition of polymeric materials is being altered to achieve the desired changes in properties.

Several aspects of mixing and compounding of polymeric and ceramic compositions may be integrated at conceptual level, since most of the factors affecting dispersion of the components, e.g. agglomoration, flocculation, mechanical work etc., can be treated in a unified manner. Furthermore, the same mixing equipment, e.g. continuous compounding extruders, and many basic formulation components, e.g. fillers and pigments, are used for both polymeric and ceramic compositions (see, for instance, the first level 2 objectives in table 6.3). Aspects of quality control may be unified quite easily, since the concepts and principles involved are independant of the product concerned and the same (or similar) physical tests, e.g. optical methods, mechanical property measurements etc., may be used to assess the quality of mixing. There is little scope, however, for the integration of concepts underlying the mixing and compounding of polymeric and ceramic compositions with those involved in the production of metal compositions, except in some highly specific cases, e.g. mixing of dry powders.

7.1.2 Inferences on the feasibility of unifying the knowledge underlying "The properties and serviceability of polymeric compositions"

The analysis of level 1, type C objectives for this area of study is shown in fig. 7.2, and the inferences can be summarised as follows:

(i) The technological elements and underlying scientific concepts are common to all four types of polymeric compositions. Hence there should be little difficulty in achieving the first level 1 objectives in an integrated manner.

(ii) The phenomenological aspects and the mechanics of the deformations and fracture are similar for all classes of materials. Considerable differences arise, however, in the interpretation of the mechanisms of large deformations and post-yield phenomena; i.e. the molecular aspects of plastic and rubbery deformations of polymeric materials are unique.

The interpretation of the viscoelastic behaviour of polymeric and ceramic compositions, on the other hand, could be approached in a unified manner.

(iii) Unified interpretations of the optical and dielectric properties of polymers and ceramics are possible, but can only be extended to metals in a very limited manner, e.g. interpretations of the electrical behaviour of semiconductors.

(iv) The kinetics of diffusion of molecular vapours and ionic species can be treated in an integrated manner for all three classes of materials, though interpretation of the mechanisms requires taking into account their difference in chemical and morphological constitutions.

(v) The basic concepts underlying the interactions of compatible additives with host matrices in the case of polymeric compositions differ substantially from those of ceramics and metal compositions.

(vi) Aspects of structure decompositions by thermal and ageing effects and associated methods of decomposition prevention are different for all three classes of materials and, therefore, would have to be treated as discrete areas of knowledge.

(vii) Irespective of their intrinsic chemical nature, materials have to meet certain performance requirements. However, whereas the mechanical performance and weathering resistance are required in all classes of materials, only polymeric and ceramic compositions have common technological links with respect to their dielectric and optical properties.

Consequently, almost total integration should be possible with respect to phenomenological evaluations of mechanical, dielectric, optical and thermal properties for the case of polymeric and ceramic compositions, whereas integration with metal technology would have to be restricted to the area of mechanical properties.

The methodology used in the evaluation of the performance has to be guided by mechanistic interpretations of the phenomenology, and in this respect considerable differences occur between the three classes of materials in question.

7.1.3. Integration feasibility of the "processability and process technology"

The analysis of level 1, type C objectives for this area of study is shown in fig. 7.3, and the inferences can be summarised as follows:

(i) A full unification of the processing technology of polymeric compositions is not possible, since a large number of processes are pertinent only to the technology of plastics.

(ii) Maximum integration in the processing of polymeric compositions is achievable with respect to solvent-fusion processes.

(iii) The processing of rubbers and plastics may be integrated on most aspects of melt processes.

(iv) There are several areas where the processing of plastics can be more readily integrated with metals and ceramic processing technology than with the processing of other polymeric compositions, e.g. solid state and thermofusion processes. In many cases, the same concepts can be used to interpret the behaviour of plastics, ceramics and metals under processing conditions, e.g. concepts of activation energy for temperature and straining rate effects on the deformations and diffusion processes. The fewer possibilities for integrating rubbers and adhesives with plastics as regarding powder thermofusion processes are only due to the present limited availability of these materials in powder form. There are signs, however, that industrial developments for the production of rubbers in powder form are taking place and, therefore, in future several plastics processes, e.g. rotational moulding, powder coating etc., could also be used for processing rubbers and adhesives.

(v) The mechanics of the deformations and, therefore, the inferences on features of the processing equipment necessary to achieve the required deformations for solid state, rubbery state and melt state processes can be treated in a unified manner irrespective of the nature of the material.

(vi) Many features of the effects of processing variables on the product performance of manufactured components can also be integrated across the whole range of materials, e.g. anisotropy, residual stresses, etc. However, although annealing after processing is carried out for both plastics, ceramics and metals, the transformations which take place cannot be explained in a unified manner.

(vii) The uniqueness of the mechanisms underlying the effects of process variables on the deformational behaviour of thermosetting polymeric compositions creates some obstacles to the integration even within the same classes of materials, c.f. plastics, rubbers and adhesives.

e) polymer/additive reactivity, compatibility and dispersability	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓
c) molecular chain relaxations and energy dissipation	✓	✓	✓	✓		✓	✓	✓				
d) stress transfer in multiphase systems	✓	✓	✓	✓			✓	✓		✓	✓	
f) free radical oxidation and hydrolitic decomposition of organic compounds	✓	✓	✓	✓								
g) visible light absorption and difraction at interfaces	✓	✓	✓	✓		✓	✓	✓				
h) high temperature free radical reactions and energetic considerations	✓	✓	✓	✓								
i) desirability function and property optimization	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓
2. Recall the principal factors which affect the mixing efficiency of a given compounding equipment and interpret the reason why a particular geometry of mixing rotors/blades etc. is being used.												
(i) Comprehension of stated objective	✓	✓	✓	✓			✓	✓				
(ii) Underlying technological knowledge												
a) high speed vortex mixers for powders and/or slurries	✓	✓	✓	✓			✓	✓		✓	✓	
b) high speed dispersion mills	✓		✓				✓					
c) low speed roll mills	✓	✓	✓	✓								
d) low speed Z blade blenders	✓	✓	✓	✓			✓	✓				
e) ball and pebble mills	✓	✓	✓	✓			✓	✓				
f) batch melt-blenders	✓	✓	✓	✓			✓	✓				
g) continuous melt-blenders	✓	✓	✓	✓				✓				
(iii) Basic concepts underlying the technology:												
a) wetting, absorption, compatibility, diffusion etc.	✓	✓	✓	✓			✓	✓		✓	✓	✓
b) agglomeration, dispersion, flocculation	✓	✓	✓	✓			✓	✓				
c) work of dispersive mixing and flow rates of dispersions and melts	✓	✓	✓	✓			✓	✓				
d) frictional heating and relationships with materials parameters and mixer geometry	✓	✓	✓	✓			✓	✓				
f) equilibrium point in quantity and quality mixing curves	✓	✓	✓	✓			✓	✓				
3. Recall the basic principles of quality control and reliability which may be applied to compoinding of polymeric compositions.												
4. Recall the basic rules governing the acceptability of quality control test procedures in high out-put production systems.												
(i) Underlying technological knowledge and basic concepts:												
a) analysis of variance, corrglations etc.	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓
b) sampling and errors,	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓
c) quality control charts	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓
d) laws of random failure and confidence limits.	✓	✓	✓	✓						✓	✓	✓

- molecular dimensions, configurations and conformations,	✓	✓	✓	✓	✓	✓	✓			
- Bond strength, bond rotation, chain relaxations etc.	✓	✓	✓	✓	✓	✓	✓			
- Structure dipoles, H-bonding and hydrophilic groups	✓	✓	✓	✓	✓	✓	✓			
- Solubility and compatibility concepts,	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- Tridimensional network, and crystallization hindrances,	✓	✓	✓	✓	✓	✓	✓			
- Glass transitions	✓	✓	✓	✓	✓	✓	✓			
- Nucleations and crystallization processes,	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- Amorphous and semicrystalline states,	✓	✓	✓	✓	✓	✓	✓			
- Spherulitic and anisotropic crystollographic arrangements	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4. Recall the well established experimental procedures which may be used to predict the performance of polymeric compositions from accelerated laboratory tests										
(i) Comprehension of stated objective	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
(ii) Underlying technological knowledge for prediction of performance										
a) Mechanical deformational behaviour - Creep	✓	✓	✓	✓	✓		✓	✓	✓	✓
- Stress relaxation	✓	✓	✓	✓	✓		✓	✓	✓	✓
b) Mechanical strength and fracture - Creep rupture	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- Effects of stress concentrations	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- Impact strength	✓		✓	✓	✓	✓	✓	✓	✓	✓
- Fracture mechanics	✓	✓		✓	✓		✓	✓	✓	✓
- Fatigue	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
c) Dielectric losses and resistivity - Effects of temperature and frequency	✓	✓	✓	✓	✓	✓	✓			
- Effects of environment and ageing	✓	✓	✓	✓	✓	✓	✓			
d) Dielectric strength - Effects of temperature	✓	✓	✓	✓	✓	✓	✓			
- Effects of environment and ageing	✓	✓	✓	✓	✓	✓	✓			
- Effects of a/c and d/c	✓	✓	✓	✓	✓	✓	✓			
f) Optical properties - Gloss	✓	✓	✓		✓	✓	✓			
- Colour	✓	✓	✓	✓	✓	✓	✓			
g) Weathering - Effects of environmental agents on mechanical, dielectric and optical properties.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
(iii) Basic concepts underlying the technology										
- Thermal activation energy concepts of mechanical deformations, dielectric polarization and conduction, effects of transitions on rates	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- Yield stresses, brittle strength and fracture criteria	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- Concepts of stress concentrations, stress corrosion and their effects on static and dynamic fatigue	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- Electro mechanical and thermal breakdown of dielectrics and effects of ionic species, charge intensifying features etc.	✓	✓	✓	✓	✓	✓	✓			
- Concepts of visible light absorption, reflection, refractions and diffractions etc.	✓	✓	✓	✓	✓	✓	✓			
- Relationships between artificial UV, O_2, H_2O, salts etc and atmospheric agents	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- Orientation and/or crystal anisotropy	✓			✓		✓		✓	✓	✓
- Stress transfer in multiphase systems	✓	✓	✓	✓		✓	✓	✓	✓	✓

- Non-Newtonian flow, elongational flow etc.		√	√		√		√	√	√				
- Flow instabilities melt fracture, orange peel etc.		√			√		(√)		(√)				
- Melt compressibility, overpacking stresses etc.		√	√				√		√		√	√	√
- Crystallization and orientation induced stresses etc.		√						√	√		√	√	√
- Molecular diffusion mechanisms		√	√		√		√	√	√				
- Surface tension, gravity effects in interpreting sagging etc.		√	(√)	√	√		√	√	√		(√)	(√)	(√)
- Reactivity, rates of cure etc.		√	√	√	√			√	√				
- Distortions, anisotropic shrinkage etc.		√					√	√	√		√	√	√
d) Thermofusion processes													
- Molecular diffusion, crystallization induced stresses etc.		√	√	(√)	√		√	√	√		(√)	(√)	(√)
- Surface energy and gravity effects in interpreting shrinkage and porosity		√						√	√		√	√	√
- Shrinkage phenomena, porosity etc.		√					(√)	√	√		√	√	√
e) Solvent fusion processes													
- Solubility parameters		√	√	√	√		√	√	√		√	√	√
- Diffusion rates		√	√	√	√		√	√	√		√	√	√
- Cure rates and associated rheological changes		√	√	√	√				√				
- Molecular configurations in solution and effects on viscosity		√	√	√	√				√				
- Thixotropy, dilatancy, liquid solido interactions during flow		√	√	√	√		√	√	√				
- Surface activity, wetting, work of adhesion etc.		√	√	√	√		√	√	√		√	√	√
3. Recall the major processing variables and special equipment features of common processing methods, and interpret the principles governing their effects on processing rate and product quality.													
4. Recall the main experimental procedures and underlying principles for the assessment of processing variables and special equipment features on output and product quality for common processes.													
(i) Generalised statements of major factors affecting processability and special features in equipment for <u>Solid State</u>, <u>Rubbery State</u> and <u>Melt State processes</u>													
- Extent of deformations and geometry of components		√	√	√	√		√	√	√		√	√	√
- Stock temperature and rates of changes in the physical state of material		√	√	√	√		√	√	√		√	√	√
- Tool (or environment) temperature and cooling rates		√	√	√	√		√	√	√		√	√	√
- Deformation rates		√	√	√	√		√	√	√		√	√	√
- Dwell time under stress		√	√	√	√		√	√	√		√	√	√
- Annealing after processing		√					√				√	√	√
(ii) Generalised statements of major factors affecting processability and special features in equipment used for other processes:													
a) Powder processes													
- Particle size and distribution		√		√				√	√		√	√	√
- Sintering temperature/time		√		√				√	√		√	√	√
- Cooling rates		√		√				√	√		√	√	√
b) Welding processes													
- Dimensions and geometry of components		√									√	√	√
- Rates of loading or pulse frequency in the generation of frictional heat		√									√	√	√
- Frequency and intensity of electric field in dielectric welding		√											
- Inertness of gas and temperature in hot gas welding		√									√	√	√
- Temperature and pressure in heated tool and forced welding		√	(√)								√	√	√
c) Solvent fusion processes													
- Gellation/curing temperature and time		√	√	√	√			(√)	(√)				
- Solvent concentration and types		√	√	√	√				(√)				
- Shear rates		(√)	√	√	√			(√)	(√)				

CHAPTER 8

CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDIES

In the light of the aims set out in Chapter 3, the conclusions may be conveniently be summarised under the following headings:

(i) Educational needs related to the development, production and utilization of polymeric compositions.

(ii) Structure and curriculum nature of courses leading to graduate and professional qualifications in polymer technology.

(iii) Educational aims and objectives for areas of study in polymer technology.

(iv) The integration of polymer technology and its relationship to technology of ceramics and metals.

The first deals with the conclusions in relation to some of the questions raised in Chapter 1, section 1.4.2 in particular, and to the first objective outlined in section 3.1. The second puts into focus the conclusions in relation to the discussions in section 1.2.2, the questions raised in section 1.4.3, and the associated objective (3) in section 3.1. The third analysės the conclusions on the application of the Stone-Anderson criterion for the derivation of aims and objectives for the polymer technology curriculum, while the fourth puts into perspective the questions raised in sections 1.4.1. and 1.4.2 and objective (5) in section 3.1.

8.1 Educational needs related to the development, production and utilization of polymeric compositions

From the results of the surveys of the activities of industry and analysis of authorative reports and statements discussed in section 4.1, 4.2 and 4.5, it is possible to derive the following conclusions:

(i) The manufacturing industry is extensively involved in business associated with the production and utilization of polymeric materials, (at least 18.5% of all manufacturing firms). Taken in connection with the results of the survey of vacancies, there can be little argument as to the employment of opportunities for qualified manpower capable of dealing with industrial problems related to polymeric materials, and the contribution that they can make to the well-being of an industrialized nation, like Great Britain. Considered in the light of the first step of Taba's procedure for curriculum development and the accepted "utilitarian" approach to education in this country, since the beginning of the century, largely influenced by prominent educators like Thomas Huxley, the introduction of studies of polymeric materials in higher education curricula is overwhelmingly justified.

(ii) The forecast horizontal integration of the traditional "polymer-based" industry within general manufacturing industries, such as building, motor, furniture, electrical, etc., together with the already substantial involvement of traditional materials technologists (such as metallurgists) with polymeric materials provides also a strong case for the incorporation of "polymer technology" into the graduate training scheme in "manufacturing technology" similar to that outlined in the Bosworth Report. This suggestion is being reinforced by the results of the survey of graduates in the traditional "polymer-based" industry, in which 40.9% of the respondents indicated that their work falls within the field of manufacturing technology. Such a scheme would bridge the gaps between several existing courses dealing with materials studies, e.g. plastics and rubber technology, metallurgy, ceramics and glass technology, production and mechanical engineering etc. The need for filling the above mentioned gaps can be inferred from an examination of fig. 4.27 and the discussions in section 5.3.

(iii) A specification for the competences related to the activities of technicians, graduates and professionals was derived in section 5.2 from a consideration of authorative statements found in the literature .

The technician was portrayed as "an executor of courses of actions involving routine procedures", the graduate was seen as "an investigator and generator of the knowledge necessary for the achievement of company objectives" and, finally, to the professional was given the attributes of "a decision maker and proposer of courses of actions".

No attempt was made, however, to differentiate between graduates and professionals in the surveys carried out as it was anticipated that difficulties would have been experienced by the respondents in establishing their own position solely on the basis of their role and responsibilities rather than on the basis of formal qualifications or nominal job titles held. Hence the specification given can only be regarded as tentative and, therefore, it would be necessary to estimate the consensus for such a specification through brain-storm exercises involving highly motivated and competent authorities representing the major industrial sectors in question (e.g. polymer compositions manufacturers, additives and auxiliary materials suppliers, processors and fabricators etc.) and selected from the various types of functions, e.g. development, production and marketing. (see figs. 4.13, 4.14, 4.15, 4.16 and 4.27).

8.2 Structure and curriculum nature of courses leading to graduate and professional qualifications in polymer technology

On the basis of the discussions in section 1.2.2 about the structure and curriculum nature of existing courses and the questions raised about these in section 1.4.3, a study was made to identify the changes which would be necessary in order better to satisfy both industrial needs and students' aspirations, aptitudes and abilities (see section 3.1).

An examination of the implications of Dressel's curriculum models, with respect to both underlying educational concepts and their implementation potential within the framework of the British educational system, has indicated that three types of curricula can be adopted for studies leading to qualifications in polymer technology. Three course schemes have been suggested (see sections 5.3 and 5.4), each of which terminates with a professional stage via an intermediate graduate stage. The first scheme adopts a vocational curriculum throughout and begins with a technician stage, in which specific aspects of the technology of polymeric compositions are being studied and which operates on a part-time, sandwich or block-release basis. This provides, therefore, a mechanism which allows the student to start on a low level course and gives him the opportunity to decide at a later stage, after he has received real-life experiences, to decide at which level he should terminate his studies. The second stage encompasses studies over the whole range of polymeric materials to provide broadening experiences necessary for the development of a greater capacity to formulate hypotheses in a wide range of situations (see p. 165). The final professional stage, on the other hand, specialises on classes of materials and/or specific aspects of the technology of these to enable the new entrants in the profession to receive in depth experiences in decision making. The rationale of developing technician, graduate and professional skills in consecutive steps may be inferred from the indication given by practising graduates and professionals of the very high importance of "knowledge of methods and practical skills" (see tables 4.14, 4.20 and 4.29) and finds strong support in the Gagne's classification of learning behaviours (see section 6.5).

In the second scheme, the graduate stage adopts a thematic curriculum in which polymer technology is an integral part of a course in "materials and manufacturing technology". This scheme is for entrants not committed to any specific profession but are attracted to the course by its relevance to and concern for real-life problems, which will enable him to make an immediate contribution in industry and allied occupations.

The very breadth of such a course would not allow the educators involved to adopt a vocational approach since it would be too difficult to identify with some precision the nature of the occupation which the graduate is likely to take. A thematic approach, on the other hand, would enable the instructors to deal with broad aspects of the various materials and manufacturing processes available and to develop the higher level cognitive skills and associated affective behaviours by in-depth treatments of selected topics.

Thematic studies concerned exclusively with polymer technology would be too restrictive in scope in so far as they cannot provide the non-committed student with sufficient opportunity to establish the role of polymeric materials in the manufacturing industry in relation to other materials (see section 5.3.2), unless it is used as the main theme for in-depth studies, on to which broadening experiences may be grafted. After graduation, the student would decide whether to take up a career in one of the several professions in specific classes of materials or aspects of the technology of these.

In the third scheme, the graduate stage begins with studies of the basic disciplines (a "pedantic" type of curriculum) and changes into a "thematic" curriculum for studies of materials and manufacturing technology. Once more, if there are practical restrictions on the duration of the course, one could use polymer technology as the main theme. This scheme may have some practical advantages over the previous one in so far as it allows the academics of pure disciplines, who do not have particular experience of or concern for industrial problems related to materials, to participate in such courses and, therefore, it enables educational institutions to utilize more effectively the available resources. A direct transformation to a vocational curriculum would interfere with students' learning, in so far as those already committed to a specific profession would find it difficult in the initial stage to relate by themselves the pure disciplines to their vocation. The non-committed student, on the other hand, would find it difficult to accept the more open-ended solutions of industrial problems and, not being motivated by the type of occupation to which vocational studies are directed, would also resist the convergent mode of thinking and practical approach to problem-solving tasks.

It is more likely that the changes in attitudes acquired are achieved through an intermediate "thematic stage" which exposes the student to real-life problems and makes him aware of the importance of his subjects of study to the well-being of the community. After this has been achieved, it should be easier to develop an interest in technological problems and motivate him towards learning the associated cognitive skills.

At every stage, each scheme would contain teaching units in areas of study which are complementary to the particular vocational subjects or themes of the main curriculum and may be taught by instructors not necessarily competent in the technology of polymers and/or other materials. Furthermore, the thematic scheme suggested may be incorporated into the structure of "Combined Honours" degrees but care must be exercised in the selection of the parallel "theme" to avoid running the risk of crossing too many frontiers of knowledge and, therefore, making it impossible for the student to acquire sufficient in-depth experiences.

Polymer technology could be studied together with a parallel thematic subject of study, such as "metallurgy", "ceramics technology", "economics of raw materials and energy utilization" etc. Each theme would contain broadening experiences to provide the integrative threads with the parallel theme.

Finally, careful consideration would have to be given to the type of specialization for the professional stage.

Although there may be various specialization routes which are possible, the most cogent question to be resolved is obviously that concerning the types of clients, i.e. the industries which the professional would have to serve.

One such possibility is to retain the existing specializations according to the type of materials, e.g. rubbers, plastics, etc. This, however, would not be adequate if the professional is to operate horizontally within the manufacturing industries which specialize in types of components or products, i.e. moulders, compounders and reclaimers, machinery manufacturers etc. Consequently, an alternative possibility is to divide the specialization routes according to the subdivision of areas of study suggested by the writer. The advantage of this type of subdivision is that, if the present "discipline-orientated" routes, i.e. chemistry, physics and engineering, are retained in order to allow graduates in these single disciplines to enter the professions, the amount of training in disciplines other than those of entry is at the minimum level. The chemists would follow a route orientated towards "the constitution and production of polymeric compositions", the physicists could be routed towards "the properties and serviceability of polymeric compositions", and the engineers towards "the processability and process technology of polymeric compositions".

8.3 Educational aims and objectives for areas of study in polymer technology

The educational aims and objectives for studies in polymer technology for the graduate and professional stages of the curriculum were derived from an analysis of the surveys of practising polymer technologists, using the guide lines suggested by authorities in the field of curriculum development, such as Bloom, Krawthwohl and Stones.

Since polymer technologists are likely to be engaged in development, marketing and production functions and each of these entails some involvement in other functions, (see figs. 4.13, 4.15 and 4.5, 4.6) the educational aims for courses in polymer technology were derived from a consideration of the types of tasks pertaining to these functions (see pp181-183). These aims are applicable to both vocational and thematic curricula. In fact a thematic curriculum cannot succeed in achieving the highest levels of affective behaviours, corresponding to valuing, organization and characterization of Bloom's taxonomy, unless it aims at developing a sense of commitment towards the polymer technology profession. By taking as an example the aim related to trouble shooting tasks within the context of polymer technology, i.e. "To develop problem solving abilities under high risks and from a limited amount of background information",

the curriculum planner would be guided in the selection of relevant themes and learning experiences in order to expose the student to the real world of polymer technologists. In so doing, not only would he serve the needs of those who would consequently enter the polymer technology profession, but would also have at his disposal the means to develop those critical skills required in a wide range of occupations.

In fact, the aims specified in Chapter 6 transcend the contents or knowledge underlying the more specific tasks (see p. 209 and fig. 6.1) and, therefore, entail a wide range of behaviours which can be developed by an almost unlimited variety of learning experiences.

It is understood that there will be additional aims derived for other units of a particular course and that some would overlap in order to provide the unifying threads for the overall curriculum.

For the derivation of educational objectives the entire polymer technology field was divided into three areas of study using as a basis the topic areas considered to be most relevant by the practitioners (figs. 4.19 and 4.24). The objectives for each area of study were then deduced from a consideration of the tasks likely to be performed by practising polymer technologists in the three functions discussed earlier (see also fig. 4.27) starting from a specification of the most general competences of a professional technologist and gradually increasing the level of specificity until the behaviours described were deemed to be synonimous with those expected to be possessed by a graduate working in the field. For one particular area of study the specificity level was extended down to include the behaviours expected of a technician. The latter exercise was carried out to show how Gagne's classification of learning behaviours may be used to categorise the levels of competences ascribed to professionals, graduates and technicians respectively.

Although the specification provided is not complete with respect to both number of levels at each stage and the range of objectives at each level, their validity was checked by analysing the competences expected of a graduate in three specific assignments: one related to development functions, one connected with marketing functions (more specifically to technical service activities) and the last representing a typical involvement of a polymer technologist in production functions. An example was given, also, of the manner in which the level of specificity of objectives may be deduced from a given task analysis (see section 6.6.2). By carrying out a task analysis on a series of typical assignments, future investigators could, therefore, use the example given as guidance for the completion, elaboration and/or modification of the hierarchy of the educational objectives contained in tables 6.1....6.10. In developing objectives for the graduate stage of the course considerable difficulties were experienced in specifying separate objectives for the vocational and thematic curricula since there are substantial similarities in the underlying philosophies (see p. 195 and section 6.3.1). The conclusion was reached, therefore, that for the planning of a thematic curriculum in

polymer technology suitable educational objectives could be drawn from those specified for the vocational curriculum according to the theme selected. Bearing in mind one of the aims of a thematic curriculum, i.e. "To emphasize the major concepts and principles of polymer technology as a means of promoting problem solving abilities required in the development, production and utilization of materials and processes",
the planner could select, for instance, the theme "Plasticization, polymer blends and composites" as a means of demonstrating the wide range of properties that can be exhibited by polymeric compositions and achieving, therefore, objectives falling in the area of study "The properties and serviceability of polymeric compositions".

8.4 The integration of polymer technology and its relationship to technology of ceramics and metals

Much of the discussions in section 1.4.2 were based on hypotheses formulated from statements expounded in the literature; hence the validation of such hypotheses became a major aim of the investigation (section 3.1). With this aim in mind, the contents of the three areas of study specified for the subject matter were decomposed into their constititutive elements (Fig. 7.1, 7.2 and 7.3) and those common to the technology of specific industrial materials based on polymers, e.g. plastics, rubbers, surface coatings and adhesives, were identified.

A cursory analysis was also made to find out whether the underlying concepts are applicable to the studies of other materials, e.g. ceramics and metals. The conclusions reached may be summarised as follows:

(1) Integration of the subject matter related to the area of study "The constitution and production of polymeric compositions" is highly feasible since most of the constituents are used in all four classes of materials. The relationships between structure and properties and the principles governing the manufacture of polymeric compositions are universal, and the

same evaluation methodology can be used in each case. The only difference between the four classes of materials is with respect to details of modifications necessary in the base polymer structure in order to utilize available raw materials and to meet specific requirements. A unification of the constitution and production of polymeric compositions with ceramics, on the other hand, is only possible in some very special cases and at a very basic conceptual level, whereas it is completely impossible to find unifying threads with extraction and alloying metallurgy.
(2) With respect to the area of study "The properties and serviceability of polymeric compositions" all the technological elements and underlying concepts are common to all four classes of polymeric compositions and, therefore, there should be little difficulty in approaching the subject in a unified manner.

Such integration may be extended into ceramics technology with respect to phenomenological evaluations of mechanical, dielectric, optical and thermal properties, whereas integration with metal technology would have to be restricted to the methodology of the evaluation of mechanical properties.

(3) A full unification of the elements underlying "The processability and process technology" of polymeric compositions is not possible, since most processes have been developed around the specific applications of the polymeric compositions considered. Not only such differences in processing technology exist between the four classes of polymeric compositions, but even within each class of materials (c.f. processing of thermoplastics and thermosetting materials). Furthermore, there are aspects of the processing of plastics which can be more readily integrated with metals and ceramics than with the processing of other polymeric compositions, e.g. solid state and thermofusion processes.

In the light of the above findings, therefore, the integrated schemes suggested in Chapter 5 are highly feasible. Even if unification of concepts and principles is not always possible, integrative threads can be found, however, by means of convergent problem-solving exercises, i.e. a problem can be defined in a manner which requires considerations of several unrelated principles for its solution and, therefore, the same teaching unit can be used to encompass the fundamental aspects of the particular classes of materials in question. In order to obtain a more precise assessment of the integration feasibilities within the general field of materials technology, it may be profitable to carry out a task analysis on a few typical assignments on ceramics and metals in order to deduce whether and where the same concepts, principles and methodology may be used.

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A P P E N D I C E S

APPENDIX I

Questionnaires used in the surveys

Ia. Survey of the British manufacturing industry and the involvements in polymeric materials

Ib. Survey of metallurgists and materials technologists in industry

Ic. Survey of B.Sc. and M.Sc. graduates of Aston University

Id. Survey of polymer technologists in industry

APPENDIX I a

Dear Sir,

I am carrying out a survey to establish the needs of Industry (as a whole) in terms of qualified manpower possessing some expertise in the field of Polymer Technology. Would you please be kind enough to complete the opposite questionnaire and return it to me at your earliest convenience.

Yours sincerely

L Mascia
Lecturer in Polymer Technology

Please indicate:

1. Whether your company deals in or is likely to be involved to any extent in polymeric materials: manufacturing, handling, equipment, consultancy etc.

2. Whether expertise in some aspects of polymer technology is available or desirable (Please indicate to what extent):
   a) Considerable
   b) Marginal c) Not at all.

FIRST FOLD

SECOND FOLD

3. Whether the background of your technologists (likely to be) engaged in polymer activities (if any) is in:

a) Engineering: mechanical chemical, electronic etc.

b) physics ....

c) chemistry ....

d) others (please specify):

....

THIRD FOLD & TUCK IN

Mr L Mascia
Department of Chemistry
The University of Aston in Birmingham
Gosta Green
Birmingham B4 7ET

August 1972

Technology

Please do not answer these if you are a teacher or research worker in academic institutions.

Q.1 Have you over the last (say) 3 years been involved to an appreciable extent with plastics materials (or plastics composites) in a capacity which required understanding their nature and behaviour?

Yes ☐ No ☐

or evaluate other forms of polymeric materials, e.g. surface coatings, adhesives etc., and felt that a basic understanding of these materials might have (or has) helped you in such a task.

Yes ☐ No ☐

Q.3 Do you consider that a broad understanding of materials acquired through formal education may have (or might have) improved your prospects in industry?

Yes ☐ No ☐ Don't know ☐

FIRST FOLD

SECOND FOLD

education on general aspects of materials is preferable to studies on single classes of materials (assuming average abilities on the part of the teacher and student alike)?

Yes ☐ No ☐

Don't know ☐

Q.5 Have you received formal education in metallurgy?

Yes ☐ No ☐

Q.6 Please indicate your age.

25-35 ☐ please tick

35-45 ☐

over 45 ☐

THIRD FOLD & TUCK IN

Mr L Mascia
Department of Chemistry
The University of Aston in Birmingham
Gosta Green
Birmingham B4 7ET

December 1973

APPENDIX I b

Please state

(i) When you graduated ....

(ii) Course attended: BSc/MSc

What is

(i) The nature of the business of your company ....

(ii) Your job title ....

(iii) Your present salary approximately £ ....

Please state

(i) a) How often you have changed job since graduation ....

b) Was this due to — Tick

a) Redundancy — a)

b) Promotion — b)

c) Dissatisfaction with previous job — c)

d) Personal reasons — d)

e) Other reasons — e)

(ii) Whether your specialistic knowledge in the field of polymer science and technology helped you to find a job: YES/NO.

Will you indicate the percentage of your time at work which is spent in the following activities

	% Total Time					
	0	1–20	20–40	40–60	60–80	80–100
(i) Research on						
a) Fundamental problems						
b) Practical problems						
(ii) Development and innovation to						
a) Invent new products/processes						
b) Improve existing products/processes						
(iii) Technical service, consultancy, trouble shooting						
(iv) Quality control and production supervision						
(v) Sales and marketing						
(vi) Administration and supervision of assistants						
(vii) Others (please specify)						

(i) List areas of your work in which you are most proficient

a) ....

b) ....

c) ....

(ii) Are your skills in these areas related to the possession of

	Wholly	Mainly	Partly	Not at all
a) Fundamental knowledge				
b) Knowledge of methods, practical skills				
c) Ability to acquire relevant information				
d) Your high level of common sense				
e) Creativity and imagination				
f) Other skills (please specify)				

(iii) Is your possession of these skills due to

	Wholly	Mainly	Partly	Not at all
a) The course you took at Aston				
b) Previous basic education				
c) Training provided within your firm				
d) Other courses attended				
e) Work experience				
f) Others (please specify)				
______________________				
______________________				

6 Indicate, for those of the following subjects which were part of your course, how useful each has been to you

	Extremely useful	Quite useful	Some use	No use
(i) Basic chemistry				
(ii) Basic physics				
(iii) Mathematics				
(iv) Polymer chemistry				
(v) Polymer physics/engineering				
(vi) Plastics technology				
(vii) Rubber technology				
(viii) Chemical engineering				
(ix) Industrial administration and technological economics				
(x) Complementary studies				

Indicate how often you have needed to apply a mathematical analysis to your work from the following sources

	Very often	Often	Rarely	Never
(i) Standard analysis available in textbooks, literature etc.				
(ii) Analysis specifically obtained in the course in polymer science and technology				
(iii) Analysis derived by yourself				

8 If you have ever attempted to use a mathematical approach to your work, indicate whether

EITHER (i) You have found it difficult to formulate a model

....

OR (ii) You have found it easy to formulate a model but were unable to solve the equations

....

9 (i) Indicate in columns 1–4, how relevant the following topic areas are to your job.

(ii) Indicate in column 5 which of those topic areas you have used in your work over the last 5 working days.

(iii) For those topics which are most relevant to your work, indicate in column 6 whether the relevant knowledge can be easily acquired without taking a formal University course in polymer science and technology.

y to Table:

Highly relevant

Moderately relevant

Some relevance

No relevance

Topic used over the last 5 working days

Relevant knowledge easily obtained

	1	2	3	4	5	6
1) Mechanisms of polymerization reactions						
2) Mechanisms of degradation reactions.						
3) Mechanisms of cross-linking reactions						
4) Technological aspects of 1, 2, 3 above						
5) Methods of molecular weight determinations						
6) Methods of structure determinations (eg NMR, ESR etc)						
7) Technological aspects of 5 and 6 above						
8) Thermal analysis						
9) Structure/properties relationship						
10) Rheology theories						
11) Technological aspects of rheology						
12) Viscoelasticity theories						
13) Technological aspects of viscoelasticity						
14) Rubber elasticity theories						
15) Technological aspects of rubber elasticity						
16) Engineering design with polymers						
17) Mechanisms of the action of additives						
18) Technological aspects of additives (eg interactions, adverse effects, dispersability etc)						
19) Mixing theories						
20) Compounding methods, efficiency, economics etc						
21) General aspects of plastics materials (eg properties/structure correlations; effects of processing; economics etc)						
22) Specific aspects of plastics (eg detailed aspects of manufacture, stabilisation etc)						
23) General aspects of rubbers (eg economics, relationships to synthetic rubbers and thermoplastics)						
24) Specific aspects of rubbers (eg details of vulcanization, methods of X-linking determinations etc)						
25) Processing of rubbers and/or plastics (technological aspects, effects on properties and economics etc)						
26) Processing of rubbers and/or plastics (production engineering aspects; quality control etc)						
27) Moulds, dies, machines etc						
28) Standard test methods: usefulness, limitations, relationships to fundamental properties etc						

	1	2	3	4	5	6
29) Basic engineering fundamentals (deformation and strength: simple and complex stresses aspects)						
30) Heat transfer: steady states						
31) Heat transfer: transient states						
32) Fracture mechanics and large deformations in rubbers and plastics						
33) Orientation and anisotropy (determinations and significance in engineering: processing and design)						
34) Reinforcement and composites (basic theories, chemical, physical and economics aspects)						
35) Dielectric properties: effects of additives and impurities						
36) Optical properties: effects of additives and morphology						
37) Statistical methods for technological research. Optimization of processes and products						
38) Technological methods of experimental design (how to deal objectively with large numbers of variables)						
39) Critical path and network analysis						
40) Computer techniques						
41) Report writing						
42) Others (specify) ________						
________						
________						
________						
________						
________						

10 Do you consider your work to be more related to

a) Engineering and manufacturing technology ....

b) Industrial chemistry ....

c) Physical chemistry ....

11 Indicate how useful each of the following experimental techniques were to your training

	Extremely useful	Quite useful	Some use	No use at all
i) Polymer synthesis				
ii) Polymer evaluation a) chemical methods				
b) physical methods				
c) technological methods				
iii) Polymer compounding and processing				
iv) Demonstrations in a) Laboratory classes				
b) Tutorials				
v) Mini projects (unguided)				
vi) Extended projects (supervised)				

The University of Aston in Birmingham

Q1 Please state,

(1) When you graduated ________________

(2) Course attended: B.Sc./M.Sc./Ph.D. *(specify subject/discipline)*

(3) Professional qualifications: A.P.I./A.I.R.I.

Q2 Which of the following more closely describes:

(1) The nature of the business of your company:

Additive manufacturers; raw polymer manufacturers; polymeric compositions manufacturers; engineering, processors, fabricators etc; machine manufacturers; end users of polymeric products, *others* ________________

(2) Your job title:

Research chemist; development chemist; development technologist; development engineer; technical service engineer/technologist; technical representative; production technologist/engineer, *others*

____

Q3 How long you have been in your present job:

a) Less than 2 years ________________

b) Between 2 and 5 years ________________

c) More than 5 years ________________

Q4 Will you indicate the percentage of your time at work which is spent in the following activities. (Total need not add to 100%).

	% Total Time							
	0	10	20	30	40	60	80	100
(1) Research on a) Scientific problems								
b) Practical problems								
(2) Development and innovation to, a) Invent new products[+]/ processes[+]								
b) Improve existing products[+]/ processes[+]								
(3) Technical service, consultancy, trouble shooting								
(4) Quality control and production supervision								
(5) Sales and marketing								
(6) Administration and supervision of assistants								
(7) Others (please specify)								
________________								
________________								
________________								
________________								

[+]Delete the one which does not apply.

	Wholly	Mainly	Partly	Not at all
a) Scientific knowledge				
b) Knowledge of methods, practical skills, etc				
c) Ability to acquire relevant information				
d) Clear thought and expression				
e) Your high level of common sense				
f) Creativity and imagination				
g) Other skills (please specify)				

(ii) Is your possession of these skills due to:

	Wholly	Mainly	Partly	Not at all
a) Formal education in polymer science and technology				
b) Previous basic education				
c) Training provided within your firm				
d) Other courses attended				
e) Work experience				
f) Others (please specify)				

If the answer to (ii)e is "wholly", please state which of the following more closely describes the reasons:

a) Knowledge required in my job is too specialized to be acquired anywhere else

....

b) Knowledge of people within the organization, practical methods available in the organization etc. are the most contributory factors to achievements in my job

....

c) Judgement necessary in performing and evaluating my work can only be acquired in industry

....

Q6 Indicate for those subjects which were part of your education, how useful each has been to you in your present and previous jobs. (Delete those subjects not taken).

	Extremely useful	Quite useful	Some use	No use
(1) Basic Chemistry				
(2) Basic Physics				
(3) Mathematics				
(4) Statistics				
(5) Chemical engineering				
(6) Mechanical/production engineering				
(7) Electrical/electronic engineering				
(8) Industrial administration and Technological economics				
(9) Polymer Chemistry				
(10) Polymer physics/engineering				
(11) Plastics Technology				
(12) Rubber Technology				
(13) Surface coatings/adhesives technology				
(14) Fibres Technology				
(15) Others (please specify)				

Q7 Indicate how often you have attempted to apply a mathematical analysis and models to your work from the following sources:

	Very Often	Often	Rarely	Never
(1) Standard analysis available in your company, textbooks, literature etc.				
(2) Analysis specifically obtained in the course in Polymer Science and Technology.				
(3) Analysis derived by yourself				

Q8 If the answer to Q7 (3) is NEVER, which of the following more closely describes the underlying reasons:

a) I find it difficult to formulate mathematical models for chemical or physical phenomena not encountered on previous occasions

....

b) I find it easy to formulate basic mathematical models but I am unable to obtain solutions to the underlying equations

....

c) I believe that presentation of data in graphical, tabular or descriptive form is adequate in my job

....

(1) In columns 1-4 how relevant the following topic areas are to your job.

(2) In column 5, those topic areas which were dealt with in considerable depth (v) and those not dealt with at all (x).

(3) In column 6, those topic areas on which you would have liked to receive further instruction.

(see p A6 for key to columns 1-6)

	1	2	3	4	5		6
	Highly relevant	Moderately relevant	Some relevance	No relevance	Dealt with in depth (v)	Not dealt with at all (x)	Would have liked more introduction
1) Mechanisms of polymerization reactions							
2) Mechanisms of degradation reactions							
3) Mechanisms of cross-linking reactions							
4) Kinetic Aspects of 1,2,3 above							
5) Technological aspects of 1,2,3 above							
6) Molecular weight determinations							
7) Methods of structure determination (e.g. NMR, X-ray, IR etc).							
8) Technological aspects of 5, 6 above							
9) Thermal analysis							
10) Structure/properties relationships							
11) Rheology theories							
12) Technological aspects of rheology							
13) Viscoelasticity theories							
14) Technological aspects of viscoelasticity							
15) Rubber elasticity theories							
16) Technological aspects of rubber elasticity							
17) Solution thermodynamics theories							

	1 Highly relevant	2 Moderately relevant	3 Some relevance	4 No relevance	5 Dealt with in depth (✓)	5 Not dealt with at all (x)	6 Would have liked more introduction
18) Technological aspects of polymer solutions							
19) Gas and liquids diffusion kinetics							
20) Technological aspects of gas and liquids diffusion in polymers							
21) Combustion inhibition theories							
22) Technological aspects of flame retardancy							
23) Engineering design with polymers							
24) Mechanisms of action of additives							
25) Technological aspects of additives (e.g. synergism, adverse effects, dispersability etc)							
26) Mixing theories							
27) Compounding methods (efficiency economics etc)							
28) General aspects of plastics materials (e.g. properties/structure correlations, availability, comparative analysis of their behaviour and performance economics etc)							
29) Specific aspects of plastics (e.g. manufacture, stabilization, processing characteristics)							
30) General aspects of rubbers (e.g. properties/structure correlations, relationships to synthetic and thermoplastics rubbers, economics etc)							
31) Specific aspects of rubbers (e.g. methods of vulcanization, X-links assessment, special applications etc)							

	1 Highly relevant	2 Moderately relevant	3 Some relevance	4 No relevance	5 Dealt with in depth (✓)	5 Not dealt with at all (x)	6 Would have liked more introduction
32) General aspects of adhesives and surface coatings (e.g. structural and formulations aspects, comparative analysis of behaviour etc)							
33) Specific aspects of adhesives and surface coatings (e.g. design of joints, preparation of substrates etc)							
34) Processing of rubbers and/or plastics (classifications, technological aspects, interactions of processing variables, economics etc)							
35) Processing of rubbers and/or plastics (production engineering aspects, quality control, finishing operations, factory organisation etc)							
36) Moulds, dies, machines etc							
37) Standard test methods (usefulness, limitations, relationship to fundamental properties etc)							
38) Basic engineering fundamentals (deformations, strength: simple and complex stresses etc)							
39) Surface and interfacial properties (e.g. adsorption, adhesion, wear etc)							
40) Heat transfer theories							
41) Mass transfer theories							
42) Thermal behaviour of polymers							
43) Fracture mechanisms and large deformations in rubbers and plastics							
44) Orientation and anisotropy (scientific methods of determination)							
45) Orientation and anisotropy (significance in engineering design, product performance etc)							

	1	2	3	4	5		6
	Highly relevant	Moderately relevant	Some relevance	No relevance	Dealt with in depth (✓)	Not dealt with at all (x)	Would have liked more information
46) Reinforcement and composites (basic theories, chemical aspects of interfaces etc)							
47) Dielectric properties (effects of additives and impurities etc)							
48) Optical properties (effects of additives, morphology, processing etc)							
49) Statistical methods for technological research. (Statistical significance of variations, errors etc)							
50) Technological methods of experimental design (how to deal objectively with large number of variables; process and product optimisation, etc)							
51) Costing methods and assessment of cost-effectiveness							
52) Critical path and network analysis							
53) Computer techniques							
54) Report writing							
55) Others (please specify)							

Q10 For those topics above which you have shown to have only "<u>some relevance</u>" to your work, indicate which of the statements below most accurately describes the underlying reason. (Use the corresponding number of the topic areas of Q 9).

Specialists are available in my company who deal specifically with the problems in this area.	The nature of my job does not warrant a great deal of knowledge in this area.	Would like to get more involved but pressure of work and inadequate facilities do not allow me to do so

Q11 Do you consider your work to be more related to:

a) Engineering and manufacturing technology ....

b) Industrial chemistry ....

c) Physical chemistry ....

d) Material science ....

Q12 Please make any comments which you think would help me in this survey. (Wit preferred!)

____

____

____

____

____

____

____

APPENDIX II a

DETAILED DATA OF THE SURVEY OF B.Sc. and M.Sc. GRADUATES OF ASTON UNIVERSITY

Table A II 1. Comparison of results on usefulness of various laboratory exercises using two different rating scales.

Table A II 2. Distribution of activities in industry according to qualification.

Table A II 3. Distribution of activities in industry according to nature of work.

Table A II 4. Moment correlation coefficients for the first 21 topics in table 4.11.

Table A II 4a. "Industrial Chemistry" against "Manufacturing Technology.

Table A II 4b. "M.Sc" against "Manufacturing Technology"

Table A II 4c. "M.Sc. vs Industrial Chemistry"

Table A II 4d. "B.Sc. vs Manufacturing Technology"

Table A II 4e. "B.Sc. vs Industrial Chemistry"

Table A II 4f. "B.Sc. vs M.Sc."

Fig. A II 1. Correlation between B.Sc. and M.Sc. for the first 21 topics.

Fig. A II 2. Correlation between M.Sc. and Industrial Chemistry for the first 21 topics.

Fig. A II 3. Correlation between Industrial Chemistry and Manufacturing technology for the first 21 topics.

APPENDIX II a

TABLE A II 1

COMPARISON OF RESULTS ON USEFULNESS OF VARIOUS LABORATORY EXERCISES USING TWO DIFFERENT RATING SCALES

Rating scales	A	B
Extremely useful	5	5
Quite useful	4	3
Some use	2	1
No use	1	0

	B.Sc.		M.Sc.	
	A	B	A	B
i) Polymer synthesis	2.4	1.75	2.5	2.0
ii) Polymer evaluation				
a) Chemical methods	2.5	1.75	3.0	2.25
b) Physical methods	3.25	2.0	3.3	2.70
c) Tech. methods	3.65	3.1	3.7	3.10
iii) Polymer compounding and processing	3.65	3.35	3.8	3.5
iv) Demonstrations in:				
a) Laboratory classes	2.57	1.83	2.0	1.7
b) Tutorials	2.62	1.80	2.4	1.8
v) Mini projects (unguided)	3.77	3.3	2.5	1.95
vi) Extended projects	4.2	4.0	3.4	2.9

b) TABLE A II 3

DISTRIBUTION OF ACTIVITIES IN INDUSTRY ACCORDING TO NATURE OF WORK

(ii)

	Total respond-ents		% people involved		Average score on total (% total time		Average score on people involved (% time)	
	Ind Chem	Manf Tech	Ind Chem	Manf Tech	Ind Chem	Manf Tech	Ind Chem	Manf Tech
1) Research								
1a) Fundamental problems	14	14	8	0	2	0	30	0
1b) Practical problems	14	14	50	60	9.5	12	19	22
Research (Total average)	14	14	30	30	6	6	25	11
2) Developments and innovation								
2a) Invent new products/processes	14	14	93	50	46	13.5	50	27
2b) Improve existing " "	14	14	80	85	20	23	25	27
Development (Total average)	14	14	86	68	33	18	38	27
3) Tech. service, consultancy trouble shooting	14	14	28.5	70	6	27	20	38
4) Quality control and production supervision	14	14	21	30	6.5	4.5	30	15
5) Sales and Marketing	14	14	0	21	0	11	0	56

Note: correlation between answers for B.Sc. with Manufacturing Technology and M.Sc. with Industrial Chemistry is apparent.

TABLE A II 4 a

PRODUCT MOMENT CORRELATION COEFFICIENT FOR THE 21 TOPICS

"IND. CHEM" vs "MAN. TECH."

	IND CHEM (X)	MAN TECH (Y)	x-x̄	Y - Ȳ	(x-x̄)(Y-Ȳ)	(x-x̄)²	(Y-Ȳ)²
1	2.75	2.90	0.65	+1.02	0.6630	0.4225	1.0404
2	3.00	2.80	0.90	+0.92	0.8280	0.8100	0.8464
3	2.90	2.00	0.80	+0.12	0.0960	0.6400	0.0144
4	1.80	1.95	-0.30	0.07	0.0210	0.0900	0.0049
5	1.85	1.87	0.25	-0.01	0.0025	0.0625	0.0001
6	3.37	1.95	1.27	0.07	0.0889	1.6129	0.0049
7	2.45	1.87	0.35	-0.01	-0.0035	0.1225	0.0001
8	2.43	1.74	0.33	-0.14	-0.0462	0.1089	0.0196
9	1.16	3.00	0.94	1.12	-1.1280	0.8836	1.2544
10	1.00	2.90	1.10	1.02	-1.1220	1.2100	1.2240
11	3.15	2.65	1.05	0.77	0.8085	1.1025	0.5929
12	1.31	2.50	0.79	0.62	-0.4898	0.6241	0.3844
13	0.48	1.60	1.62	-0.38	0.4536	2.6244	0.0784
14	0.60	1.50	1.50	-0.38	0.5700	2,2500	0.1444
15	3.20	1.37	1.10	-0.51	-0.5610	1.2100	0.2601
16	2.79	1.64	0.60	-0.24	-0.1440	0.3600	0.0576
17	2.50	1.90	0.40	0.02	0.0080	0.1600	0.0004
18	2.15	1.48	0.05	0.40	-0.200	0.0025	0.1600
19	1.90	0.95	0.20	-0.93	0.1860	0.0400	0.8649
20	1.80	1.35	0.30	(0.53	0.1590	0.0900	0.2809
21	1.50	0.60	0.60	1.28	0.7680	0.3600	1.6384
	x̄=2.105	Ȳ=1.88			0.05	0.705	0.422

r = 0.086; t = 0.377

TABLE A II4b

PRODUCT MOMENT CORRELATION COEFFICIENT BETWEEN "M.Sc" and "MAN. TECH"

FOR THE FIRST 21 TOPICS

	M.Sc (X)	MAN TECH(Y)	$(x-\bar{x})$	$(y-\bar{y})$	$(x-\bar{x})(y-\bar{y})$	$(x-\bar{x})^2$	$(y-\bar{y})^2$
1	2.90	2.90	0.98	0.97	0.9506	0.9604	0.9409
2	2.85	2.80	0.93	0.87	0.8091	0.8649	0.7569
3	2.70	2.00	0.78	0.07	0.0546	0.6084	0.0049
4	1.80	1.95	-0.12	0.02	-0.0024	0.0144	0.0004
5	1.90	1.87	-0.02	-0.06	0.0012	0.0004	0.0036
6	2.50	1.95	0.58	0.02	0.0116	0.3364	0.3364
7	2.00	1.87	0.08	-0.06	-0.0048	0.0064	0.0036
8	2.05	1.74	0.13	-0.19	-0.0247	0.0164	0.0361
9	2.10	3.00	0.18	1.07	0.1926	0.0324	1.1449
10	1.18	2.90	-0.74	0.97	-0.7178	0.5476	0.9409
11	3.00	2.65	1.08	0.72	0.7716	1.1664	0.5184
12	1.84	2.50	-0.08	0.57	-0.0456	0.0064	0.3249
13	0.50	1.60	-1.42	-0.33	0.4686	2.0164	0.1089
14	0.63	1.50	-1.29	-0.43	0.5547	1.6641	0.1849
15	2.60	1.37	0.68	-0.56	-0.3808	0.4624	0.3136
16	2.20	1.64	0.28	-0.29	-0.0812	0.0784	0.0841
17	2.55	1.90	0.63	-0.03	-0.0189	0.3969	0.0009
18	1.22	1.48	-0.70	-0.45	0.3150	0.4900	0.2025
19	1.20	0.95	-0.72	-0.98	0.7056	0.5184	0.9604
20	1.40	1.35	-0.52	-0.58	0.3016	0.2704	0.3364
21	1.17	0.60	-0.75	-1.33	0.9975	0.5625	1.7689
	$\bar{x}=1.92$	$\bar{y}=1.93$			0.231	0.451	0.375

$r = 0.56; \quad t = 3.00$

TABLE A II 4 c

PRODUCT MOMENT CORRELATION COEFFICIENT BETWEEN "M.Sc." AND "IND. CHEM"

FOR THE FIRST 21 TOPICS

	M.Sc (x)	IND CHEM(Y)	$(x-\bar{x})$	$(Y-\bar{Y})$	$(x-\bar{x})(Y-\bar{Y})$	$(x-\bar{x})^2$	$(Y-\bar{Y})^2$
1	2.90	2.75	0.98	0.66	0.6468	0.9604	0.4356
2	2.85	3.00	0.93	0.91	0.8463	0.8649	0.8281
3	2.70	2.90	0.78	0.81	0.6318	0.6084	0.6561
4	1.80	1.80	-0.12	-0.29	0.0348	0.0144	0.0841
5	1.90	1.85	-0.02	-0.24	0.0048	0.0004	0.0576
6	2.50	3.37	0.58	1.28	0.7424	0.3364	1.6384
7	2.00	2.45	0.08	0.36	0.0288	0.0064	0.1296
8	2.05	2.43	0.13	0.34	0.0442	0.0169	0.1156
9	2.10	1.16	0.18	-0.93	-0.1674	0.0324	0.8649
10	1.18	1.00	-0.74	-1.09	0.8066	0.5476	1.1881
11	3.00	3.15	1.08	1.06	1.1448	1.1664	1.1236
12	1.84	1.31	-0.08	-0.78	0.0624	0.0064	0.6084
13	0.50	0.48	-1.42	-1.61	2.2862	2.0164	2.5921
14	0.63	0.60	-1.29	-1.49	1.9221	1.6641	2.2201
15	2.60	3.20	0.68	1.11	0.7548	0.4624	1.2321
16	2.20	2.70	0.28	0.61	0.1708	0.0784	0.3721
17	2.55	2.50	0.63	0.41	0.2583	0.3969	0.1681
18	1.22	2.15	-0.70	0.06	-0.0420	0.4900	0.0036
19	1.20	1.90	-0.72	-0.19	0.1368	0.5184	0.0361
20	1.40	1.80	-0.52	0.29	0.1508	0.2704	0.0641
21	1.17	1.50	0.75	-0.59	0.4425	0.5625	0.3481
	$\bar{x}$=1.92	$\bar{Y}$=2.09			0.518	0.539	0.704

r = 0.84; t = 6.74 (highly significant)

TABLE A II 4 d

PRODUCT MOMENT CORRELATION COEFFICIENT BETWEEN "B.Sc" AND "MANUFACTURING TECHNOLOGY" FOR THE FIRST 21 TOPICS

	B.Sc (x)	MAN TECH (Y)	$(x-\bar{x})$	$(Y-\bar{Y})$	$(x-\bar{x})(Y-\bar{Y})$	$(x-\bar{x})^2$	$(Y-\bar{Y})^2$
1	2.50	2.90	0.72	0.97	0.6984	0.5184	0.9409
2	2.70	2.80	0.92	0.87	0.8004	0.8464	0.7569
3	2.20	2.00	0.42	0.07	0.0294	0.1764	0.0490
4	0.54	1.95	-1.24	0.02	-0.0248	1.5376	0.0004
5	1.54	1.87	-0.24	-0.06	0.0144	0.0576	0.0036
6	2.30	1.95	0.52	0.02	0.0104	0.2704	0.0004
7	1.75	1.87	-0.03	-0.06	0.0018	0.0009	0.0036
8	1.87	1.74	0.09	-0.19	-0.0171	0.0081	0.0361
9	2.35	3.00	0.57	1.07	0.3959	0.3249	1.1449
10	1.72	2.90	0.06	0.97	0.0582	0.0036	0.9409
11	2.46	2.65	0.68	0.72	0.4896	0.4624	0.5184
12	1.55	2.50	-0.23	0.57	-0.1311	0.0529	0.3249
13	1.48	1.60	-0.30	-0.33	0.0990	0.0900	0.1089
14	1.33	1.50	-0.40	-0.43	0.1720	0.1600	0.1849
15	1.56	1.37	-0.22	-0.56	0.1232	0.0484	0.3136
16	2.04	1.64	0.26	-0.29	-0.0754	0.0676	0.0841
17	1.88	1.90	0.10	-0.03	-0.0030	0.0100	0.0009
18	1.62	1.48	-0.16	-0.45	0.0720	0.0256	0.2025
19	1.52	0.95	-0.26	-0.98	0.2548	0.0676	0.9604
20	1.60	1.35	-0.18	-0.58	0.1044	0.0324	0.3364
21	0.82	0.60	-0.96	-1.33	0.2768	0.9216	1.7689
	$\bar{x}=1.78$	$\bar{Y}=1.93$			0.16	0.271	0.4134

r = 0.48; t = 2.44 (doubtful statistical significance)

TABLE A II 4 e

PRODUCT MOMENT CORRELATION BETWEEN "B.Sc" AND "IND. CHEM" FOR THE 21 TOPICS

	B.Sc (x)	IND CHEM (Y)	(x-x̄)	(Y-Ȳ)	(x-x̄)(Y-Ȳ)	$(x-\bar{x})^2$	$(Y-\bar{Y})^2$
1	2.50	2.75	0.72	0.65	0.468 +	0.5184	0.4225
2	2.70	3.00	0.92	0.90	0.828 +	0.8464	0.8100
3	2.20	2.90	0.42	0.80	0.336 +	0.1764	0.6400
4	0.54	1.80	-1.24	-0.30	0.372 +	1.5576	0.0900
5	1.54	1.85	-0.24	-0.25	0.060 +	0.0576	0.0625
6	2.30	3.37	0.52	1.27	0.660 +	0.2704	1.6129
7	1.75	2.45	-0.03	0.35	0.001 -	0.0009	0.1225
8	1.87	2.43	0.09	0.33	0.003 +	0.0081	0.1089
9	2.35	1.16	0.57	-0.94	0.536 -	0.3249	0.8836
10	1.72	1.00	0.06	-1.10	0.066 -	0.0036	1.2100
11	2.46	3.15	0.68	1.05	0.714 +	0.4624	1.1025
12	1.55	1.31	-0.23	-0.79	0.182 +	0.0529	0.6241
13	1.48	0.48	-0.30	-1.62	0.486 +	0.0900	2.6244
14	1.38	0.60	-0.40	-1.50	0.600 +	0.0160	2.2500
15	1.56	3.20	-0.22	1.10	0.024 -	0.0484	1.2100
16	2.04	2.70	0.26	0.60	0.156 +	0.0676	0.3600
17	1.88	2.50	0.10	0.40	0.040 +	0.0100	0.1600
18	1.62	2.15	-0.16	0.05	0.008 -	0.0256	0.0025
19	1.52	1.90	-0.26	-0.20	0.052 +	0.0676	0.0400
20	1.60	1.80	-0.18	-0.30	0.054 +	0.0324	0.0900
21	0.82	1.50	-0.96	0.60	0.576 +	0.9216	0.3600
	3738	4400			5.425/21	6.6656/21	14.786/21
	x̄=1.78	Ȳ=2.1			0.258	0.317	0.704

r = 0.55; t = 2.88 (doubtful statistical significance)

TABLE A II 4f

PRODUCT MOMENT CORRELATION COEFFICIENT BETWEEN B.Sc. AND M.Sc. FOR THE FIRST 21 TOPICS

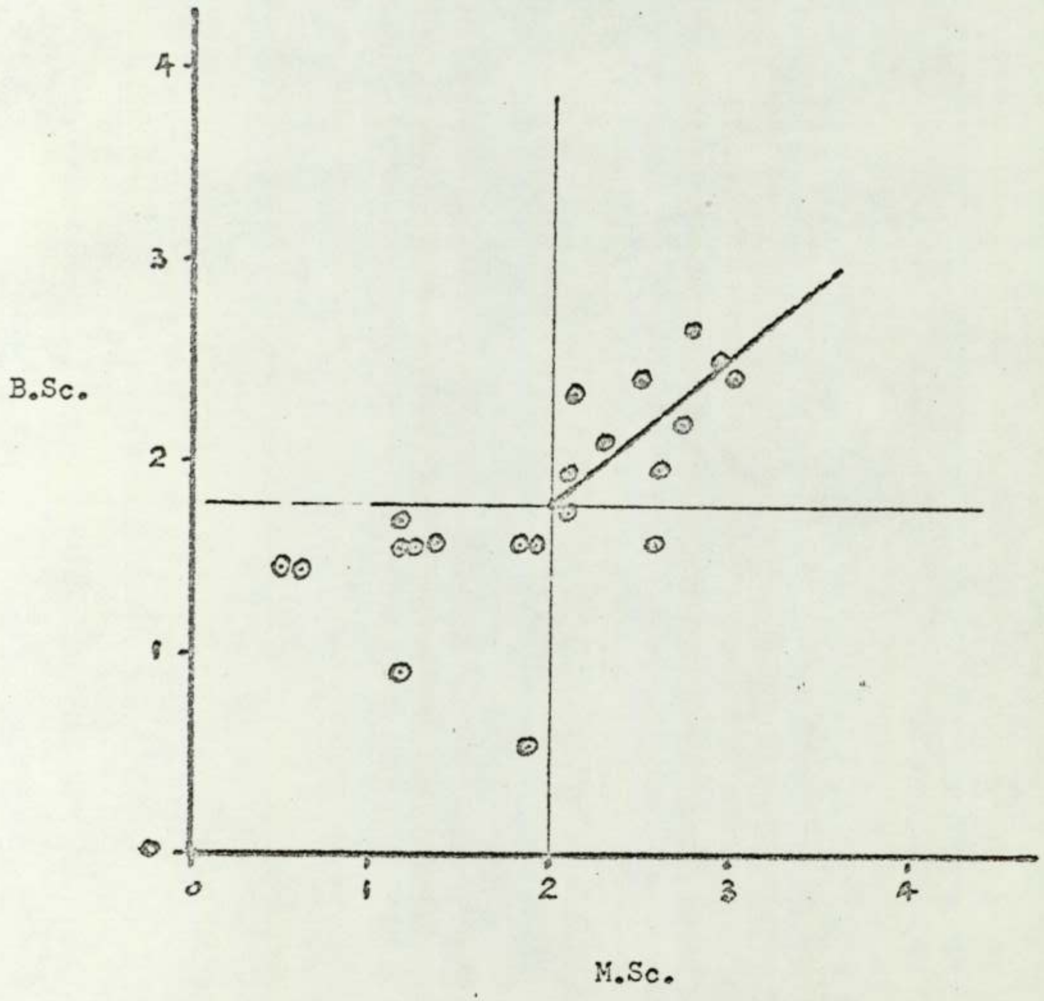
	B.Sc(x)	M.Sc(Y)	$(x-\bar{x})$	$(Y-\bar{Y})$	$(x-\bar{x})(Y-\bar{Y})$	$(x-\bar{x})^2$	$(Y-\bar{Y})^2$
1	2.50	2.90	0.72	0.98	0.7056	0.5184	0.9604
2	2.70	2.85	0.92	0.93	0.8556	0.8464	0.8649
3	2.20	2.70	0.42	0.78	0.3276	0.1764	0.6084
4	0.54	1.80	-1.24	-0.12	0.1488	1.5376	0.0144
5	1.54	1.90	-0.24	-0.02	0.0048	0.0576	0.0004
6	2.30	2.50	0.52	0.58	0.3016	0.2704	0.3364
7	1.75	2.00	-0.03	0.08	-0.0024	0.0006	0.0064
8	1.87	2.05	0.09	0.13	0.0117	0.0081	0.0169
9	2.35	2.10	0.57	0.18	0.1026	0.3249	0.0324
10	1.72	1.18	-0.06	-0.74	0.0444	0.0036	0.5476
11	2.46	3.00	0.68	1.08	0.7344	0.4624	1.1664
12	1.55	1.84	-0.23	-0.08	0.0184	0.0529	0.0064
13	1.48	0.50	-0.30	-1.42	0.4260	0.0900	1.7040
14	1.38	0.63	-0.40	-1.29	0.5160	0.1600	1.6641
15	1.56	2.60	-0.22	0.68	-0.1496	0.0484	0.4624
16	2.04	2.20	0.26	0.28	0.0728	0.0676	0.0784
17	1.88	2.55	0.11	0.63	0.0693	0.0121	0.3969
18	1.62	1.22	-0.16	-0.70	0.1120	0.0256	0.4900
19	1.52	1.20	-0.26	-0.72	0.1872	0.0676	0.5184
20	1.60	1.40	-0.18	-0.52	0.0936	0.0324	0.2704
21.	0.82	1.17	-0.96	-0.75	0.7200	0.9216	0.5625
	$\bar{x}=1.78$	$\bar{Y}=1.92$			0.267	0.417	0.494

$r = 0.55$; $t = 2.88$ (doubtful statistical significance)

FIG. A II 1

CORRELATION BETWEEN B.Sc. AND M.Sc. SCORES FOR THE FIRST 21 TOPICS

r = 0.55 (strong correlation for the high score topics)



CORRELATION BETWEEN "M.Sc" AND "IND. CHEM" FOR THE FIRST 21 TOPICS

r = 0.84 . (very strong correlation)

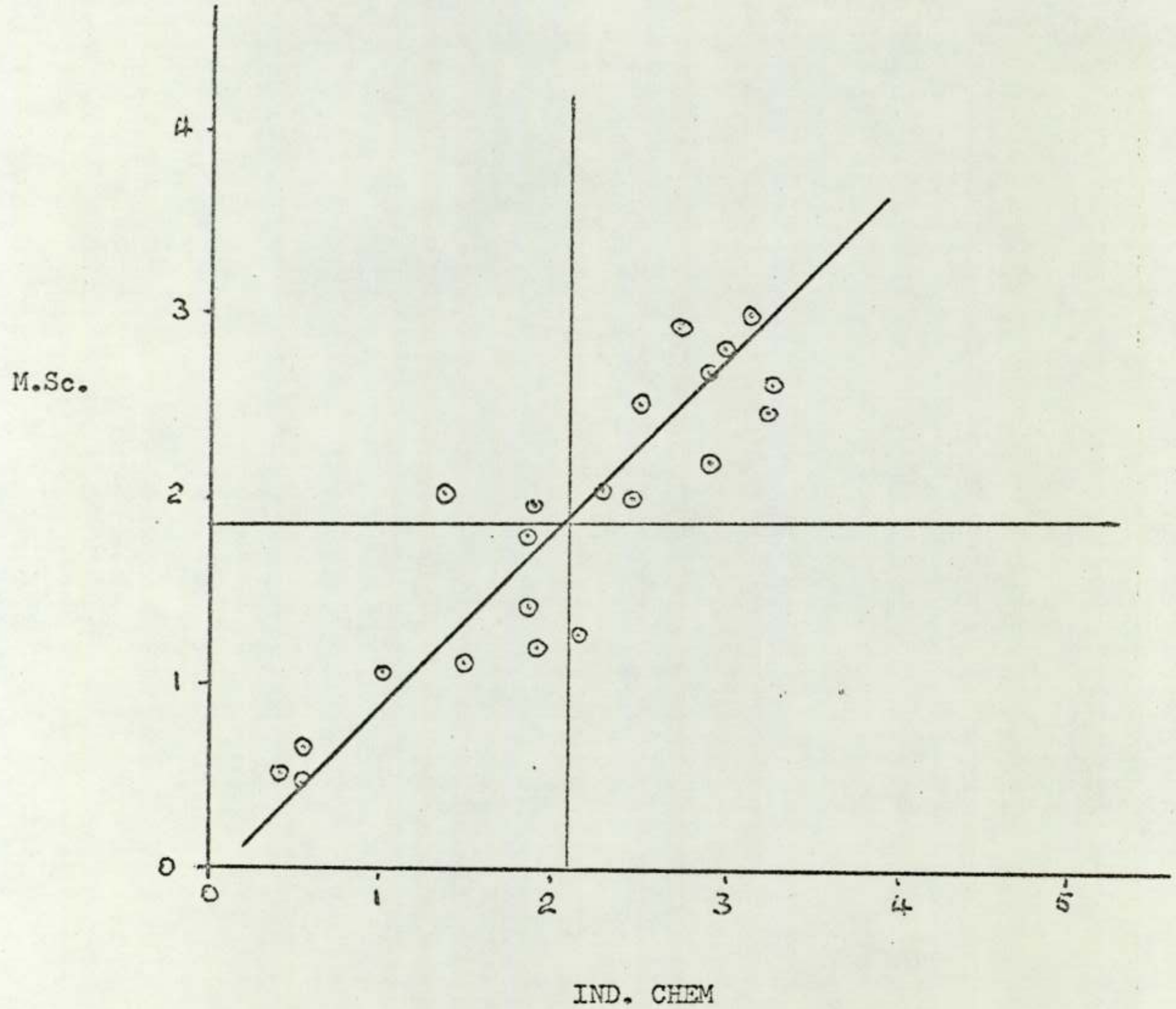
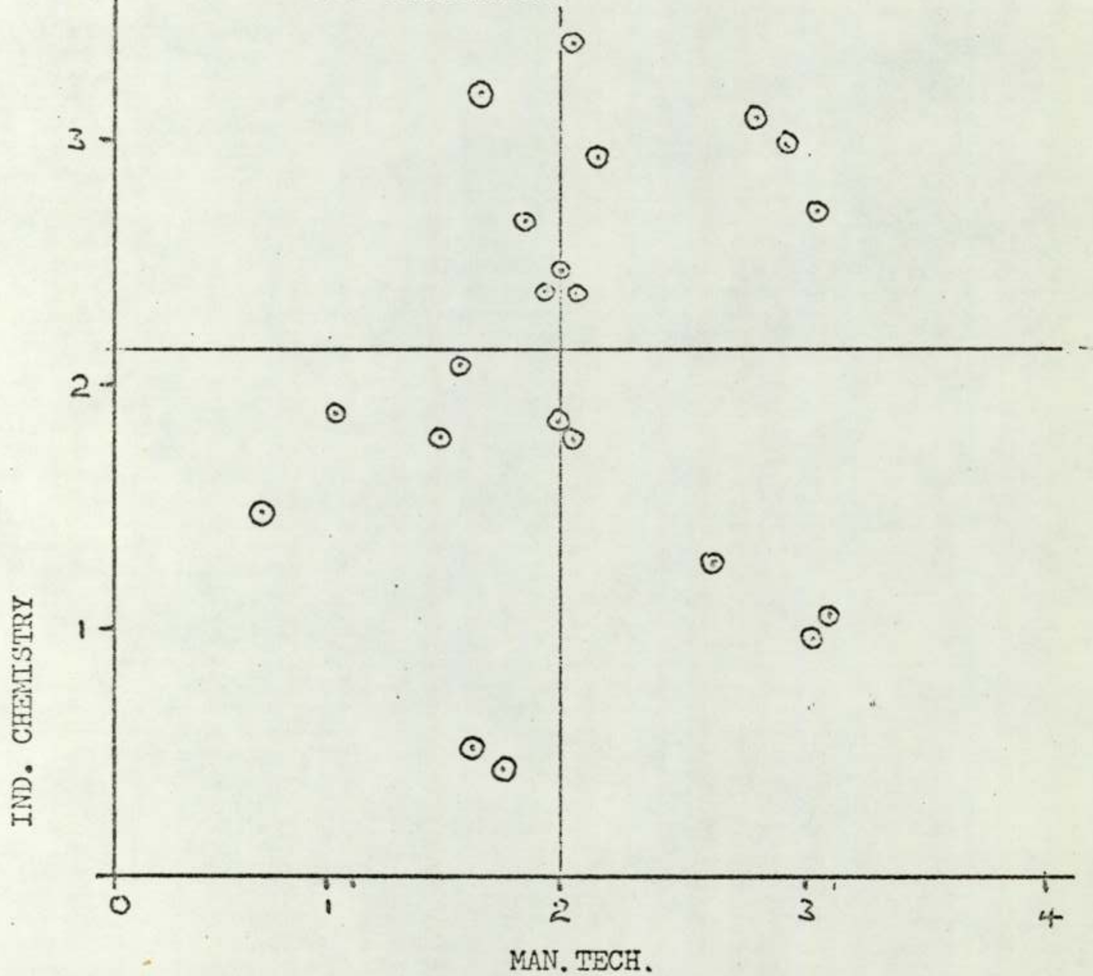


FIG. A II 3

CORRELATION BETWEEN IND. CHEM AND MAN. TECH. FOR THE FIRST 21 TOPICS

r = 0.086 →0 (no correlation)



APPENDIX II b

DETAILED DATA OF THE SURVEY OF A RANDOM CROSS-SECTION OF GRADUATES IN THE POLYMER BASED INDUSTRIES

Table B II 1. Detailed distribution of tasks of graduates in the polymer based industries.

Table B II 2. The relative importance of abstract behaviours for graduates in the polymer based industries.

Table B II 3. Distribution of tasks in the polymer based industries, classified according to job titles.

Table B II 4. Usefulness of subjects studied classified on the basis of job titles.

Table B II 5. The use of mathematics, classified on the basis of job titles.

Table B II 6. Relevance of topic areas for the first 21 topics, classified on the basis of degree taken. Including breakdown of results for columns 5 and 6 of question 9.

Table B II 7. Detailed breakdown of answers to question 9. Results classified on the basis of degree taken, job title designation used, and area of study to which the work of respondents is related. Rating: Highly relevant = 5; Moderately relevant = 3; some relevance = 2; no relevance = 0.
Fig. BII1 Response of polymer chemists/technologists, using two different ratings (0,1,2,3) and (0,1,3,5).

Table BII8 Comparison of bias introduced by weighting factors for different types of distribution

DETAILED DISTRIBUTION OF TASKS OF GRADUATES INVOLVED IN POLYMER WORK IN INDUSTRY

		N=88	N=77	N=6	N=12	N=4	N=4	N=7	N=18	N=3	N=3
Time spent (%) on specified activities		Poly. science & tech. (Chemistry route)	Chemistry	Poly. science & tech. (Physics route)	Physics	Chem. Eng. (+ Poly. sci. & tech.)	Chem. Eng.	Mech. Eng. (+ Poly. Eng./Tech)	Mech. Eng.	Electrical eng.	Others
Research on scientific problems	Mean	4.3	6.1	13.3	14.2	5.0	0.0	2.8	1.1	10.0	26.7
	S.D.	10.5	13.2	13.7	21.8	5.0	0.0	4.5	3.1	14.1	37.7
Research on practical problems	Mean	7.7	9.0	18.3	7.5	5.0	0.0	10.0	6.7	10.0	0.0
	S.D.	9.5	12.1	14.6	5.9	8.6	0.0	10.7	11.5	8.2	0.0
Research (total)	Mean	12.0	15.1	31.6	21.7	10.0	0	12.8	8.8	20.0	16.7
	S.D.	10.0	12.8	22.3	13.1	13.6	0	7.6	7.3	11.2	18.9
Development to improve existing products	Mean	14.9	14.0	16.7	15.8	15.0	20.0	21.4	18.9	3.3	10.0
	S.D.	15.7	14.4	14.9	19.3	5.0	14.1	18.1	21.3	4.7	14.1
Development to invent new products	Mean	11.9	11.4	13.3	7.5	12.5	15.0	14.3	5.0	10.0	0.0
	S.D.	17.4	13.2	13.7	11.6	16.4	16.6	10.5	6.1	14.1	0.0
(Total) Development Work	Mean	26.8	25.4	30.0	23.5	27.5	35.0	35.7	23.0	13.3	10.0
	S.D.	16.6	13.8	11.3	15.5	21.4	31.6	14.3	13.7	9.4	7.1
Technical service, consult., trouble shooting	Mean	18.4	16.6	16.6	13.3	17.5	27.5	25.7	17.2	36.7	40.0
	S.D.	19.9	17.6	13.7	19.3	24.9	17.8	18.4	19.4	33.0	29.4
Quality control Production Supervision	Mean	11.4	7.8	8.0	4.2	17.5	5.0	5.7	3.9	6.7	6.7
	S.D.	19.8	16.7	16.0	8.6	17.8	8.7	10.5	7.5	9.4	9.4
Sales & Marketing	Mean	14.6	9.9	0.0	0.8	27.5	2.5	2.8	13.0	0.0	0.0
	S.D.	25.0	17.5	0.0	2.7	23.8	4.3	4.5	20.3	0.0	0.0
Admin. & supervision of assistants	Mean	13.1	18.1	21.7	25.0	20.5	12.5	25.7	19.4	16.7	6.7
	S.D.	13.8	18.6	19.5	22.2	10.9	4.3	20.6	18.7	17.0	4.7
Others	Mean	5.3	8.9	0.0	10.0	7.5	17.5	0.0	12.2	3.3	0.0
	S.D.	12.9	19.2	0.0	22.7	8.3	30.3	0.0	20.7	4.7	0.0
Total (mean) time		101.6	101.8	107.9	98.3	130.0	13.5	108.4	98.4	96.7	96.8

APPENDIX II b TABLE B II 2

THE RELATIVE IMPORTANCE OF FACTORS AFFECTING TECHNOLOGICAL SKILLS

Weighting: Wholly = 5, Mainly = 4, Partly = 2, Not at all = 0		Scientific knowledge	Practical skills, knowl. of methods etc.	Ability to acquire relevant information	Clear thought & expression	Common sense	Creativity & imagination	Training in the firm	Other courses attended	Work experience	Average no. of observations
Polym. Sci & techn. (Chemistry route)	$\bar{x}$	2.7	2.9	2.6	2.8	2.9	2.3	1.5	1.1	3.1	
	S.D.	1.2	1.1	1.2	1.2	1.2	1.2	1.5	1.0	1.1	84
Chemistry	$\bar{x}$	2.7	2.5	2.7	3.1	3.0	2.5	1.7	1.4	3.2	
	S.D.	1.0	1.1	1.0	1.1	1.1	1.1	0.7	1.1	1.1	76
Polym.Sci & techn. (Physics route)	$\bar{x}$	3.3	2.7	2.7	3.0	3.5	2.4	1.7	1.4	3.2	
	S.D.	0.9	0.9	0.9	1.0	1.1	0.8	0.7	0.8	6.7	6
Physics	$\bar{x}$	2.5	2.2	3.0	3.6	3.6	2.6	0.7	1.3	3.0	
	S.D.	0.8	1.0	1.3	1.1	1.1	1.0	0.9	0.9	1.0	13
Chem. Engin. (Polym.Eng/Tech	$\bar{x}$	3.5	2.0	3.2	2.5	2.5	2.0	1.5	1.5	2.5	
	S.D.	0.9	1.5	1.3	0.9	0.9	1.4	0.9	0.9	0.9	4
Chem. Engin.	$\bar{x}$	2.5	3.0	3.2	3.2	3.0	2.0	2.0	1.5	3.5	
	S.D.	0.9	1.0	1.3	1.3	1.0	0.0	0.0	0.9	0.9	4
Mech. Eng. (Polym.Eng/Tech)	$\bar{x}$	2.8	3.8	3.3	3.3	2.9	2.7	1.3	0.7	3.1	
	S.D.	1.0	0.9	1.2	1.2	1.0	1.2	1.5	0.9	1.0	7
Mechanical Eng.	$\bar{x}$	2.4	2.7	2.9	3.6	3.1	2.9	1.8	1.4	3.7	
	S.D.	0.8	0.9	1.0	0.9	1.2	1.0	1.4	1.2	0.8	16
Electrical Eng.	$\bar{x}$	3.0	2.0	3.3	4.5	4.3	3.3	2.0	2.0	2.7	
	S.D.	1.0	0.0	0.9	0.5	0.5	0.9	0.0	0.0	0.9	3
Others	$\bar{x}$	2.0	2.0	2.0	2.0	4.0	4.0	2.0	2.0	2.7	
	S.D.	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.9	3
Total	Grand $\bar{x}$	2.7	2.7	2.7	3.1	3.0	2.4	1.6	1.3	3.1	
	Grand x	1.1	1.1	1.1	1.2	1.2	1.1	1.3	1.1	1.1	

APPENDIX II b TABLE 3 II 3

DISTRIBUTION OF TASKS OF GRADUATES IN THE POLYMER BASED INDUSTRIES, CLASSIFIED ACCORDING TO JOB TITLES

Values are: Mean ± 1 standard deviation	Research chemists N=23	Research physicists N=6	Development chemists N=39	Development technologists N=40	Development engineers N=9	Technical Service technologists N=24	Production Engineers/ technologists N=16	Technical Sales representatives N=9	R & D Managers/ directors N=22	Production Managers/ Directors N=10	Others N=30	Statistical inference F Ratio	D.F.	Approx. (%)
Research on scientific problems	19.6±19.6	28.3±27.3	4.8± 9.2	3.5± 6.5	4.4± 6.8	2.1± 6.4	0.0± 0.0	0.0± 0.0	4.1± 5.7	0.0± 0.0	5.6±17.6	6.6278	10 211	0.001
Research on practical problems	16.5±14.3	13.3±13.7	8.2± 7.6	9.7±11.3	12.2±12.3	6.2-10.3	3.7- 6.9	3.3- 4.7	7.3-10.9	5.0- 9.3	4.3- 7.2	2.9511	10 211	0.04
Development to invent new products/processes	18.7±23.3	15.0±15.0	12.4±10.41	19.5±17.7	18.9± 9.9	3.7±6.3	2.5± 5.6	2.2±4.2	14.5±13.1	2.0± 4.0	2.0± 4.0	6.6343	10 211	0.001
Development to improve existing products/processes	14.9±15.3	11.7±14.6	22.4±18.7	22.5±16.7	32.2±20.4	11.7±10.3	13.1±14.0	0.0±0.0	12.7±10.5	7.0 ± 7.8	5.7± 8.8	5.9725	10 211	0.003
Tech. Service, consultancy, trouble shooting	7.3± 7.9	10.0±11.5	21.5±13.3	17.8±13.3	13.3±12.5	49.2±20.2	14.4±20.9	16.7± 9.4	12.7±12.1	15.0±16.3	15.0±16.3	10.9954	10 211	>0.0001
Sales and marketing	1.7± 3.8	0.0± 0.0	2.7± 5.1	4.1± 8.7	3.3± 4.7	7.9±11.5	2.5±7.5	62.2±23	11.8±13.3	11.8±13.4	15.0±28.0	13.2726	10 210	>0.0001
Quality control and production supervision	2.7± 6.8	1.7± 3.7	7.3± 9.3	6.0± 8.3	4.4± 9.5	6.3± 9.5	38.1±32.4	7.8±18.7	4.5± 9.4	29.0±30.0	4.0± 8.0	10.1269	10 210	> 0.0001
Administration and supervision of assistants	11.3±11.9	13.3± 7.4	18.2±15.2	15.4±14.3	14.4±10.6	12.9±11.0	23.1±24.7	4.4± 4.9	20.0±16.5	13.0±14.8	24.7±25.0	1.9427	10 210	0.2
Others	9.1±21.2	6.7±11.1	3.3± 6.3	4.7±13.4	4.4±12.6	4.2±10.3	1.2± 3.3	3.3± 6.7	15.0±27.3	16.0±21.1	12.3±21.2	1.6939	10 211	0.2

APPENDIX II b TABLE B II 4

USEFULNESS OF SUBJECTS STUDIED, CLASSIFIED ON BASIS OF JOB TITLES

5 = Extremely useful / 4 = Quite useful / 2 = Some use / 0 = No use	Research chemists	Development chemists	Research physicists	Development technologists	Development engineers	Technical service technologists	Production technologists	Sales representative	Res. and Dev. Managers	Production Managers	Others
Usefulness of:											
Basic chemistry	4.4	3.8	2.8	3.1	2.0	2.9	2.6	4.5	3.5	2.8	3.2
Basic physics	3.3	3.1	4.6	2.8	2.4	2.4	2.8	3.0	3.4	2.5	3.1
Mathematics	3.3	2.8	4.1	3.3	2.5	2.7	3.3	3.1	3.3	2.9	3.8
Statistics	2.1	2.5	3.8	2.7	2.6	2.5	2.8	2.8	3.2	2.2	3.3
Chem. Eng.	1.3	1.8	4.0	3.0	2.0	2.4	2.2	2.0	2.0	2.7	2.1
Mech./Prod.Eng.	-	-	-	3.2	4.5	3.3	3.6	-	-	4.7	3.8
Elec/Electron.En.	-	-	-	1.6	2.3	2.0	2.7	-	2.6	3.3	2.8
Ind.Admin/Tech. Econ	2.7	2.2	2.0	2.5	1.6	2.4	2.9	2.5	4.2	3.3	3.8
Polymer chem.	4.1	4.4	5.0	3.2	3.0	3.2	2.7	4.1	3.8	2.8	3.8
Polymer phys/ engineering	3.1	3.1	4.0	2.6	4.0	2.7	3.0	3.4	2.7	2.5	2.6
Plastics techn.	3.8	3.8	4.0	3.0	4.3	3.2	4.9	2.8	4.0	2.7	4.0
Rubber techn.	1.7	3.7	2.0	3.5	1.3	3.6	4.1	4.2	4.7	3.5	3.2
Surface coatings/ Adh. Tech.	1.4	3.6	2.0	1.8	2.0	2.2	2.8	2.7	2.0	3.5	2.0

APPENDIX II b TABLE B II 5

THE USE OF MATHEMATICS; CLASSIFIED ON THE BASIS OF JOB TITLES

STANDARD RELATIONSHIPS

Weighting: very often = 5, often = 3, rarely = 1, never = 0		Very often (%)	Often (%)	Rarely (%)	Never (%)	Mean score
N = 24	Research chemists	4.2	33.3	28.2	33.2	1.5
N = 7	Research physicists	0	57	43	0	2.1
N = 33	Development chemists	0	27.2	36.5	36.5	1.2
N = 40	Development technologists	5	22.5	52.5	20	1.8
N = 9	Development engineers	22.2	22.2	22.2	33.3	2.0
N = 24	Tech. Service technol.	0	8.4	54	37.6	0.79
N = 15	Prod.Eng./Techn.	0	13.4	40	56.6	0.8
N = 9	Sales/Techn. Represent.	0	22.2	55.6	22.2	1.2
N = 22	Res. Dir. Manager	4.6	22.7	36.3	36.3	1.3
N = 10	Prod./Manager	0	10	20	70	0.5
N = 28	Others	17.8	25	32.2	25	2.0
RELATIONSHIPS DERIVED BY THE WORKER						
N = 24	Research chemists	4.2	28.2	20.7	46	1.3
N = 7	Research physicists	0	57	28.5	14.3	2.0
N = 31	Development chemists	0	19.7	19.7	61.6	0.72
N = 40	Development technologists	5	12.5	30.0	52.5	0.9
N = 9	Development engineers	0	11.1	44.3	44.5	0.78
N = 24	Tech. Service techn.	0	0	28.2	71.8	0.3
N = 16	Prod.Eng./Techn.	6.2	25	31.5	37.2	1.4
N = 9	Sales/Techn. Represent.	11.1	11.1	22.2	55.5	1.1
N = 21	Res. Dir. Manager	0	28.6	33.3	38	1.2
N = 10	Prod. Manager	0	10	40	50	0.7
N = 28	Others	17.9	25	21.3	35.7	1.8

APPENDIX II b, TABLE B II 6

Mean + 1 S D values

Rating:
Highly relevant =5
Moderately relevant = 3
Some relevance =1
No relevance =0

Topic	Polymer/Chemistry N=87	Chemistry N=75	Polymer/Physics N=6	Physics N=13	Polymers/Chem. Eng. N=4	Chemical Engineering N=4	Polymers/Mech. Eng. N=7	Mechanical Engineering N=18	Polymer/Chemists: Would've liked more (% total)	Polymer/Chemists: Dealt with in depth (% resp.)	Chemists: Would've liked more (%)	Polymer/Physics: Would've liked more (%)	Polymer/Physics: Dealt with in depth (%)	Physics: Would've liked more (%)	Polym./Chem Eng.: Would've liked more (%)	Polym./Chem Eng.: Dealt with in depth (%)	Chem. Eng.: Would've liked more (%)	Polym/Mech Eng.: Would've liked more (%)	Polym/Mech Eng: Dealt with in depth (%)	Mech. Eng.: Would've liked more (%)	Frequency of high scores: Would've liked more	Frequency of high scores: Dealt with in depth	Frequency of low scores: Would've liked more	Frequency of low scores: Dealt with in depth
Processing of rubbers and plastics (technol. aspects, interactions of variables)	5.08	3.90	4.46	4.85	5.00	3.67	5.02	3.20	28.5	49	27.8	75	16	38.5	50	50	75	14.5	57	22.2	3	2	1	1
Technol. aspects of X-linking and degradation reactions	4.76	4.65	3.53	4.16	5.91	4.15	1.74	1.82	28.8	49	38	16.6	16.7	30.5	50	50	75	14.3	0	22.2	2	1	2	2
Gen. aspects of plastics (properties/structure, comparative analysis of behaviour)	4.53	4.49	3.00	4.40	5.37	4.53	4.19	3.94	29.5	43	43	33.3	33.3	46.3	50	50	75	28.5	57	16.7	3	2	0	0
Processing of rubbers and plastics (production engineering aspects)	4.53	3.42	3.84	4.02	5.36	3.67	5.33	3.94	40	29.5	20.3	75	16	38.5	50	50	75	28.5	57.2	22.2	4	2	0	1
Compounding methods (efficiency, economics)	4.52	3.90	3.84	2.85	5.16	3.00	1.85	1.65	34	35	25.7	50	16	23	25	75	75	28.5	28.5	11.1	2	1	0	1
Standard test methods (usefulness, limitations, fundamentals)	4.28	4.36	4.70	3.88	4.41	4.72	5.02	2.60	25	43	29.2	0	16	38.5	0	50	50	14.3	43	11.1	1	1	3	1
Technol. aspects of additives (synergisms, dispersibility)	4.40	4.54	2.61	2.93	5.16	3.34	0.48	0.67	34	37.3	29.2	33.3	0	23.1	50	0	75	14.3	0	11.1	2	3	2	3
Structure/properties relationships	4.32	4.07	4.70	4.93	2.34	4.16	1.97	1.96	21.5	59	33.3	16.5	50	61.5	25	25	50	14.3	28.5	11.1	2	2	2	0
Specific aspects of plastics (manufact., stabilization, processing char.)	4.31	4.03	4.63	3.08	5.00	5.16	4.41	3.14	25	48.5	36.7	50	16	30.7	75	50	75	28.5	48	16.7	3	2	0	1
Costing methods and assessment of cost-effectiveness	4.14	4.05	3.84	4.32	5.91	3.00	3.87	4.64	61.3	4.5	31.5	16.7	16.7	53.7	75	25	100	43	15	22.2	5	0	1	3
General aspects of rubbers (structure/properties, relationships to synthetics)	4.28	3.04	1.96	3.83	5.91	0.00	1.83	2.04	20.3	47.8	20.3	16.7	16	46.3	50	50	25	28.5	30.7	11.1	3	1	3	1
Mechanisms of X-linking reactions	4.01	3.79	3.50	3.28	4.15	0.68	3.18	2.33	17	62	26.6	16.7	0	30.7	0	25	25	14.3	14.3	22.2	0	1	4	2
Moulds, dies, machines, etc.	4.11	2.95	4.63	1.96	4.17	3.56	5.41	5.35	21.6	37.2	20.2	83.3	0	23.1	0	25	50	14.3	85	11.1	2	1	2	1
Mechanisms of action of additives	4.04	4.15	4.48	2.19	4.63	3.34	0.73	0.63	28.3	40	34.0	33.3	33.3	23.1	25	25	75	14.3	0	11.1	1	0	2	1
Reinforcement and composites (basic theories, interfaces etc.)	3.91	2.89	3.82	4.94	4.17	1.00	3.85	1.14	29.5	27.2	22.8	0	33.3	38.5	50	0	50	28.3	30	22.2	2	0	1	1
Mixing theories	3.87	3.49	3.02	3.34	3.56	2.22	2.21	1.95	23	3.05	21.5	16.7	0	30.7	0	75	50	28.5	0	11.1	1	1	3	2
Specific aspects of rubbers (e.g. vulcanizations, X-linking assessment)	4.00	3.07	1.96	4.13	5.29	0.00	2.35	0.74	15.9	54.5	19	33.3	0	38.5	50	0	25	14.3	43	5.6	1	1	4	2
Thermal behaviour of polymers	3.66	3.49	4.04	4.01	3.73	3.60	2.48	1.97	11.4	40	28	16.7	16	30.7	50	25	75	14.5	0	16.7	2	0	2	1
Technol. aspects of rheology	3.52	4.17	4.63	3.90	2.34	3.34	2.38	1.60	27.2	36.5	29.3	16.7	16.7	46.2	25	0	50	28.6	28.5	22.2	1	0	0	1
General aspects of adhesives and surface coatings	3.47	3.95	3.04	2.21	3.05	3.67	1.85	2.45	38	17	35.5	16.7	16.5	38.5	50	0	75	43	0	16.7	3	0	0	3
Mechanisms of degradation reactions	3.33	3.42	2.00	2.46	4.17	2.22	1.62	1.08	11.4	44.3	25.3	0	16.5	30.7	75	0	50	16.7	0	11.1	2	0	3	3
Surface and interfacial properties (adsorption, adhesion, wear)	3.42	3.54	4.16	4.25	1.00	3.04	3.29	2.21	30.7	16	25.3	16.7	0	46.5	25	25	75	30.7	16	5.6	1	0	2	2
Engineering design with polymers	3.43	2.67	4.15	4.37	5.00	3.56	3.56	3.06	32	18.2	24	75	15	46.5	75	75	50	43	43	11.1	4	1	1	1
Tech. aspects of experimental design	3.24	3.33	3.82	5.49	4.17	1.18	3.60	2.71	42	13.5	39.3	16.5	53.3	38.5	50	50	50	30.7	28.5	0	3	2	2	0
Specific aspects of adhesives	3.07	3.19	2.58	2.21	3.41	3.67	2.78	1.26	34.2	11.3	27.3	16.7	0	38.5	25	0	50	30.7	0	11.1	1	0	2	4
Mechanisms of polymerization	2.89	3.39	3.02	1.38	5.00	0.68	2.44	2.04	12.5	75	26.5	16.7	33.3	23	0	50	0	28.5	30.7	16.7	0	2	4	0
Rheology theories	2.63	3.10	4.10	3.69	1.18	2.22	2.78	1.14	11.4	43	29	16.7	33.3	30.7	0	0	25	30.7	43	16.7	0	0	3	1

Scores = 0 - 1 - 3-5

1. Mechanisms of polymerization reactions

2. Mechanisms of degradation reactions

3. Mechanisms of cross-linking reactions

4. Kinetic aspects of 1, 2, 3 above

5. Technological aspects of 1, 2, 3 above

6. Molecular weight determinations

7. Methods of structure determination (e.g. NMR, X-ray, IR etc)

8. Technological aspects of 5, 6 above

9. Thermal analysis

10. Structure/properties relationships

11. Rheology theories

12. Technological aspects of rheology

13. Viscoelasticity theories

14. Technological aspects of viscoelasticity

15. Rubber elasticity theories

16. Technological aspects of rubber elasticity

17. Solution thermodynamics theories

18. Technological aspects of polymer solutions

19. Gas and liquids diffusion kinetics

20. Tech. aspects of gas and liquids diffusion in polymers

21. Combustion inhibition theories

22. Tech. aspects of flame retardancy

23. Engineering design with polymers

24. Mechanisms of action of additives

25. Tech. aspects of additives (e.g. synergism, adverse effects, dispersability)

26. Mixing theories

27. Compounding methods

28. General aspects of plastics materials

29. Specific aspects of plastics

30. General aspects of rubbers

31. Specific aspects of rubbers

32. General aspects of adhesives & surface coatings

33. Specific aspects of adhesives & surface coatings

34. Processing of rubbers and/or plastics

35. Processing of rubbers and/or plastics (prod. eng. aspects)

36. Moulds, dies, machines etc

37. Standard test methods (usefulness, limitations)

38. Basic engineering fundamentals

39. Surface and interfacial properties

40. Heat transfer theories

41. Mass transfer theories

42. Thermal behaviour of polymers

43. Fracture mechanisms & large deformations in rubbers and plastics

44. Orientation and anisotropy (scientific methods of determination)

45. Orientation and anisotropy (significance in eng. design)

46. Reinforcement and composites (basic theories)

47. Dielectric properties (effects of additives)

48. Optical properties (effects of additives)

49. Statistical methods for technological research

50. Technological methods of experimental design

51. Costing methods and assessment of cost-effectiveness

52. Critical path and network analysis

53. Computer techniques

POLY CHEM N=87	CHEM N=75	POLY PHYS N=6	PHYS N=13	POLY CHEM N=4	CHEM ENG N=4	POLY MECH ENG N=7	MECH ENG N=18
1.34±1.55=2.89	1.69±1.70=3.39	1.33±1.69=3.02	0.54±0.84=1.38	3.00±2.00=5.00	0.25±0.43=0.68	1.28±1.16=2.44	0.77±1.27=2.04
1.73±1.60=3.33	1.71±1.71=3.42	1.00±1.88=2.00	1.08±1.38=2.46	2.25±1.92=4.17	1.00±1.22=2.22	0.57±1.05=1.62	0.34±0.74=1.08
2.19±1.82=4.01	2.04±1.75=3.79	1.83±1.67=3.50	1.46±1.82=3.28	2.50±1.65=4.15	0.25±0.43=0.69	1.42±1.76=3.18	0.78±1.55=2.33
0.66±1.16=1.82	1.03±1.37=2.40	1.35±1.70=3.05	0.67±1.37=2.04	0.75±0.43=1.18	1.50±2.06=3.56	0.29±1.37=1.66	0.11±0.31=0.42
2.95±1.81=4.76	2.83±1.82=4.65	2.00±1.53=3.53	2.38±1.78=4.16	3.75±2.16=5.91	2.50±1.65=4.15	0.71±1.03=1.74	0.67±1.15=1.83
0.72±1.14=1.86	0.78±0.99=1.77	1.33±1.24=2.57	0.38±0.48=0.86	0.75±0.43=1.18	0.50±0.50=1.00	0.00±0.00=0.00	0.22±0.71=0.93
0.79±1.19=1.98	1.01±1.22=2.33	2.20±1.60=3.80	0.84±0.77=1.61	0.25±0.43=0.68	0.25±0.43=0.68	0.00±0.00=0.00	0.28±0.44=0.72
1.07±1.48=2.55	1.26±1.55=2.81	1.58±1.60=3.80	1.38±1.54=2.92	0.25±0.43=0.68	0.50±0.50=1.00	0.00±0.00=0.00	0.17±1.37=0.54
0.50±1.03=1.53	1.05±1.25=2.30	1.63±1.40=3.03	0.92±1.44=2.36	0.00±0.00=0.00	0.25±0.43=0.68	0.42±1.05=1.47	0.17±0.37=0.54
2.43±1.89=4.32	2.28±1.79=4.07	3.63±1.37=4.70	2.92±2.01=4.93	1.25±1.09=2.34	2.50±1.66=4.16	1.14±0.83=1.97	0.67±1.29=1.96
1.17±1.46=2.63	1.57±1.53=3.10	2.50±1.60=4.10	1.83±1.86=3.69	0.75±0.43=1.18	1.00±1.22=2.22	1.14±1.64=2.78	0.39±0.75=0.75
1.83±1.69=3.52	2.24±1.93=4.17	3.00±1.63=4.63	2.23±1.67=3.90	1.25±1.09=2.34	1.25±1.09=3.34	1.14±1.24=2.38	0.44±1.16=1.60
0.72±1.27=1.99	1.01±1.32=2.33	3.00±1.63=4.63	2.46±2.13=4.59	0.75±0.43=1.18	2.00±2.12=4.12	0.57±1.05=1.62	0.33±0.47=0.80
1.29±1.61=2.90	1.39±1.66=3.04	2.67±1.79=4.46	2.54±2.31=4.85	0.50±0.50=1.00	2.00±2.12=4.12	0.86±0.99=1.85	0.39±0.75=1.14
0.72±1.27=1.99	0.74±1.40=2.14	2.00±2.45=4.45	2.84±2.21=5.05	0.50±0.50=1.00	0.75±1.30=2.05	0.43±1.05=1.48	0.11±0.31=0.44
1.16±1.55=2.71	0.92±1.58=2.50	2.00±2.45=4.45	2.46±2.45=4.91	1.25±1.10=2.35	0.75±1.30=2.05	0.43±1.05=1.48	0.11±0.31=0.44
0.21±0.77=0.98	0.24±0.51=0.75	1.00±1.00=2.00	0.53±0.84=1.37	0.75±1.30=2.05	0.00±0.00=0.00	0.00±0.00=0.00	0.17±0.68=0.85
0.80±1.40=2.20	0.95±1.35=2.30	1.83±1.21=3.04	0.77±1.05=1.82	1.25±2.16=3.41	0.25±0.43=0.68	0.43±1.05=1.48	0.33±0.74=1.07
0.27±0.83=1.10	0.36±1.24=1.60	1.33±1.24=2.57	0.30±0.46=0.76	0.75±1.30=2.05	0.25±1.30=2.05	0.00±0.00=0.00	0.11±0.31=0.42
0.59±1.19=1.78	0.73±1.10=1.83	1.33±1.24=2.57	0.61±1.07=1.68	1.50±2.06=3.56	1.00±1.22=2.22	0.00±0.00=0.00	0.17±0.68=0.85
0.64±1.32=1.96	0.89±1.35=2.24	0.33±0.47=0.80	0.77±1.47=2.24	0.75±0.43=1.18	0.75±1.30=2.05	0.14±0.35=0.49	0.22±0.71=0.93
1.57±1.42=2.99	1.33±1.61=2.94	1.17±0.89=2.06	1.46±1.82=3.38	1.50±2.06=3.56	0.50±0.50=1.00	0.14±0.35=0.49	0.41±0.77=1.18
1.59±1.84=3.43	1.12±1.55=2.67	3.00±1.15=4.15	2.69±1.68=4.37	4.00±1.00=5.00	1.50±2.06=3.56	1.50±2.06=3.56	1.61±1.45=3.06
2.14±1.90=4.04	2.26±1.89=4.15	2.50±1.98=4.48	0.92±1.27=2.19	3.00±1.63=4.63	1.25±1.09=3.34	0.28±0.45=0.73	0.22±0.41=0.63
2.56±1.84=4.40	2.54±2.00=4.54	1.67±0.94=2.61	1.30±1.63=2.93	3.50±1.66=5.16	1.25±1.09=3.34	0.14±0.34=0.48	0.23±0.42=0.67
2.07±1.80=3.87	1.63±1.79=3.49	1.33±1.69=3.02	1.61±1.73=3.34	2.50±1.06=3.56	1.00±1.22=2.22	0.86±1.35=2.21	0.66±1.29=1.95
2.58±1.94=4.52	1.97±1.93=3.90	2.17±1.67=3.84	1.15±1.70=2.85	3.50±1.66=5.16	2.00±1.00=3.00	0.85±1.00=1.85	0.70±0.95=1.65
2.63±1.90=4.53	2.65±1.84=4.49	2.00±1.00=3.00	2.46±1.98=4.44	4.50±0.87=5.37	2.75±1.78=4.53	2.43±1.76=4.19	2.00±1.94=3.94
2.36±1.95=4.31	2.25±1.78=4.03	3.00±1.63=4.63	1.31±1.77=3.08	5.00±0.00=5.00	3.50±1.16=5.16	2.57±1.84=4.41	1.44±1.70=3.14
2.23±2.05=4.28	1.32±1.72=3.04	0.80±1.16=1.96	1.84±1.99=3.83	3.75±2.16=5.91	0.00±0.00=0.00	0.85±0.98=1.83	0.83±0.21=2.04
1.97±2.03=4.00	1.29±1.79=3.07	0.80±1.16=1.96	2.08±2.05=4.13	3.25±2.04=5.29	0.00±0.00=0.00	1.00±1.35=2.35	0.27±0.47=0.74
1.72±1.75=3.47	2.10±1.85=3.95	1.67±1.37=3.04	1.07±1.14=2.21	1.75±1.30=3.05	1.75±1.92=3.67	0.86±0.99=1.85	1.00±1.45=2.45
1.39±1.68=3.07	1.49±1.70=3.19	1.33±1.25=2.58	1.07±1.14=2.21	1.25±2.16=3.41	1.75±1.92=3.67	1.14±1.64=2.78	0.50±0.76=1.26
3.15±1.93=5.08	2.04±1.86=3.90	2.67±1.79-4.46	2.61±2.24=4.85	4.00±1.00=5.00	1.75±1.92=3.67	3.14±1.88=5.02	1.50±1.80=3.30
2.62±1.91=4.53	1.56±1.86=3.90	2.17±1.67=4.46	2.15±1.87=4.02	4.5±0.86=5.36	1.75±1.92=3.67	3.57±1.76=5.33	2.00±1.94=3.94
2.08±2.03=4.11	1.35±1.60=2.95	3.00±1.63=4.63	1.00±0.96=1.96	2.25±1.92=4.17	1.50±2.05=3.56	4.71±0.70=5.41	2.33±2.02=5.35
2.61±1.67=4.28	2.55±1.81=4.36	3.33±1.37=4.70	3.00±1.88=3.88	3.00±1.41=4.41	2.67±2.05-4.72	3.14±1.88=5.02	1.28±1.32=2.60
1.24±1.47=2.71	1.35±1.55=2.90	2.67±1.80=4.47	3.23±1.84=5.07	3.00±2.00=5.00	1.50±2.06=3.56	3.85±1.45=5.30	2.16±1.80=3.96
1.71±1.71=3.42	1.86±1.68=3.54	2.00±2.16=4.16	2.61±1.64-4.25	1.00±0.00=1.00	1.75±1.29=3.04	1.71±1.58=3.29	0.83±1.38=2.21
0.77±1.24=2.01	0.55±0.87=1.42	1.67±0.94=2.61	1.92±2.05=3.97	3.00±1.41=4.41	0.75±1.29=2.04	1.28±1.58=2.86	0.78±1.08=1.86
0.32±0.73=1.05	0.39±0.81=1.20	1.67±1.37=3.04	0.58±1.38=1.96	1.50±2.06=3.56	0.50±0.50=1.00	0.43±0.49=0.92	0.55±0.95=1.50
1.93±1.73=3.66	1.92±1.57=3.44	2.67±1.37=3.04	2.07±1.94=4.01	2.00±1.73=3.73	1.75±1.92=3.67	1.43±1.05=2.48	0.94±1.03=1.97
1.02±1.42=2.44	1.26±1.58=2.84	2.67±1.79=4.46	2.85±1.95=4.80	0.50±0.50=1.00	0.50±0.50=1.00	1.14±1.64=2.78	0.39±0.76=1.05
0.69±1.25=1.94	0.75±1.08=1.83	2.67±1.79=4.46	1.84±1.66=3.50	0.25±0.43=0.68	1.00±1.23=2.23	0.85±1.72=2.57	0.33±0.94=1.27
0.80±1.18=1.98	0.74±1.14=1.88	3.00±1.63=4.63	2.30±1.85=4.15	0.00±0.00=0.00	1.00±2.22=3.22	2.00±2.14=4.14	0.44±0.96=1.40
2.01±1.90-3.91	1.36±1.53=2.89	2.00±1.82=3.82	3.15±1.79=4.94	2.25±1.92=4.17	0.50±0.50=1.00	2.00±1.85=3.85	0.39±0.75=1.14
0.95±1.44=2.39	1.08±1.37=2.45	2.00±2.16=4.16	1.54±1.78=3.32	0.50±0.50=1.00	0.25±0.43=0.68	0.28±0.45=0.73	0.38±0.49=0.87
0.64±1.05=1.69	0.99±1.34=2.33	1.83±1.67=3.50	1.00±1.17=2.17	0.25±0.43=0.68	0.50±0.50=1.00	1.28±0.45=0.74	0.23±0.42=0.65
1.21±1.26=2.47	1.51±1.44=2.95	1.85±1.21=3.04	3.31±1.68=4.99	1.75±1.92=3.67	1.25±1.09=2.34	1.43±1.76=3.19	1.00±1.20=2.20
1.60±1.64=3.24	1.67±1.66=3.33	2.33±1.49=3.82	3.84±1.65=5.49	2.25±1.92=4.17	0.75±0.43=1.18	2.00±1.60=3.60	1.17±1.54=2.71
2.39±1.75=4.14	2.32±1.73=4.05	2.17±1.67=3.84	2.38±1.94=4.32	3.75±2.16=5.91	2.00±0.43=1.18	2.14±1.73=3.87	3.18±1.46=4.64
1.05±1.19=2.24	1.23±1.44=2.67	1.17±1.77=2.94	1.25±1.54=2.79	2.50±1.66=4.16	0.75±0.43=1.18	1.71±1.83=3.54	1.61±1.46=3.07
0.95±1.27=2.22	1.26±1.38=2.64	1.83±1.21=3.04	2.76±1.58=4.34	2.00±1.73=3.73	0.75±0.43=1.18	1.57±1.92=3.49	1.17±1.25=2.42

RES CHEM N=24	DEV CHEM N=34	RES PHYS N=7	DEV TECH N=40	DEV ENG N=9	TECH SER TECH/EN, N=24	PROD ENG/TECH N=15	SALES TECH REP N=9
2.33±1.86=4.19	1.53±1.54=3.01	1.14±0.83=1.97	1.12±1.38=2.50	0.67±0.94=1.63	0.91±1.18=2.09	1.40±1.54=2.94	1.67±1.56=3.23
2.00±1.68=3.68	2.26±1.75=4.01	1.28±1.57=2.85	1.57±1.49=3.06	1.56±0.95=1.51	1.75±1.63=3.38	0.93±1.12=2.05	0.89±0.88=1.77
2.17±1.70=3.87	2.81±1.93=4.74	2.57±1.84=4.41	1.92±1.59=3.61	0.56±0.95=1.51	1.58±1.60=3.18	2.13±2.02=4.15	1.55±1.64=3.19
1.62±1.58=3.20	1.22±1.64=2.84	1.29±1.58=2.87	0.67±1.16=1.83	0.11±0.31=0.44	0.30±0.68=0.98	0.64±1.29=1.93	0.44±0.49=0.93
2.91±1.71=4.62	3.18±1.73=4.91	2.71±1.66=4.37	3.00±1.88=4.88	0.78±0.91=1.69	2.70±1.96=4.66	2.40±1.99=4.39	2.33±1.82=4.15
1.08±1.22=2.30	1.12±0.93=2.05	1.00±0.93=1.93	0.62±0.83=1.45	0.11±0.31=0.44	0.62±0.85=1.47	0.21±0.41=0.62	0.44±0.50=0.94
1.67±1.62=3.29	1.18±1.46=2.64	1.42±1.49=2.91	0.85±0.86=1.71	0.22±0.41=0.63	0.62±0.86=1.48	0.26±0.44=0.70	0.22±0.41=0.63
1.05±1.50=2.55	1.29±1.44=2.64	2.28±1.91=4.19	1.13±1.59=2.72	0.44±0.96=1.30	1.42±1.52=2.94	0.35±0.81=1.16	1.12±1.17=2.29
1.29±1.40=2.69	0.84±1.13=1.97	1.57±1.67=3.24	0.74±1.15=1.89	0.44±0.95=1.39	0.45±0.70=1.15	0.07±0.20=0.27	0.11±0.31=0.42
3.25±1.73=4.98	2.45±1.70=4.15	4.14±1.45=5.59	2.67±1.64=4.41	1.45±1.16=2.61	1.66±1.88=3.54	1.78±1.65=3.43	1.78±1.93=3.71
1.58±1.68=3.26	1.53±1.43=2.96	2.00±1.60=3.60	1.20±1.40=2.60	1.00±1.49=2.49	1.33±1.49=2.82	1.76±1.48=3.24	1.00±1.49=2.49
1.96±1.51=3.47	2.41±1.89=4.30	2.71±1.66=4.37	2.15±1.89=4.04	1.44±1.70=3.14	1.75±1.80=3.55	1.27±1.48=2.75	1.33±1.56=2.89
1.08±1.41=2.49	0.82±1.19=2.01	3.43±1.98=5.41	1.25±1.66=2.91	0.44±0.95=1.39	0.83±1.34=2.17	0.53±0.80=1.33	0.55±0.95=1.50
1.42±1.70=3.12	1.41±1.61=3.02	3.71±2.05=5.76	1.95±1.92=3.81	1.11±1.66=2.77	1.29±1.51=2.80	0.66±0.79=1.45	0.67±0.94=1.61
0.79±1.32=2.11	0.63±1.17=1.80	3.71±1.74=5.45	1.07±1.71=2.78	0.33±0.94=1.27	0.25±0.43=0.68	0.78±1.56=2.34	0.25±0.41=0.63
0.70±1.24=1.33	1.03±1.29=2.32	3.42±1.98=5.40	1.52±2.03=3.55	0.33±0.94=1.27	0.70±1.09=1.79	1.07±1.62=2.69	0.67±0.94=1.61
0.52±1.05=1.57	0.33±0.86=1.19	1.14±1.24=2.38	0.22±0.69=0.91	0.00±0.00=0.00	0.12±0.33=0.45	0.26±0.76=1.02	0.22±0.41=0.63
1.30±1.54=2.84	1.38±1.98=3.36	1.00±1.30=2.30	0.57±0.83=1.40	0.50±1.00=1.50	0.95±1.36=2.31	0.66±0.78=1.44	0.78±1.54=2.32
0.52±0.87=1.39	0.38±0.87=1.25	0.85±0.98=1.83	0.35±0.82=1.17	0.00±0.00=0.00	0.20±0.64<0.84	0.33±0.78=1.11	0.00±0.00=0.00
0.56±0.87=1.43	0.67±1.15=1.82	1.42±1.39=2.81	0.90±1.54=2.44	0.00±0.00=0.00	0.92±1.28=2.20	0.47±1.02=1.49	0.11±0.31=0.43
0.45±0.89=1.34	0.48±1.01=1.49	1.28±1.82=3.10	0.87±1.62=2.49	0.11±1.31=1.42	1.25±1.71=2.96	0.35±0.81=1.16	0.56±0.96=1.62
0.95±1.30=2.25	1.00±1.37=2.37	1.71±1.82=3.53	1.60±1.75=3.35	0.67±1.24=1.91	1.91±2.05=3.96	1.46±1.78=3.24	1.45±1.71=3.16
1.00±1.53=2.53	1.27±1.77=3.04	2.71±1.27=3.98	1.92±1.79=3.71	2.44±2.31=4.75	1.58±1.46=3.04	1.80±1.83=3.63	1.33±2.00=3.33
2.27±1.71=3.98	2.50±1.92=4.42	1.85±2.03=3.88	1.75±1.75=3.60	0.22±0.41=0.63	2.91±2.14=5.05	2.06±1.84=3.90	1.22±1.62=2.84
2.04±1.78=3.82	2.88±1.84=4.72	1.85±2.03=3.88	2.40±1.92=4.32	0.44±0.95=1.39	2.95±2.09=5.04	1.85±1.88=3.73	2.11±1.59=3.70
1.17±1.27=2.44	2.12±1.80=3.92	2.14±2.03=4.17	2.07±1.84=3.91	0.44±0.95=1.39	1.86±1.75=3.61	1.93±2.08=4.01	1.45±1.70=3.15
1.30±1.42=2.72	2.29±1.88=4.17	1.57±2.19-3.76	2.52±2.00=4.52	0.44±0.49=0.93	2.54±2.21=4.75	2.40±2.02=4.42	2.56±1.77=4.33
2.43±1.88=4.31	2.70±1.81=4.51	3.28±1.27=4.55	2.17±1.94=4.11	2.66±1.63=4.29	2.79±1.84=4.63	2.62±1.96=4.58	2.67±1.96=4.63
2.30±1.78=4.08	2.06±1.75=3.81	1.00±0.92=1.92	2.02±2.07=4.99	2.53±1.92=4.25	2.35±1.92=4.25-	2.25±2.13=4.38	2.67±1.88=4.55
1.30±1.42=2.72	1.84±2.00=3.94	2.85±1.72=4.57	2.25±2.22=4.45	0.77±1.22=1.99	1.12±1.50=2.62	1.40±1.94=3.34	1.00±1.70=2.70
0.87±1.33=2.20	1.58±1.97=3.55	2.57±1.84=4.41	2.15±2.13=4.28	0.33±0.94=1.27	1.20±1.65=2.85	1.33±1.98=3.31	0.55±0.95=1.50
1.39±1.69=3.08	2.41±1.93=4.34	1.71±1.16=2.87	1.55±1.58=3.13	1.78±1.68=3.46	1.83±1.67=3.50	1.44±1.62=3.06	1.89±1.59=3.48
1.13±1.65=2.78	2.03±1.96=3.99	1.57±1.90=3.47	1.15±1.56=2.71	1.44±1.95=3.39	1.37±1.47=2.84	0.87±0.96=1.83	1.78±1.68=3.46
1.83±1.81=3.64	2.53±2.00=4.53	2.14±2.03=4.17	2.15±1.88=4.03	1.67±2.00=3.67	2.33±1.91=4.14	3.62±1.80=5.42	3.11±1.66=4.77
1.04±1.49=2.53	2.15±1.98=4.01	1.00±0.93=1.93	2.02±1.81=3.83	3.22±2.15=5.37	1.42±1.80=3.22	2.60±2.15=4.75	2.45±1.71=4.16
1.09±1.59=2.68	1.51±1.91=3.42	3.43±1.68=5.11	2.69±1.70=4.39	3.25±2.05=5.30	3.00±1.71=4.71	2.63±1.76=4.39	1.67±1.83=3.50
2.78±1.69=4.97	2.47±1.68=4.15	3.00±1.51=4.51	1.55±1.69=3.24	3.00±2.05=5.05	1.67±1.62=3.29	1.47±1.67=3.14	2.33±1.63=3.96
1.43±1.35=2.78	1.12±1.49=2.61	2.71±1.98=4.69	2.08±1.94=4.02	1.22±1.62=2.84	1.92±1.58=3.50	1.44±1.45=2.84	1.00±1.50=2.50
1.56±1.47=3.03	2.16±1.80=3.96	2.29±2.12=4.41	0.98±1.21=2.19	1.00±1.49=2.49	0.87±1.33=2.20	1.07±1.43=2.50	1.44±1.50=2.94
0.61±0.87=1.48	0.51±1.02=1.53	0.67±1.10=1.77	0.61±1.10=1.71	0.33±0.47=0.80	0.45±1.04=1.49	0.43±0.82=1.25	0.22±0.41=0.63
0.43±0.88=1.50	0.34±0.77=1.01	2.43±1.40=3.83	2.00±1.65=3.65	1.67±1.56=3.23	1.83±1.77=3.60	1.43±1.76=3.19	0.11±0.31=0.42
2.41±1.75=4.16	1.94±1.59=3.53	3.86±1.46=5.32	1.30±1.58=2.88	1.11±1.66=2.77	0.96±1.40=2.36	0.57±0.82=1.39	1.22±1.03=2.25
1.61±1.63=3.24	1.30±1.58=2.88	2.86±1.35=4.21	0.77±1.19=1.96	1.00±1.70=2.70	0.79±1.22=2.01	0.40±1.25=1.65	0.50±1.00=1.50
1.27±1.57=2.84	0.68±1.15=1.83	3.14±1.55=4.69	0.93±1.21=2.14	1.78±1.68=3.46	0.71±0.98=1.69	0.93±1.76=2.69	0.22±0.41=0.63
0.96±1.30=2.26	0.82±1.36=2.18	3.29±1.28=4.57	1.43±1.67=3.10	1.11±1.37=2.48	1.37±1.65=3.02	1.87±2.12=3.99	0.67±0.94=1.61
1.96±1.78=3.74	1.76±1.86=3.62	2.57±1.84=4.41	1.15±1.72=2.87	0.22±0.42=0.64	0.96±1.34=2.30	0.93±1.34=2.27	2.00±1.76=3.76
0.87±1.11=0.98	0.76±0.94=1.70	1.29±1.76=2.45	0.67±1.07=1.68	1.66±0.94=2.60	1.21±1.65=2.86	1.00±1.63=2.63	1.23±1.62=2.85
0.91±0.93=1.84	0.76±1.13=1.90	3.29±0.70=3.90	1.42±1.32=2.74	1.78±1.47=3.25	1.29±1.30=2.59	1.33±1.44=2.77	0.44±0.96=1.40
1.43±1.47=3.00	1.50±1.42=2.92	3.00±1.51=4.51	1.92±1.69=3.61	2.11±1.59=3.70	1.67±1.72=3.39	1.53±1.63=3.16	0.22±0.42=0.64
1.74±1.62=3.36	1.79±1.62=3.41						0.22±0.42=0.64
		1.57±1.91=3.48	1.02±1.30=2.32	1.11±1.10=2.21	1.04±1.13=2.21	1.57±1.50=3.02	1.22±1.03=2.25
0.91±1.24=2.15	1.03±1.38=2.41	3.00±1.07=4.07	1.35±1.12=2.47	1.00±1.15=2.15	0.61±0.71=1.32	1.00±1.32=2.32	1.25±1.10=2.35
1.62±1.62=3.24	0.97±1.22=2.19						

RES/DEV-MAN/DIR N=21	PROD MAN/DIR N=10	ENG MAN TECHNOLOGY N=88	ENG MAN TECH/NATURAL SCI N=14	NAT SCIENCE N=52	IND CHEM N=42	ENG/IND CHEM/ NAT SCI/PHYS CHEM N=8	PHYS CHEM N=4
2.09±2.00=4.09	0.80±1.47=2.27	1.16±1.48=2.70	0.78±1.72=1.59	1.15±1.38=2.53	2.24±1.99=4.18	2.22±1.54=3.76	1.00±1.22=2.22
1.76±1.82=3.58	0.80±0.87=1.67	1.02-1.44=2.46	1.78-1.32=3.10	1.98=1.71=3.69	1.93-1.78=3.71	2.00-1.54=3.76	1.25±1.10=2.35
2.41±1.85=4.26	0.90±1.44=2.34	1.59±1.73=3.32	2.29±1.75=4.04	2.00±1.78=3.78	2.35±1.91=4.26	2.87±1.62=4.49	1.00±1.22=2.22
0.90±1.14=2.04	0.20±0.40=0.60	0.56±1.18=1.74	0.38±0.48=0.86	0.92±1.20=2.12	0.98±1.37=2.35	2.13±2.03=4.16	0.25±0.43=0.68
3.04±1.71=4.75	1.20±1.94=3.14	2.10±1.88=3.98	3.29±1.67=4.96	2.96±1.81=4.77	2.86±1.79=4.65	3.50±1.65=5.15	1.75±1.92=3.67
0.95±1.09=2.04	0.10±0.30=0.40	0.36±0.66=1.02	0.36±0.48=0.84	1.05±1.17=2.22	0.93±1.32=2.25	1.00±0.86=1.86	0.50±0.50=1.00
1.10±1.22=2.32	0.10±0.30=0.40	0.40±0.68=1.08	0.75±0.83=1.58	1.17±1.31=2.48	1.24±1.63=2.87	0.75±0.43=1.18	1.00±0.00=1.00
1.40±1.62=3.02	0.00±0.00=0.00	0.80±1.41=2.21	0.78±1.01=1.79	1.47±1.53=3.00	1.05±1.56=2.61	1.00±0.87=1.87	1.00±1.22=2.22
1.35±1.56=2.91	0.00±0.00=0.00	0.52±1.14=1.66	0.31±0.82=1.13	1.25±1.37=2.62	0.77±1.17=1.84	1.00±0.87=1.87	0.50±0.50=1.00
2.40±1.76=4.24	0.70±0.90=1.60	1.65±1.68=3.33	3.07±1.71=4.78	2.73±1.90=4.63	2.74±1.86=4.60	2.50±2.13=4.63	1.00±0.00=1.00
1.95±1.82=3.77	0.50±0.92=1.42	0.99±1.36=2.35	1.64±1.23=2.87	1.55±1.68=3.23	1.34±1.47=2.81	2.25±1.64=3.89	1.75±1.30=3.05
2.60±1.93=4.53	0.90±1.64=2.54	1.42±1.72=3.14	2.43±1.88=4.31	2.36±1.88=4.24	1.76±1.48=3.24	2.75±1.04=4.79	2.25±1.30=3.55
1.65±1.68=3.33	0.10±0.30=0.40	0.67±1.19=1.86	1.72±1.53=3.25	1.99±1.76=3.25	0.81±1.38=2.19	1.12±1.54=2.66	0.75±1.30=2.05
1.71±1.77=3.48	0.30±0.45=0.75	1.06±1.46=2.52	2.07±1.98=4.05	1.94±1.94=3.88	1.13±1.61=2.15	1.37±1.65=3.02	0.75±1.30=2.05
1.85±1.90=3.75	0.10±0.30=0.40	0.58±1.24=1.82	1.79±2.18=3.97	1.32±1.77=3.09	0.52±1.09=1.61	1.00±1.69=2.69	0.00±0.00=0.00
1.95±1.90=3.85	0.10±0.30=0.40	0.86±1.40=2.26	2.14±2.26=4.40	1.51±1.87=3.38	0.70±1.25=1.95	1.14±1.64=2.78	0.00±0.00=0.00
0.20±0.40=0.60	0.10±0.30=0.40	0.17±0.60=0.77	0.07±0.26=0.33	0.41±0.92=1.33	0.20±0.68=0.88	0.75±0.97=1.72	0.50±0.50=1.00
0.81±1.18=1.99	0.10±0.30=0.40	0.62±1.19=1.81	0.43±0.82=1.25	0.85±1.25=2.10	1.17±1.66=2.83	2.00±1.93=3.93	1.00±0.00=1.00
0.30±0.71=1.01	0.00±0.00=0.00	0.16±0.52=0.68	0.57±1.05=1.62	0.62±1.14=1.76	0.17±0.54=0.71	0.50±0.50=1.00	0.25±0.43=0.68
0.55±0.74=1.29	0.00±0.00=0.00	0.47±1.06=1.53	0.57±1.29=1.86	1.00±1.42=2.42	0.51±0.83=1.34	0.75±0.97=1.72	0.25±0.43=0.68
0.73±0.68=1.41	0.40±0.91=1.31	0.65±1.24=1.89	0.86±1.55=2.41	0.75±1.48=2.23	0.67±0.69=1.73	1.00±0.93=1.93	0.25±0.43=0.68
1.50±1.56=3.06	0.30±0.45=0.75	1.26±1.64=2.90	1.86±1.73=3.59	1.34±1.68=3.02	1.23±1.55=2.78	1.57±1.29=2.89	0.25±0.43=0.68
2.53±1.89=4.42	1.20±1.72=2.92	1.91±1.83=3.74	2.93±1.91=4.84	1.79±1.74=3.53	0.93±1.49=2.42	1.57±1.68=3.26	0.00±0.00=0.00
2.14±1.55=3.69	0.33±0.47=0.80	1.30±1.74=3.04	2.36±1.80=4.16	2.25±1.93=4.08	2.29±1.84=4.13	3.50±1.32=4.82	1.00±1.22=2.22
2.45±1.80=4.25	1.40±1.85=3.25	1.86±1.96=3.82	2.36±2.09=4.45	2.32±1.93=4.25	2.56±1.76=4.32	3.38±1.87=5.25	0.75±0.43=1.18
2.28±1.80=4.08	1.70±1.84=3.54	1.47±1.82=3.39	2.50±1.80=4.30	1.65±1.65=3.30	1.79±1.08=3.47	2.00±1.94=3.94	1.50±1.50=3.00
2.27±1.81=4.08	2.30±2.05=4.35	2.06±2.00=4.06	3.36±1.84=5.20	2.00±1.91=3.91	1.88±1.67=3.55	1.88±1.53=3.31	0.75±1.30=2.05
3.29±1.85=5.14	1.80±1.53=3.33	2.54±1.86=4.40	2.86±1.88=4.74	3.06±1.78=4.84	2.11±1.63=3.74	3.62±1.65=5.27	0.50±0.50=1.00
2.95±1.81=4.82	2.50±2.20=4.70	2.35±1.98=4.33	1.79±1.94=3.73	2.38±1.87=4.25	2.27±1.71=3.98	3.25±1.56=4.81	0.25±0.43=0.68
2.57±1.94=4.51	1.50±1.96=3.46	1.53±1.91=3.44	1.79±2.11=4.90	2.02±2.00=4.02	1.31±1.63=2.94	1.86±1.73=3.59	0.00±0.00=0.00
2.52±1.99=4.51	1.10±1.57=2.67	1.31±1.19=3.10	2.86±2.26=5.12	1.77±2.02=3.79	1.44±1.77=3.21	1.62±1.73=3.35	0.00-0.00=0.00
2.41±1.92=4.33	1.11±1.66=2.77	1.35±1.61=2.96	1.36±1.49=2.85	1.85±1.72=3.57	2.33±1.79=4.12	1.75±1.85=4.60	0.50±0.50=1.00
1.95±1.77=3.72	0.67±0.94=1.61	0.98±1.42=2.40	1.21±1.42=2.63	1.53±1.70=3.23	1.79±1.76=3.55	3.00±1.73=4.73	0.25±0.43=0.68
3.18±2.06=2.40	2.40±1.74=4.14	2.73±2.01=4.74	3.57±1.76=5.33	2.91±1.97=4.88	1.65±1.73=3.38	2.88±1.90=4.78	0.25±0.43=0.68
2.95±2.15=5.10	3.00±1.55=4.55	2.68±2.01=4.69	3.21±1.78=4.99	1.94±1.79=3.73	1.38±1.63=3.01	2.12±2.26=4.38	0.00±0.00=0.00
0.57±2.10=4.67	2.30±1.67=3.97	2.56±2.12=4.68	2.50±1.80=4.30	1.55±1.56=3.11	0.93±1.28=2.21	1.63±2.00=3.63	0.00±0.00=0.00
2.90±1.57=4.47	1.40±1.35=2.75	2.45±1.77=4.22	2.86±1.60=4.46	3.17±1.60=4.77	2.05±1.64=3.59	3.63±1.93=5.59	1.50±0.86=2.36
2.57±1.84=4.41	1.22±1.40=2.62	1.85±1.91=3.76	2.21±1.52=3.73	2.02±1.82=3.84	0.83±1.10=1.93	1.63±1.49=3.12	0.25±0.43=0.68
2.24±1.57=3.81	0.62±0.99=1.61	1.39±1.62=3.01	2.14±1.88=4.02	2.13±1.81=3.94	1.40±1.28=2.68	3.00±1.73=4.73	1.75±1.29=3.04
0.80±0.87=1.67	0.78±1.23=1.01	1.10±1.42=2.52	0.79±1.26=2.05	0.96±1.27=2.23	0.22±0.57=0.79	0.63±0.48=1.11	0.75±1.30=2.05
0.35±0.47=0.82	0.37±0.99=1.36	0.47±0.96=1.43	0.57±1.05=1.62	0.57±1.00=1.57	0.20±0.56=0.76	0.63±0.99=1.62	0.75±1.30=2.05
2.20±1.57=3.77	1.22±1.31=2.53	1.74±1.64=3.58	1.69±1.68=3.37	2.41±1.71=4.12	1.66±1.42=3.08	2.87±1.62=4.49	0.50±0.50=1.00
1.89±1.48=3.37	0.00±0.00=0.00	0.93±1.32=2.25	1.71±1.53=3.24	2.06±1.96=4.02	0.65±1.01=1.66	2.12±1.54=3.66	0.00±0.00=0.00
1.04±1.17=2.21	0.00±0.00=0.00	0.66±1.28=1.94	1.00±1.13=2.13	1.19±1.43=2.62	0.64±1.34=1.94	1.25±1.39=2.64	0.25±0.43=0.68
1.25±1.37=2.62	0.00±0.00=0.00	0.88±1.13=2.19	1.71±1.16=2.87	1.34±1.57=2.91	0.51±1.17=1.68	1.25±1.75=3.00	0.00±0.00=0.00
2.29±1.98=4.27	0.78±1.22=2.00	1.43±1.71=3.20	2.64±1.76=4.40	2.13±1.79=3.92	1.41±1.46=2.87	2.75±2.30=4.05	0.25±0.43=0.68
1.40±1.53=2.93	0.33±0.47=0.80	0.87±1.38=2.25	1.36±1.67=3.03	1.45±1.62=3.07	0.61±1.00=1.00	1.12±1.17=2.29	0.50±0.50=1.00
0.85±1.13=1.98	0.12±0.33=0.45	0.64±1.20=1.84	0.71±0.79=1.50	1.06±1.16=2.22	0.48±0.82=1.20	1.00±1.58=2.58	2.25±1.92=4.17
2.33±1.83=4.10	0.89±1.52=2.41	1.11±1.33=2.44	2.57±1.68=4.25	1.89±1.49=3.38	1.14±1.49=3.38	1.75±1.30=3.05	2.50±1.66=4.16
2.52±1.79=4.31	1.75±2.10=3.85	1.50±1.57=3.07	3.21±1.78=4.99	2.13±1.79=3.92	1.14±1.46=2.62	1.63±1.11=2.74	2.75±2.28=5.03
2.13±1.51=3.70	1.33±1.56=2.89	1.24±1.35=2.59	2.15±1.81=4.03	[illegible]±1.03=1.95	1.05±1.15=2.20	1.25±1.39=2.64	1.50±2.06=3.56
1.50±1.47=2.97	1.22±1.62=2.84	[illegible]	1.86±1.88=3.74	1.48±1.52=3.00	0.98±1.08=2.06	0.88±0.93=1.81	1.75±1.30=3.05

RES CHEM N=24 A	B	C	D	DEV CHEM N=34 A	B	C	D	DEV TECH N=40 A	B	C	D	TECH SERVICE N=24 A	B	C	D
45	36.4	54.5	9.1	26.5	11.1	77.8	11.1	37.5	46.7	46.7	6.6	45.8	18.2	81.8	0
37.5	22.2	66.7	11.1	35.3	8.3	91.7	0	40.0	37.5	43.7	18.7	37.5	22.2	77.8	0
20.8	50.0	50.0	0.0	29.4	14.3	85.7	0	40.0	62.5	25	12.5	45.8	9.1	90.9	0
50.0	41.6	58.4	0.0	20.6	0	100	0	25.0	50	30	20	8.3	0	100	0
37.5	44.4	44.4	11.2	23.5	0	87.5	12.5	32.5	38.5	55.8	7.7	29.2	0	85.7	14.3
54.2	61.5	30.8	7.7	23.5	25	75	0	37.5	33.4	60	16.6	29.2	92.8	42.8	14.4
41.6	90.0	10.0	0.0	41.2	57.2	35.7	7.1	55	72.7	18.2	9.1	41.7	70	20	10
22.4	28.6	57.1	14.3	23.5	12.5	87.5	0	25	60	40	0	37.5	33.3	55.5	11.1
29.2	50.0	50.0	0.0	11.8	50	50	0	30	83.3	8.3	8.4	33.3	37.5	37.5	25
16.7	25.0	75.0	0.0	32.6	9.1	72.7	18.2	35	21.4	57.1	21.5	29.2	14.3	71.4	14.3
29.3	57.3	42.7	0.0	23.5	25	62.5	12.5	44	13.5	53.5	33	37.5	43.5	43.5	12
29.2	28.6	51.1	14.3	14.7	0	80	20	37.5	20	53.3	26.7	25.0	33.3	50	16.7
39.3	37.5	50.0	12.5	26.5	11.1	55.6	35.4	37.5	6.7	66.7	24.6	37.5	44.4	65.6	0
37.5	33.3	44.4	22.3	23.5	25	50	25	30	8.3	75	13.3	29.2	28.5	61.0	14.4
27.2	14.3	85.7	0.0	23.5	0	50	50	22.5	11.1	66.7	22.2	20.8	40	60	0
37.2	11.1	77.8	11.1	26.5	0	66.7	33.3	17.5	14.3	57.2	28.6	12.5	33.3	33.3	33.3
33.3	25.0	62.5	12.5	8.8	0	33.3	66.7	12.5	0	60	40	8.3	0	100	0
33.3	25.0	75.0	0.0	17.6	16.7	66.6	16.7	30	16.7	66.6	16.7	25.0	50	37.5	12.5
25.0	0.0	100	0.0	8.8	33.3	66.7	0	15	16.7	66.7	16.7	8.3	0	100	0
29.2	0.0	100	0.0	23.5	37.5	50	12.5	22.5	11.1	77.8	11.1	33.3	50	50	0
16.7	0.0	75	25	20.8	18.6	42.8	28.6	10	0	75	25	20.8	40	60	0
33.3	0.0	75	25	11.8	25	50	25	27.5	9.1	81.8	9.1	20.8	20	80	0
16.7	0.0	50	50	11.8	50	50	0	30	33.3	33.3	33.3	20.8	20	60	20
25.0	16.7	33.3	50	20.5	0	42.8	57.2	37.5	40	26.7	33.3	12.5	0	0	100
25.0	0.0	50	50	17.6	33.3	33.3	33.3	37.5	20	60	20	16.7	25	25	50
25.0	16.7	50	33.3	20.6	14.3	71.4	14.3	25	30	60	10	16.7	25	0	75
29.2	28.6	42.8	28.6	26.5	22.2	44.4	33.4	27.5	45.4	54.6	0	20.8	20	20	60
20.8	40	60	0.0	23.5	12.5	50	37.5	20	37.5	62.5	0	25.0	33.3	50	16.6
29.2	57.1	42.9	0.0	17.6	27.3	45.4	27.3	15	0	83.3	16.7	37.5	55.5	44.5	0
29.2	16.7	83.3	0.0	23.5	12.5	62.5	25	7.5	0	100	0	29.2	28.6	57.2	4.2
25.0	33.3	50.0	16.7	14.7	0	40	60	7.5	83.3	66.7	0	29.2	28.6	57.2	19.2
33.3	12.5	62.5	25.0	26.5	11.1	88.9	0	32.5	46.1	46.1	7.8	45.8	27.3	63.7	9.1
33.3	37.5	50.0	12.5	20.6	14.3	57.3	28.4	30	25	50	25	41.7	30	60	10
29.2	14.3	57.1	28.6	20.6	28.6	57.2	74.2	27.5	27.3	63.6	9.1	20.8	40	40	20
33.3	25.0	50	25.0	29.4	10	80	10	20	50	50	0	20.8	50	50	0
37.5	33.3	33.3	33.3	23.5	50	12.5	37.5	32.5	53.8	46.2	0	29.2	42.8	42.8	14.4
12.5	0.0	100	0.0	38.2	23.1	53.8	23.1	27.5	45.4	36.4	18.2	20.8	40	60	0
41.6	40	40	20	35.3	16.6	75	8.3	32.5	46.1	46.1	7.6	41.7	30	60	10
45.8	18.2	63.6	18.2	41.2	14.3	57.2	28.6	25	10	70	20	37.5	22.2	55.6	22.2
37.5	22.2	45.4	22.2	23.5	12.5	37.5	50	52.5	19.1	66.7	14.2	45.8	18.2	72.7	9.1
37.5	0.0	80	20	8.8	0	0	100	30	16.6	75.	8.3	20.8	20	80	0
20.8	14.3	57.1	23.6	44.1	6.7	66.7	26.7	50	25	65	10	45.8	9.1	63.6	27.2
29.2	33.3	66.7	0.0	41.2	35.7	35.7	27.6	37.5	26.7	46.7	26.7	33.3	25	67.5	12.5
20.8	20	60	20	26.5	22.2	63.6	22.2	27.5	36.4	68.6	0	25.0	0	67.4	33.6
29.2	14.3	28.6	51.1	20.6	42.8	28.6	28.6	35	7.1	78.6	14.2	33.3	12.5	75	12.5
29.2	42.8	42.8	14.4	35.5	0	58.3	41.7	37.5	13.3	60	26.6	33.3	25	75	12.1
50.0	25.0	66.6	8.4	35.3	25	58.3	8.7	32.5	38.4	46.1	15.4	20.8	40	40	20
50.0	16.7	58.3	25.0	29.4	10	90	0	37.5	20	73.4	6.6	33.3	0	87.5	12.5
41.6	10.0	40.0	50.0	32.4	18.2	36.4	45.5	40	43.8	25	31.2	37.5	22.2	44.4	33.3
55.1	30	30	40	23.5	50	37.5	12.5	22.5	44.5	33.3	22.2	41.7	10	50	40
37.5	44.3	11.4	44.3	41.6	40	30	30	37.6	53.2	26.6	20.2	37.5	30	44.5	29.5
33.2	25	50	25	26.5	33.3	33.3	33.3	32.5	88.5	46.5	15.4	58.3	42.7	35.7	21.6
				26.3	55.5	11.2	[illegible]	80.0	50	33.3	16.7	42	50	30	20

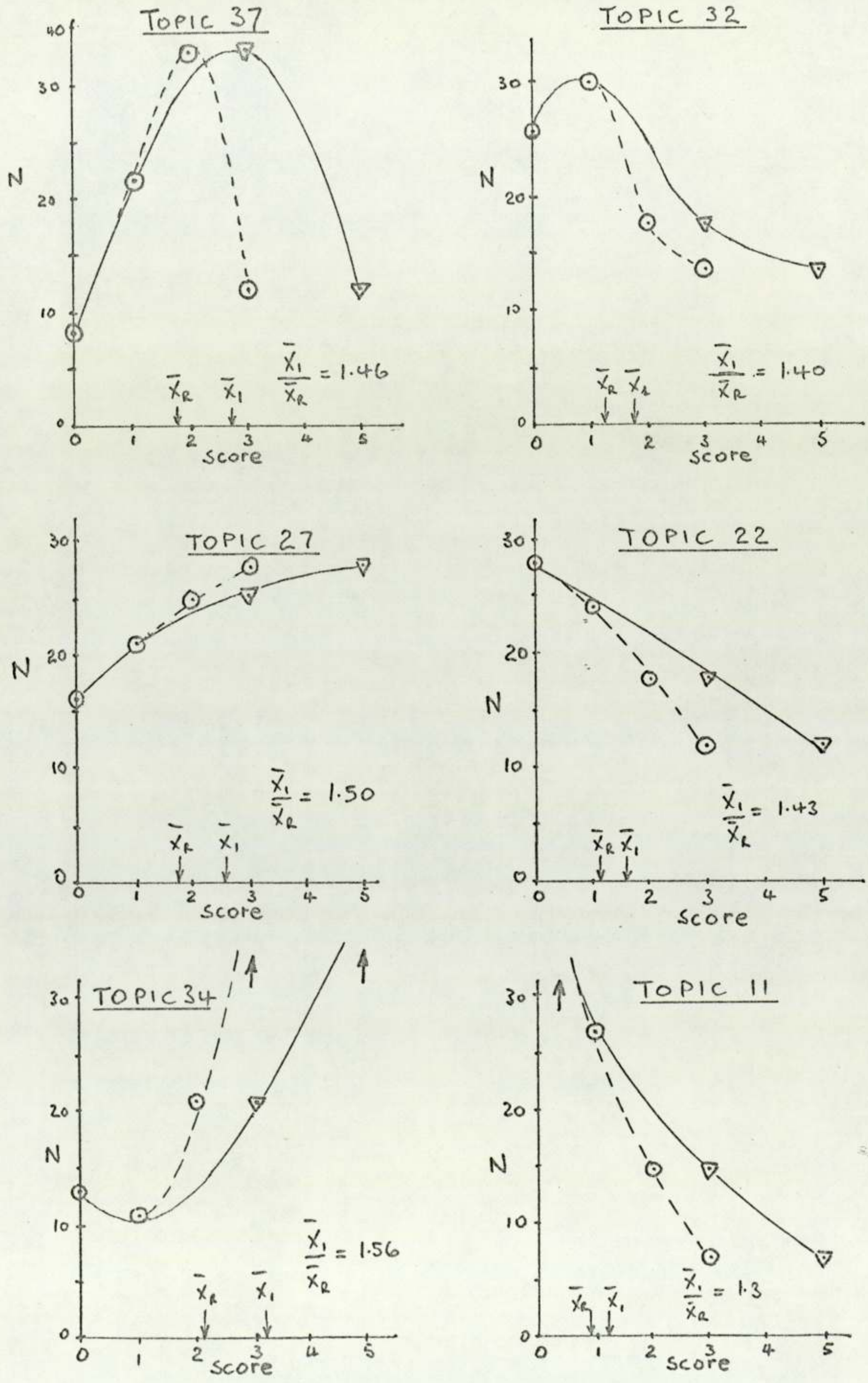
A = % respondents who ticked "some relevance" column

B= % respondents who specified "specialists are available"

C= % respondents who specified "only broad knowledge is required"

D= % respondents who specified "would like to get more involved"

Fig. II B1 Response of polymer chemists/technologists, using two different ratings (0,1,2,3) and (0,1,3,5)



Comparison of "bias" introduced by weighting factors for different types of distributions

Reference rating (R) = 0,1,2,3
Small bias rating (1) = 0,1,3,5
Large bias rating (2) = 0,2,6,10

Response of polymer chemists/technologists to the relevance of the following topics:	Type of distribution	Mean values ($\bar{X}$)			Standard deviation (σ)			Bias factor for mean values		Bias factor for mean + standard deviation	
		R	1	2	R	1	2	$\bar{X}_1/\bar{X}_R$	$\bar{X}_2/\bar{X}_R$	$(\bar{X}_1+\sigma_1)/(\bar{X}_R+\sigma_R)$	$(\bar{X}_2+\sigma_2)/(\bar{X}_R+\sigma_R)$
37. Standard test methods: usefulness, limitations, relationship to fundamental properties	Broad normal	1.79	2.61	5.23	0.84	1.67	2.96	1.46	2.95	1.63	3.15
32. General aspects of adhesives and surface coatings: structural and formulations aspects, etc.	Broad, skewed at lower end of scale	1.23	1.72	3.46	1.04	1.75	3.62	1.40	2.83	1.53	3.12
27. Compounding methods: efficiency, economics etc.	Broad, skewed at upper end of scale	1.72	2.58	5.29	1.10	1.94	3.85	1.50	3.04	1.61	3.24
11. Rheology theories	Narrow, skewed at upper end of scale	0.9	1.17	2.49	0.96	1.46	3.05	1.3	2.77	1.41	2.98
34. Processing of rubbers and/or plastics: technological aspects, interaction of processing variables etc.	Narrow, skewed at upper end of scale	2.03	3.15	6.42	1.10	1.93	3.85	1.55	3.15	1.63	3.30
22. Technological aspects of fire retardants	Broad, skewed at lower end of scale	1.10	1.57	3.40	0.81	1.42	2.83	1.43	3.08	1.57	3.26