the development of higher education

the teaching of sciences in african universities

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The Development of Higher Education in Africa
The Teaching of Sciences in African Universities

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Report of the Seminar
on the Teaching of Basic Sciences
in African Universities
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CONTENTS

INTRODUCTION

In December 1962, a group of participants from English-, French- and Arabic-speaking countries of Africa met in Morocco to discuss their common problems related to the teaching of basic sciences at university level.

The occasion was the first Unesco Seminar on Basic Science Teaching in African Universities. Since this was a pioneering effort, the programme was frankly an exploratory one. The thirty-four participants from nineteen African countries were all persons actively engaged in teaching the basic sciences in African universities and were united in their recognition of the essential role of science education for nations striving to achieve a high level of social and economic development. They also realized that knowledge of the present situation was necessary before a rational plan of action to meet the science education needs of Africa could be drawn up. The seminar provided the necessary opportunity for formal and informal communication about what is being taught and how it is being taught in the different science faculties of Africa. The task of discussing all the basic sciences and the needs of all African universities was obviously too great to be dealt with at a single conference, and for this reason discussions were limited to some selected problems. The unanimous wish was expressed therefore that seminars on each of the basic sciences should be organized in the future.

The purpose of the seminar was to examine problems related to the teaching of mathematics, physics, chemistry, biology and geology at university level, with special emphasis on African needs. Unesco commissioned one expert in each of these fields, from countries outside Africa,[1] to write working papers for the seminar that would focus the attention of the participants on the general problems of teaching the basic sciences, as seen by experts from other parts of the world, and lead to a consideration of what approaches and solutions were adaptable to African needs. These five basic documents on science teaching appear as sections II to VI, inclusive, in Part Two. Several of these experts were present in Rabat as consultants and shared in the exchange of experiences on an international scale.

Through a questionnaire prepared by Unesco and distributed to the participants further useful information was obtained concerning the science faculties in their respective countries. Some of this material was used in the preparation of the document by T. L. Green (p. 37-46).

1. Except for Professor J. Miège from Dakar University, Senegal.

The 'Essential Conclusions and Recommendations' which follow give a summary of the most important ideas which were the outcome of the discussions.

The seminar, in which representatives of the United Nations and Specialized Agencies and several observers from non-governmental organizations also participated, was opened by H. E. Youssef Ben Abbes, Minister of Education of Morocco. The closing session was presided over by H. E. Mohammed El Fasi, Rector of the Mohammed V University. Professor V. Kovda, Director of the Department of Natural Sciences represented the Director-General of Unesco.

The agenda included two parts: (a) problems related to the teaching of each particular science; (b) inter-disciplinary problems and those related to organization and administration. The seminar elected the following officers:

Chairman of the seminar and general rapporteur: Henri Arzelies (Morocco).

Chairmen and rapporteurs for particular topics:

(a) *Problems related to each particular science*

Mathematics: Alemayehu Haile (Ethiopia), chairman; Arsène Poaty (Congo—Brazzaville), rapporteur.

Physics: Edward L. Yates (Rhodesia and Nyasaland), chairman; Mohammed Aduan Zmerli (Tunisia), rapporteur.

Chemistry: Mustapha Hassan (Soudan), chairman; Yusef Salah El-Din Kotb (U.A.R.), rapporteur.

Geology: Mr. Mohammed Diouri (Morocco), chairman; Hajjoub Msougar (Morocco), rapporteur.

Biology: Mr. Hussein Said (U.A.R.) and Antoine De Bont (Congo—Léopoldville), chairmen; Mrs. Gladys Anoma (Ivory Coast) and Albert Sasson (Morocco), rapporteurs.

(b) *Inter-disciplinary problems and those related to organization and administration*

Relations between science teaching in secondary schools and university science teaching: Rachid Oussedik (Algeria) chairman; Pie N'Dayizigamiye (Burundi) and Denis Morgan (Basutoland), rapporteurs.

University-government co-operation: Henri Masson (Senegal),- chairman; Ebenezer Laing (Ghana), rapporteur.

New teaching methods: Arthur Hunter (Kenya), chairman; Jean Charette (Congo—Léopoldville), rapporteur.

Place of research and teaching; and training of university teaching staff: Ebenezer Laing (Ghana), chairman; Mrs. Gladys Anoma (Ivory Coast), rapporteur.

Co-operation between African universities: Bede Nwoye Okigbo (Nigeria), chairman; Albert Delvaux (Burundi), rapporteur.

The participants wished to express their deep gratitude to the Director-General of Unesco who was responsible for having organized the seminar which had presented an opportunity for the discussion of problems of major importance for the development of science teaching in African universities.

They also desired to express their warm appreciation both to the Government of the Kingdom of Morocco for the generous welcome and effective co-operation of the Moroccan authorities, and to the Rector and the scientific staff of the Mohammed V University whose active assistance and kind hospitality contributed so greatly to the success of the seminar and to the creation of a friendly international atmosphere.

ESSENTIAL CONCLUSIONS AND RECOMMENDATIONS OF THE RABAT SEMINAR

In order to improve science teaching in African universities the seminar makes the following recommendations and requests Unesco's aid and assistance in this field.

GENERAL RECOMMENDATIONS

1. Meetings devoted to each specific science should be periodically organized: (a) conferences at which participants would exchange the results of their experience in teaching methods, course content and laboratory work; (b) extended seminars on recent developments in each science.
2. National or regional scientific societies should be formed for the purpose of establishing and maintaining contacts with international scientific unions in the field of research and teaching.
3. The relevant authorities in African States are urged to hasten the setting up of national bodies (national scientific councils, academies of science, etc.), to organize and co-ordinate scientific research.
4. Unesco is requested to give support by all possible means to the protection of ecological stations and of animal or plant species that are dying out.
5. It is recommended that a specialized agency, Unesco for example, collect information which would make it possible to evaluate the admission standards for different universities and to learn more about the educational systems of different countries in relation to higher education.
6. It would be useful if the organization concerned could draw up a list of existing trained personnel and those who will be available in five years and in ten years time. This list is absolutely essential for drafting a plan designed to encourage studies in specialities that are lagging behind and for organizing effective assistance.

BASIC TEACHING AND AFRICANIZATION OF CURRICULA

7. The essential aim of education should be to develop the scientific attitude and the ability to use the scientific method. This is particularly important in the modern age, when the body of scientific knowledge undergoes considerable development during a single lifetime. Our students must become capable, through their studies, of adapting themselves to subsequent changes. This

orientation of education implies that the accent should be placed in all fields on principles and methods.

8. On the other hand, and this is not a contradiction, this basic training should be inspired and guided by local conditions. In writing textbooks, authors should take care to use language that will appeal to the student's imagination. In other words, scientific concepts should be reformulated, using analogies and images based on local nature and culture.
9. The Africanization of curricula seems particularly necessary in geology and biology. However, and all delegates insisted on this point, Africanization should never lead us to forget the universal nature of education. In biology, as in other subjects, a leading place must be given to unifying principles.
10. There is an urgent need to set up supply bodies responsible for providing whole, live and preserved specimens (as well as slides of zoological sections) for teaching.

RELATIONS BETWEEN THE CLASSICAL DISCIPLINES AND NEW DISCIPLINES

11. The various classical disciplines have increasingly numerous and complex relationships. The relations between physics, chemistry and biology are drawing ever closer; they have led to the creation of new sciences such as biochemistry and biophysics. These sciences should be given a leading place in our universities through the establishment of teaching and laboratory chairs.

SECONDARY AND UNIVERSITY EDUCATION

12. It is essential that universities and secondary schools collaborate closely in the preparation of modern curricula for secondary schools and in the training of science teachers.
13. Any committee responsible for modifying an education system must take into account the points of view both of the university and the secondary school. The general concensus was that both systems proceed from the same guiding principles, that there is no hiatus. Thus from the secondary level the student should gradually be trained in the scientific attitude and not merely in the acquisition of knowledge. The need for modern training is obvious in higher education and it should be recognized as equally important in secondary education. The only difference is a difference in level.
14. It is essential in the modern world that a minimum general scientific training should be given to everyone. Specialization, and particularly the division between scientists and non-scientists should not occur too soon; it was also recommended that the division should never be absolute.

TEACHING AND RESEARCH

15. A university teacher must necessarily be engaged in research work. Research is an essential condition for the continuous development of the intellectual standard of teaching staff, and for a living education adapted to the modern world.
16. Teacher training for science teachers is often neglected. It is strongly recommended that seminars and meetings between teachers be arranged to permit exchange of teaching experience and discussion of problems.

ORIENTATION AND CONDUCT OF RESEARCH

17. The orientation of research should be decided in relation to African needs, while preserving the universities' freedom in this field. In no case should basic research be abandoned or decreased. On the contrary, it should be developed in harmony with applied research.
18. It is essential to ensure the continuity of research, which is closely bound up with the stability of university staff. Ways must be found (i.e. suitable conditions) to encourage national and expatriate specialists to remain as long as possible at the university. Foreign professors are too often appointed for short periods which do not allow them to develop and continue research work.

PART ONE

REPORT OF THE SEMINAR

In Chapters I and II that follow[1] *will be found the practical, or what might be termed the 'visible', results of the discussions. This should help the technicians of education, with the support of a specific text, to influence their respective administrations by suggesting internal reforms, Unesco assistance, collaboration with other States, and so on, in particular fields.*

But there are other results, perhaps more important although they are 'invisible'. The personal contacts established in this way, many of which will be lasting, cannot fail to further understanding between nations and contribute to the harmony sought after by all men of good will. There can be no doubt that in this respect education plays the principal part. If young people the world over are educated by teachers who regard the different countries as the voices in a single choir, who lay stress on the ridiculous and totally outmoded nature, in the Space Age, of hostility between peoples, mankind will embark on a course that is beneficial to all.

1. Text prepared by Professor Henri Arzelies, in collaboration with the Unesco Secretariat, on the basis of the reports of the meeting and drawing also on the material contained in the working papers for the seminar.

I. PEDAGOGICAL PROBLEMS

GENERAL PROBLEMS

GENERAL PURPOSE OF EDUCATION; THE SCIENTIFIC ATTITUDE

The essential aim of education should be to develop the scientific attitude and the ability to use the scientific method.

Obviously, this attitude rests on the acquisition of a certain complement of knowledge; there can be no attitude or principles in the abstract. But the volume of knowledge must not, or should not, overwhelm the student. This idea was expressed by the French moralist, Montaigne, in the classic phrase: 'A well-formed mind rather than a well-packed one'.

Every student, even if he is later to undertake technical studies, must first receive a basic training. The technical applications that follow, whatever their importance, must be secondary. It is inadvisable to adopt a purely utilitarian attitude too soon; a solid basic training is bound to have a good influence on later specialization, and even on the speed of learning.

This is particularly important in the modern age, when the body of scientific knowledge undergoes considerable development during the span of a single lifetime. Our students become capable, through their studies, of adapting themselves to changes.

This orientation of education implies that in all fields the accent should be placed on principles and methods.

For instance, in chemistry, the study of monographs should not be regarded as an end in itself, but as a means of demonstrating and learning to understand the structures and mechanisms of reaction.

We must offer a truly modern education, not by merely adding new subjects each year, but by constantly rethinking education in relation to the current state of the sciences. Our students must become the scientists of tomorrow, not of yesterday or the day before.

Finally, several delegates insisted that the development of the scientific attitude must explicitly include the social training that such an attitude demands. The student should be encouraged to apply the scientific attitude both in his personal life and in his life as a citizen, which would imply a certain struggle against superstition and prejudice. However, other delegates considered that caution should be exercised in this respect: how was one to distinguish between prejudices and respectable customs? The distinction was not always self-evident and, in particular, the scientific attitude should not be confused with the attitude of European civilization towards certain problems.

THE CLASSICAL DISCIPLINES AND THE NEW DISCIPLINES

Throughout the seminar stress was laid on the need for modern education, one aspect of such modernization being concerned with the relations between the various classical disciplines. It was strongly advised—and this is particularly feasible in the African universities which are being set up or developed—that rigid and outmoded compartmentalization which in no way reflects the real world should be avoided.

The relations between physics, chemistry and biology are drawing ever closer, and have led to the creation of new sciences, such as biochemistry and biophysics. These should be given a leading place in our universities through the establishment of teaching and laboratory chairs.

THE PHILOSOPHY AND HISTORY OF SCIENCES

There was much support for the suggestion that courses or seminars on the philosophy of science (so far restricted to the study of philosophy) be introduced into the cycle of scientific studies. In physics and chemistry especially, there is great need for this kind of training. General concepts such as those of time and space have become the object of study and definition. Indeed, they present scientists with difficulties to which they are not accustomed. It is therefore highly important, in certain theories, to give these terms a precise meaning, and not the ordinary or philosophical meaning. An examination of physics theories and of the concepts of causality and determinism, etc., is also essential to modern physicists.

In geology and biology the problems of biological time, transformation, etc. would gain from an examination as a whole. Obviously these courses should be given by a professor trained in scientific research and well-versed in the philosophy of science. The first condition is essential, since the aim is not to transplant certain courses from the philosophy faculties to the science faculties, but to create a new scientific education. There is often a wide difference of attitude to such problems between philosophers and scientists.

The history of science is much less important. It is inadvisable to use the historical method of instruction for what we must teach our students is the science of today, not its history. The historical form of presentation is only very rarely the best and, in any case, it would either be serious and much too long, or it would be superficial. On the other hand, it is desirable that, in the form of observations or annexes to his course, the student should be given some idea of the historical development of the question. It is not a bad thing to show that certain results which are now common knowledge were once discussed at length (for instance, the existence of two categories of charge, positive and negative).

AFRICANIZATION OF CURRICULA

We have just emphasized the point that all good scientific education should have a general character. However, and this is not a contradiction, this basic training should be inspired and guided by local conditions.

The Africanization of curricula seems particularly necessary in geology and biology. No professor would today give the same botany course in Africa as in Europe, but a good deal of progress has still to be made. The importance of choosing the maximum number of examples from the surrounding environment must be stressed constantly; and of course the richness and diversity of African flora and fauna facilitate such a choice.

All delegates insisted nevertheless that Africanization should never lead us to forget the universal nature of education. In biology, as in other subjects, a leading place must be given to unifying principles.

The problems arising in connexion with the Africanization of curricula are dealt with in the chapters devoted to each particular science.

TEXTBOOKS[1] IN NATIONAL LANGUAGES

All African countries represented at the seminar now use French or English as the vehicle of science although strong tendencies may be observed, particularly in the Arab countries, towards developing the use of national languages and some textbooks are prepared in these languages.

In this connexion, the following technical question arose: should mathematical formulae also be 'nationalized', i.e., should the local alphabet be used in place of the Latin and Greek alphabets? Japan and the U.S.S.R., which use Latin and Greek letters for formulae, were cited as examples.

No agreement was reached on this point. It was considered that this was a purely national affair. Decisions will be tested in practice.

ACCELERATED TRAINING

In view of African needs, it is often desirable to consider the use of crash programmes in certain areas of education. But—and this was one of the main themes of the seminar—accelerated training should never be carried on to the detriment of the standard of education. Certain delegates fearing that such training might lead to a lowering of standards even expressed their opposition in principle.

However, the duration of certain studies might be limited by using new methods and eliminating many details. Standards can be maintained in spite of decreasing the volume of knowledge taught.

NEW TEACHING METHODS

Teaching machines

These gave rise to heated reactions and discussions. The idea consists in dividing the information to be transmitted into a series of progressive stages which can be taught successively and immediately checked. If the pupil's reply is correct, he proceeds to the following stage; if not, the machine allows him to discover and rectify his mistake.

This technique involves the preparation of a programme. One of the most interesting aspects is that the machine can actually be dispensed with, the programme-learning manual being sufficient.

1. *Note.* A discussion arose on the meaning of the word 'textbook'. In fact, a distinction must be drawn between the study (a general work, very full) and the textbook (essentially intended for students). There is also a type of text that might be termed 'Sources for the study of . . .'; it contains various sorts of information, for instance, bibliographies specially chosen to facilitate the preparation of a course.

Reactions to teaching machines are usually emotional. In fact, there is no question of completely replacing the teacher by a machine, thus delivering the students, bound hand and foot, to robots. But the use of these machines can free the teacher from many of the tiresome tasks of transmitting knowledge, leaving him a greater freedom for his principal role, which is to train the mind.

The advantage of the method has already been demonstrated by its use in the United States (more than a thousand machines); large-scale planning also exists in the U.S.S.R. In education, as in other fields such as state management, most of the brainwork can advantageously be carried out by a machine.

Why not study the introduction of such methods in the African countries, in relation to the desire for accelerated training? The question stands; it would be unscientific to set it aside out of a purely emotional prejudice.

The discussion on the use of teaching machines produced the following criticisms and replies.

1. The true task of education is to train inventive and creative minds but this cannot be accomplished by inflexible methods.

   Reply. Before we can become creative, we must learn a large number of facts. The limited role of the machine lies here.

2. Teaching-machines are better for teachers than for students.

   Reply. For teachers the usefulness of machines, and of this method in general, is beyond doubt. To begin with, no textbook has ever been written with the enormous advantage, for the author, of knowing at every stage the pupil's reaction to the text he is writing. Further, it is always an excellent thing for the teacher to clarify his aims in the teaching of the various disciplines.

3. The supporters of this method are not themselves in agreement on the psychological theories underlying it.

   Reply. Controversy is not necessarily a weakness: it does not always hinder progress, and is sometimes a condition for progress.

4. This method may be useful for secondary education, but definitely not for university teaching.

   Reply. It can be useful for certain limited aims of university teaching; for instance, to help a student to catch up on a subject, such as trigonometry or calculus, which is holding him back in other courses.

Television

Attention may be drawn to several uses: (a) to reach a wider public through broadcasting in the normal sense; mass education is a problem which the university should not overlook, and this problem is particularly acute in Africa; (b) in a large class, it can be used to show all students the details of an experiment set up on a table; (c) for self-criticism of a lecture or demonstration.

A closed-circuit television system would therefore often be valuable. There are grounds for hesitation over the cost of the installation and for wondering whether it might not be preferable to use the funds available for the purchase of experimental equipment.

Projectors

There are three uses: they can replace the blackboard in the presentation of complicated diagrams or diagrams which gain from being shown in great detail. Films of a few minutes duration can be used to illustrate a particular fact in an ordinary course, and special showings of films of twenty to thirty minutes duration may be given as a supplement to the course.

The great advantage of the film is the freedom it gives in relation to time, space, scale, danger, etc. The obstacles to the use of films are mainly technical: the need for a dark room and the time lost in handling the film. These difficulties can be solved, however, by using a loop film-projector which is extremely simple to handle and moderate in price. The films are silent, so that the teacher can make whatever comments he judges appropriate.

Experimental or 'take-home' kits

These kits, which the student can use to set up his own experiment, have been criticized on three grounds: they are too expensive, they are limited in application, and the experiments can be carried out by other means.

In reply to these criticisms it was stated that inexpensive kits are available both for secondary and for university education. Their great advantage is that they allow the student to take his experiment home with him, and spend as much time on it as he wishes. Restrictions must be imposed on certain chemistry experiments which might be dangerous. A further difficulty was pointed out: in certain countries living conditions for students (e.g., dormitories shared by several people) render the use of take-home kits impossible.

PROBLEMS RELATING TO EACH OF THE BASIC SCIENCES

MATHEMATICS [1]

The discussion dealt only with the teaching of mathematics to non-mathematicians. Since the latter make up 90 per cent of all students this fact must guide the direction of studies and curricula.

We are thus concerned with mathematics at the service of the other sciences, the training of mathematicians being a highly specialized subject that was not tackled.

Special courses must be provided for non-mathematicians and curricula for such courses should be drawn up in relation to needs, while preserving the rigour required of mathematics teaching. This is what Professor Tatarkiewicz, in his background paper, calls the postulate of rigour. Incidentally, this rigour should not be transformed into a quite unnecessary axiomatization. Only committees consisting of mathematicians and users can draw up acceptable curricula.

Courses for non-mathematicians, whatever the type of instruction, can be placed in two categories: (a) courses for physicists and certain chemists; (b) courses for other users (biology, medicine, geology).

The general outline in the Tatarkiewicz report provides a widely accepted basis for the study and orientation of curricula for both types of course. In particular, all the biologists stressed the need for a mathematical minimum, and protested against the out-dated conception that only people with no grasp of mathematics study the 'natural sciences'.

For the first type of course (physicists and certain chemists), it is difficult to give precise information, and the classification proposed by Mr. Tatarkiewicz is only one possibility. Moreover, a distinction must be drawn between general training designed to raise the student's standard and the choice of subjects to be dealt with;

1. See also section II (p. 47), 'The university teaching of mathematics as a basis for the experimental sciences', by K. Tatarkiewicz.

this latter aspect is less important and the choice may vary. The important point is the standard.

Who should teach these mathematics courses? Teachers who are well-acquainted with the turn of mind and the needs of those for whom they are intended. A mathematician concerned with work of axiomatization is not suitable, nor is a laboratory technician. The decision depends on local possibilities and, above all, on the nature of the course.

In mathematics courses intended for the physicist, the ideal solution would seem to be to have half the teaching given by a mathematician interested in physics and half by a theoretical physicist essentially concerned with mathematical physics. This system has been operating for several years in certain faculties to the complete satisfaction of physicist users.

For the time being the same system seems more difficult to apply to mathematics for biologists, purely because of the shortage of teachers. Here, too, it would be desirable that certain aspects of mathematics be presented by the users themselves.

PHYSICS[1]

Avoiding rigid categories

The division of physics according to the old terminology or on the lines of historical development is sometimes still useful, particularly at the beginning of studies. But it is essential to abandon it as soon as the need to do so is felt, and for that reason administrative patterns should not be restrictive.

Consequently, starting at a certain level, instruction is not necessarily given in optics or electricity, but the results of the Maxwell equations are developed; the dynamics of vibrations are studied, not acoustics or electrical engineering. This kind of economy of thought must at all costs be introduced into teaching.

Theoretical and experimental teaching

In basic training, the two aspects should be closely combined.

The experimental aspect covers two types of teaching between which a distinction should be made: (a) classroom experiments that are an integral part, or are sometimes even the basis of the course (in this case it was suggested that the lecture-room should also be a practical room, instead of having merely a bench for experiments); (b) practical work carried out for several hours at a stretch by the students (this work is distinct from the course, but should be prepared and presented in the form of lectures given by the directors of practical studies). It might occasionally be useful for the student to start on an experiment before receiving any theoretical introduction; however, reactions must be carefully examined before this Socratic method is more generally adopted.

Once the basic training has been acquired, it is at present desirable to continue specialization and direct the student either towards theoretical studies or towards experimental work; but in no case should the two be mutually exclusive.

Physics at the service of the other sciences

Two conceptions were discussed: a single course common to non-physicists, or several different courses adapted to the various sciences.

1. See also section III (p. 56), 'On the teaching of physics as one of the basic sciences at university level', by G. Holton.

Support for the first was based mainly on practical arguments: the concentration of effort would help to make up, to some extent, for the shortage of personnel.

However, this solution cannot be regarded as ideal, and its adaptation to certain universities, particularly French-speaking universities, comes up against objections of principle.

Specialization should be taken even further; for non-physicists, at least two types of course are needed, probably three: (a) chemistry requires a high-level training in physics, which calls for knowledge of the corresponding mathematical language (a chemist must be capable, for example, of applying the Schrödinger equation; therefore he needs precise knowledge of differential equations and partial derivatives; (b) biology and geology require instruction at a lower level, and with a different orientation (let us say, as an indication of the level, that the student must be able to handle the simple differential equations of physics, and apply statistics and probability theories); and (c) medical students also require instruction adapted to their needs. For the last the mathematical level may be lower than in the preceding cases, but nevertheless the use of simple integration or differentiation calculations is involved. The choice of subjects will be based on medical needs; for instance, acoustics will be studied in relation to the hearing mechanism, and so on. In any case, the strictly utilitarian conception of an applied science course (learning to use a particular piece of apparatus) was rejected. The course should include basic training, and the study of general ideas and theories as a basic culture. However, it was recommended that popularization be avoided, and therefore that the number of general questions studied be limited.

With regard to the teaching of physics to non-physicists, the conclusion was reached that all students, whatever their specialization, should be given precise knowledge in certain fields; they should also be educated to an appropriate level, which would subsequently allow them to broaden their knowledge by individual study.

CHEMISTRY [1]

Teaching in chemistry can help to solve problems of health, agriculture, industry, animal and mineral resources. This implies the need for a grounding in practical work. Obviously, this does not mean merely training in techniques; techniques must be used with intelligence and critical understanding.

The chemists particularly stressed the importance of the recommendations already given above, and that

Discussion should be encouraged among African chemistry teachers on the question of the relative emphasis to be given to principles and to factual knowledge.

The scientific attitude and the ability to use the scientific method should be developed in African students.

Students should be provided with a set of principles and a fund of functional facts. An important place should be given to physical chemistry. Molecular models and reaction mechanisms should be given special attention and the role of monographs reduced.

The student's basic skills in laboratory manipulation should be developed, both qualitatively and quantitatively.

A chemistry student must be trained in a way that prepares him for work as a chemist in his own country, giving him the general knowledge that will serve as a

1. See also section IV (p. 86), 'A dynamic approach to university chemistry teaching', by M. Brenner.

basis for local specializations. Countries should therefore adapt their curricula to their own needs.

As an example of such adaptation, we may quote from a note by Professor M. Crawford, Dean of the Faculty of Science, Makerere University College:

'The new B.Sc. degrees in chemistry of the University of East Africa will be taught at Makerere University College with: (a) physical bias, and (b) organic bias.

'Those chemists who go in for teaching geological or physico-chemical work will profit by the course with the physical bias; those who pursue medical, agricultural, nutritional or toxicological chemical courses will benefit by the additional organic chemistry in the organic-biased course.

'Once the student has eventually opted for chemistry, he must then receive not necessarily the ideal training as seen from an international point of view but a training which will equip him for the work required of chemists in his country, in this case, East Africa.'

In his subsequent career, the chemist will have to make accurate analyses of agricultural, botanical, mineral, or forensic samples.

Chemistry courses for those who are not intending to specialize in this subject should also include the basic principles of chemistry; concepts relating to the student's future specialization are an application of these principles.

How should chemistry be taught?

Chemistry is an experimental science. The African student must find out for himself that he can act in a scientific way by combining ideas with facts. This brings him power to change his environment. What better place for him to make this discovery than in a chemistry laboratory? Here he must first be allowed to make observations and record them accurately. Then he should think about them—what do they mean?—in what way can they be organized?—what new questions do they suggest?

Ideas are read in texts and discussed in the classroom. The student gains insight into how these ideas may explain the facts he observed in the laboratory. This process of encountering facts and ideas alternates with a rising tempo, and before long the student gains a genuine feeling for chemistry as a dynamic process, in which facts are unearthed in the laboratory and ideas are applied to those facts to arrange them into orderly patterns which give them meaning. This is a proper way to relate theoretical and practical study, and by doing it in this way, the student himself develops as a scientific worker and not as a technician or purely as a rote-memorizer.

GEOLOGY [1]

The presence of abundant and as yet under-exploited resources in the African substratum makes it essential to accord geology teaching the importance it deserves in order to ensure rapid training in all African countries of a large number of qualified specialists in the following branches:

1. University-level geologists, with extensive scientific knowledge, capable of undertaking scientific work in the field of geology.
2. Prospector-geologists, capable of carrying out geological surveys and prospecting ore deposits, trained at specialized technical schools.
3. Mining engineers capable of practical work in mines and on mining sites, i.e. engineers who can organize the exploitation of ore deposits. These engineers will receive training in technical schools or advanced institutes.

1. See also section V (p. 93), 'Geology teaching at university level', by G. P. Gorshkov.

4. Geologist-engineers capable of carrying out preliminary studies of sites on which buildings, roads, railways, bridges, dams, etc. will be constructed.
5. Middle-grade specialists (mining technicians, etc.) trained in technical schools at a level half-way between secondary and higher education.

It should be stressed that in geology teaching special attention must be paid to the study of geophysical prospecting methods, the geology of oil and hydrogeology.

While on this subject, it should not be forgotten that in the training of specialists practical instruction should count as much as, if not more than, theoretical education. Excursions and expeditions should therefore be organized as frequently as possible in order to give students experience of work in the field.

To ensure the rapid training of African specialists, Unesco's assistance is requested:

1. To establish in Africa universities and specialized technical schools in the various branches of geology.
2. To develop establishments already existing in Africa, whose libraries and supplies of teaching and research equipment need to be supplemented.
3. To send professors and specialists from other countries to Africa.
4. To send African students to the best-equipped foreign universities and technical schools.
5. To prepare African geology textbooks, a first-priority task which requires the collaboration of all specialists. Some texts of this kind, precise and detailed, already exist in South Africa.
6. To set up an African geological association.
7. To establish an institute through which exchanges of publications, geological charts and geological collections could be made between African geologists and geologists in other parts of the world.
8. To publish and disseminate the work entitled *Survey of the Natural Resources of the African Continent*, prepared by the Natural Sciences Department of Unesco.

BIOLOGY [1]

Delegates thought it advisable not to separate animal from plant biology. The same general problems arise in both cases.

All participants insisted on the need to adapt curricula to the African environment, from which the maximum number of examples should be chosen.

The following difficulties were pointed out: (a) current textbooks describe European species; (b) it is not always easy to obtain a sufficient number of animals when they are needed; (c) in hot humid climates, it is essential, but difficult, to effect the preservation of specimens rapidly; (d) certain replacement species have not been studied in detail, with the result that their anatomy has not yet been fully described; this is a task that local universities should undertake as soon as possible.

Naturally, some time will be required before suitable textbooks taking local animals as examples can be published. Moreover, in a vast country such as Nigeria, the difference in conditions of the various regions of the country may mean that the species chosen as models for study are not the same in all areas. For example, the savannah region of northern Nigeria is quite different, ecologically, from the forest zones located nearer the coast.

It is urgent that supply bodies be set up as soon as possible for the purpose of providing the animals needed in education. These supply bodies should maintain close relations with universities possessing the qualified staff needed to direct them,

1. See also section VI (p. 97), 'Teaching of biology at university level in Africa', by J. Miège.

and also with local fishery laboratories (which are already supplying unofficial assistance), which can provide marine specimens.

They must also meet the rapidly increasing needs of schools. They should be in a position not only to supply whole, live and preserved specimens, but also slides of zoological sections; in fact, most schools do not possess the necessary equipment to make slides and preparations.

Air-conditioned rooms will, of course, be necessary for the preparation and preservation of most materials and slides.

At least at the beginning, it is difficult to imagine that this body would be financially independent, even if universities and schools, as is only natural, paid for what they received. Initially, therefore, a governmental subsidy would be needed.

Once this body was operating normally, it should be able to satisfy customers outside West Africa. Most of the zoology departments of universities in Europe, America and other temperate zones need tropical animals for advanced studies, particularly insects and reptiles. Anyone who has tried to obtain the necessary animals for advanced zoological studies in Europe knows how difficult it is; nevertheless, they are abundant in tropical countries. The sale of such specimens in large quantities to countries all over the world might therefore be envisaged. Thanks to aircraft, the transport of these animals is very easy, and it is even possible to bring live specimens to Europe or America in a few hours. The countries of West Africa could take advantage of this situation, since it would bring them foreign currency. If contacts were established with a large undertaking, the volume of business might be considerable.

All biologists insisted that biology laboratories should have botanical and zoological gardens, and that sufficient resources be made available for their upkeep.

Excursions were considered to be a particularly effective means of education, capable of giving rise to a sense of vocation. The wish was expressed that they should be arranged more often.

Delegates suggested the establishment of herbaria, including both local plants and plants from other countries, and of experimental gardens and urged the protection of ecological stations and of animal or plant species that are dying out.

Participants expressed the wish that Unesco should further the translation of basic works and undertake a survey of periodicals concerning Africa.

II. PROBLEMS OF ORGANIZATION AND ADMINISTRATION

COLLABORATION BETWEEN UNIVERSITY AND GOVERNMENT

Liaison

The scientific future of a country, and thus its whole future, depends on the relations between the university and the government.

Universities have widely varying status with regard to their degree of independence (full independence, financial independence, etc.). But, regardless of this status, it is essential that relations be established in a climate of co-operation and collaboration, and that such collaboration be close and effective.

A liaison body is essential, whatever its form and title (Higher Education Council, University Senate, etc.). This question was discussed in detail at Tananarive[1] and reference should be made to the documents of that meeting.

Research and teaching

Participants unanimously accepted the principle that a university teacher is also, necessarily, a specialist engaged on research work. Research is one of the two activities of a science faculty; moreover, it is one of the conditions, perhaps the main condition, for teaching that is alive and adapted to the modern world. The traditions of old-established universities, which have a long history of teaching and research, present a good balance in this respect, in spite of the diversity of systems. They show that the teaching services imposed by administrations leave plenty of time for research.

The solution to the shortage of senior teaching personnel in Africa must not be sought in the elimination, even temporary, of research activities, for this would lead to intellectual strangulation.

However, it would appear desirable not to make research activities in any way exclusive. The educational training and improvement of higher education teachers are very often neglected. While there can be no question of a training school, it

1. 'Conclusions and Recommendations' in: *The Development of Higher Education in Africa* (Report of the Conference on the Development of Higher Education in Africa, Tananarive, 3 to 12 September 1962), Paris, Unesco, 1963.

would be desirable to organize seminars and meetings between different universities at which teaching problems could be discussed and studied.

Orientation and conduct of research

The orientation of certain research activities should be considered and developed in relation to African needs. For this purpose, governments draw the attention of the university to the economic situation and needs of the country; they may even point to the urgent need for certain specific work. In fact, there is a tremendous demand for applied research in Africa. Nevertheless, at the risk of prejudicing the future, the meeting expressed a strong wish that the universities should maintain their freedom, particularly with regard to the orientation of research. The initiation and development of basic research should not be regarded as a luxury but as a vital element in any university worthy of that name.

African universities cannot restrict themselves to purely utilitarian activities, without becoming intellectually second-class institutions. They must remain on the world scene, or enter into it, making their contribution on the same footing to the work of all countries.

Attention was drawn to the fact that very often it is from fundamental research that the most fruitful applications arise. An examination of works published by African universities shows, however, that applied research is being carried on everywhere and often constitutes the sole activity.

While supporting the development of this applied research to its full extent, delegates were unanimous in desiring an increase in the African scientific output of basic research.

Particularly in new African States, the sound functioning of research teams raises the problem of continuity, which has become one of the most important practical problems. A unanimous wish was expressed that the foreign teachers and research workers whom Africa needs should not all pass like meteors and be replaced. African universities would like their foreign staff not merely to touch down on African territory between plane stops. The desired stability can only be obtained through the maintenance or the creation of a climate of suitable conditions. This depends both on the African country and the country of origin.

Contacts between industry and university through the government

In the following text, industry means both industry and agriculture. The university trains specialists for the country concerned. The country, in other words its industry, must in turn offer at the right time the outlets that are needed, otherwise students will go abroad.

It is therefore essential to establish contacts. Where they do not yet exist, bodies should be created under the aegis of the government, in which both industry and the universities are represented. If industrialists advise on studies and the creation of establishments (such as engineering schools), local outlets will be easier to find.

Budgeting

The need for budgets adapted to modern needs was stressed. It is an advantage to distinguish between operating budgets and special equipment budgets.

Even for independent universities, the State must intervene in financing, otherwise scientific education will lag behind modern development. The major part of budgets is allocated to requirements for personnel and equipment.

Nevertheless, an important aspect consists in the budgetary section devoted to publications. Because of the considerable development of research throughout the world, reviews can no longer absorb articles by all research workers. All scientific units now dispose of personal information media, varying from internal preliminary reports (though issued to experts who request them) to reviews and published works. It is absolutely indispensable to have sufficient publishing facilities, otherwise already obsolete results will be published late, thus falling outside the world context.

Another important feature is the appropriation for participation in meetings. Direct discussions between experts have become essential. Failure to participate means cutting oneself off from international collaboration, which can result in continuing, under difficulties, with a useless task. Obviously, participation in international scientific meetings should be offered to the most highly qualified specialists at each country's disposal.

Recruitment of teachers

The recruitment of expatriate teachers is important in the young African States, and is a government responsibility. The following suggestions were made for the improvement of the process of recruitment. A preliminary stage of direct contacts between universities would facilitate the selection of suitable personnel. The government would then intervene at the request of the university to make the appointment effective. This process would be more rapid and effective than advance announcements by governments to other governments of vacant chairs.

The government must create suitable conditions: both a moral climate and material conditions which will allow for top-level recruitment. We may here quote the Tananarive recommendations: [1]

'... it is recognized that it would be impossible to offer sufficient incentives to expatriates without topping their salaries. In order to meet these conditions, there is general agreement that expatriates should receive special emoluments payable preferably in their home countries by the government or agency that has recruited them, or by the employing African institution of higher education. In addition, it is important that adequate housing for the expatriate staff member and his family, as well as arrangements for the education of his children, be provided. It is also important to grant travel allowances for the expatriate staff to maintain connexions with academic life in their own countries.'

We would also like to repeat the Tananarive recommendation that there should be no distinction, given equal qualifications, between foreign and local teachers:

'... there is general agreement that equality in basic salary between expatriate and African staff is essential for the well-being of the university and the maintenance of a favourable academic atmosphere'. This, of course, in no way prejudges the question of special removal and expatriation allowances.

It is up to governments to review the general living standards of teachers in order to permit the return of the élite to teaching. Salaries for higher education teachers should be comparable with those offered by industry for equivalent degrees and abilities. However, salaries are only one aspect of the problem. The prestige of teaching should be raised by all available means. This is absolutely essential for the future of the country.

1. 'Conclusions and Recommendations', *op. cit.*

Training for university-level teaching personnel

Obviously there can be no question of a school for senior education teachers. This does not mean, however, that no teacher training is necessary. Unfortunately, only too frequently a doctor of science may prove to be an excellent research worker but a mediocre teacher. It would be desirable for teachers to volunteer for teacher training courses, and that contacts be organized between different systems of education. The example of informal discussions between participants in this seminar provides an eloquent illustration of the value of such contacts.

Furthermore, promotion should take account not only of research work but of teaching abilities and services rendered. It is out of the question to set up an inspection system, but indirect means are available to promotion committees. Too many of these committees scornfully reject any reference to teaching ability.

RELATIONS BETWEEN SECONDARY AND UNIVERSITY EDUCATION

Where difficulties arise, each places the blame on the other. Both are, in fact, right; if secondary education trains students for the university, it is the university, at least in part, which trains secondary teachers.

There can be no question of changing only one system, but each in relation to the other. The point of view of 'the other' must never be lost sight of. We should like to see detailed discussions within bodies where both systems are represented.

The guiding spirit of secondary education and higher education must proceed from the same basic principles; there should be no hiatus between the two.

The general conclusions that emerged from discussions were as follows: science teaching should develop the scientific attitude, starting at secondary level.

The information taught must be modernized at all levels. The curricula of secondary school science and higher education science should not be determined by historical considerations; it is inadmissible that the science of the last thirty years should be reserved to higher education. The only difference between the two systems is a difference in level. But this statement requires fuller explanation. Certain ideas or principles, for example the uncertainty principle, can be introduced before the students have reached the necessary mathematical level for a final enunciation. In fact, the work of the subconscious in the understanding of an idea is most important, but it requires time and the subconscious must be given material for thought at an early stage.

The division into physics, chemistry, etc. is not always desirable. The wish was expressed that certain topics should be taught without taking these divisions into account. For instance, the concept of energy, its conservation and modes of transfer could very usefully be studied both in physics, chemistry and biology. This has, of course, certain implications for the work of teachers.

Agreement was reached on the need, in the modern world, for a minimum of scientific training for everyone. The division into science and letters should not, therefore, take place too early and should never be absolute. Lawyers, politicians and diplomats need a certain scientific knowledge or they may commit grave errors of judgement.

The importance of the practical aspect, laboratory work, should never be overlooked. Secondary schools should be given modern equipment and not tools for odd jobs.

Delegates were informed that important surveys and experiments on the reform of secondary education were under way in various countries. Abundant material is available that might serve for adaptation to African countries.

University entrance conditions

It is impossible to lay down the details of requirements because of the diversity of educational systems. Of course, this is regrettable in so far as the comparison of degrees is concerned: passage from secondary school to university takes place in what might be called a frontier area covering several years. In other words, two or three years of study, comparable from the point of view of curricula, are attached either to secondary school or to the university depending on the system.

The majority of delegates recognized that a minimum of scientific knowledge should be required for admission to a university but, at the same time, they insisted that all rigidity should be avoided. In view of needs, admission to university should be available to a very wide range of students. It is not entrance that counts, but the ability to continue study and the end product. However, there was agreement on the need for some control which might take several forms: regular students might be admitted provided they held the secondary school leaving certificate; a faculty entrance examination for persons not holding this diploma but still young (abilities and knowledge should be checked); for older persons, only ability should be checked.

Attention was drawn to new examination methods in the form of tests, but opinions varied widely on the importance that should be attached to such methods. The pertinent comment was made that such tests should be drawn up in relation to the population undergoing examination, and after a special psychological study. Tests prepared in Europe are not necessarily applicable in Africa and, in this context, indeed, Africa itself cannot be taken as a single entity.

It frequently occurs in African countries that the ability to take instruction in a language other than the national language is required. The greatest possible effort should be made, however, to avoid eliminating pupils who are scientifically gifted solely for linguistic reasons. Great discretion should be exercised since adaptation to a new environment will come through habit. Provision might possibly be made for practical courses in the language of instruction used at the university.

Training of secondary school teachers

The education of the secondary school science teacher within the general teaching programme of the university, and in science faculties in particular, demands a reconsideration of the present curricula which are devised along traditional lines, not so much outmoded as ill-adapted to the needs of the modern scientific age. Students in our universities desiring to become science teachers need to have their training so orientated that a full appreciation of the impact of science and technology on social change (through ways of thought, ways of living, etc.) is consciously included in the vocational courses. The ability to communicate ideas and stimulate the right attitude of mind in secondary school science classes demands a similar approach within the training course. The participants recommended that four years of academic studies be set as a minimum requirement for the training of science teachers in secondary schools. In considering the various African institutions where science training is being given or may effectively be given, the various types of teacher training colleges, pedagogical institutes and university faculties of education which may all contribute towards the training of science teachers, should be taken into account. In any case, a complete reappraisal of the present science teaching curriculum, methods of training and the introduction of schemes for continued training of science teachers was recommended. These latter would include refresher courses on various branches of science and even the secondment of teachers, already in service, in order that they might be freed from the classroom for short periods so that further study (in relation to their particular interests) might be undertaken at the local university.

Competition from industry and the lack of attraction of the teaching profession for students are a cause of grave concern to all countries. Two remedies were suggested unanimously: (a) upgrading the teaching profession, not only by achieving a greater equality of salaries with industry, but also by according teachers the social and moral prestige they enjoyed formerly; (b) teachers at the secondary and higher levels should try to observe their students and pick out those who are gifted for teaching, guiding them in that direction. Particularly at the higher level, they should avoid making unfavourable comparisons between teaching and research.

Science curricula in secondary schools

It is unfortunate that there is a general lack of a 'functional-operational relationship' between the university and the secondary school; this tends to inhibit any attempt at modifying methods of science teaching in the secondary school, in relation to (a) general education and (b) university studies. In order, therefore, to make such recommendations as are offered here in any way effective, a plea was made for much more co-operation between school and university teachers. Based on this co-operation, which may be brought about by personal contacts, the setting up of official investigatory bodies, teachers' associations and the like, the seminar would recommend action as follows: (a) a joint survey study by both the university and the secondary school concerning the aims and objectives of science education; (b) special studies concerned with curriculum development in secondary schools; (c) experiment and action research designed to improve science teaching methods in secondary schools; (d) a critical reappraisal of university science curricula; (e) the improvement of science teaching methods within the university; (f) the development of teaching aids and their introduction into university science faculties; (g) critical reviews of methods of examination and evaluation of students taking science subjects in both the secondary schools and the university; (h) the introduction of joint studies (between schools and universities) of predictive devices and examinations; (i) the rapid expansion of re-training and refresher courses for science teachers at all levels; (j) the introduction of long-term evaluatory studies on science and general education.

While it is appreciated that the recommendations outlined above are complex and of a long-term nature, the urgency of the problem must be stressed and such projects as could be carried into effect now should be pursued.

COLLABORATION BETWEEN THE AFRICAN COUNTRIES

Exchange of students between universities

These exchanges would be valuable, but pose problems of language, and of the equivalence of diplomas, particularly during the initial years of university courses.

The participants considered that the language problem was not a major obstacle and could be overcome in particular by the use of crash courses.

It would be desirable for African universities to offer a few fellowships each year to students from other regions, African or otherwise.

Exchange of professors and specialists

These exchanges need not necessarily be reciprocal—though this is desirable—in view of the shortage of personnel. They could be limited to very short periods, during which the specialist or professor would give a series of lectures.

Exchange of scientific information

Unesco could provide assistance in the dissemination of documents and bibliographies. Each university could prepare and distribute abstracts of its own publications, together with a list of research workers, their research fields and, where necessary, an inventory of their laboratory equipment.

It would be desirable to set up a scientific society for the whole of Africa, composed of several sections covering the various disciplines.

Some delegates considered that this proposal might be submitted to the university rectors who would shortly be meeting in Khartoum.

Equivalence of diplomas

Unesco should help to set up a study group to consider this problem.

It would be regrettable for universities to increase in number without any effective control of their educational standards or any guarantee of the equivalence of diplomas.

Full use of university teaching staff and laboratory equipment

The possible uses of university teaching staff in research and teaching have already been examined above.

The following activities may be considered: (a) supervision of students' work, (b) extramural activities, (c) the improvement of education in general, and (d) expert advice to governments and large organizations.

It is obvious that in order to carry out all these tasks, teaching staff will have to be considerably increased.

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PART TWO

BASIC DOCUMENTS

I. SOME IMPORTANT ASPECTS OF SCIENCE TEACHING AT AFRICAN UNIVERSITIES[1]

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Reference was made at the beginning of the publication to two kinds of results, the 'visible' and the 'invisible'. Further bases of division also exist, such as that between the objective and the subjective, and the writers of this document have therefore sought to provide certain other data, and to interpret them in the present section. While these data and their significance may be familiar to the delegates to the seminar, in view of the fact that university science teaching is in full development in Africa, it is important that the situation be known to others elsewhere, from whom help must come.

The data presented below derive from twenty answers to questionnaires. Of those returned not all were complete. In preparing the following statements use has been made of all material available in relation to each point.

BASIC DATA

Scientific associations, societies, etc.

Reference was made to the existence of twenty-five scientific associations of various kinds in eight Unesco Member States from whom replies were received. One Member State recorded the absence of any such association. As may be expected such associations were best developed in States with the longest histories. Many of the associations are linked to parent bodies, indeed, several of these are branches of the British Royal Institutes.

Realizing the value of such associations, particularly in facilitating various kinds of exchange, all Member States appear to be seeking to develop them.

Scientific journals

The need for scientific journals requires no emphasis in view of the importance of the exchange of information. Again, journals are found most often in the institutions of States with the longest history of development and they are most

1. This document has been prepared in the light of discussion during the seminar, and of information provided by participants on the situation of university science teaching in their respective countries.

often lacking in the youngest institutions. Lack of such journals was recorded in four Member States. The existence of local branches of the larger scientific associations helped to meet the situations as it provides some avenue of publication, which is important both to the exchange of information and to the morale of young workers.

Scientific supplies

Science cannot be taught without the necessary apparatus and supplies and, while something can be done to build the former and collect the latter, no laboratory can be independent of commercially produced materials. It will be seen from the list on page 40 that shortages of apparatus and supplies were rated, respectively, seventh and eighth, and lack of special services (which would include maintenance and repair of advanced apparatus) was rated third in the given list of nine difficulties.

Three Member States appear to be entirely without a scientific supply agency representative and are thus forced to depend upon ordering direct from overseas main suppliers or main agencies. Others have local representatives and in some there is even local production (e.g. of the commonly used gases). While the lack of local agents and the potential inconveniences resulting therefrom can be mitigated by careful ordering procedures these may be rendered less effective by delivery delays. This point was mentioned only once by respondents, and then in connexion with that Member State which appeared to be best supplied with local agents.

Exchange of supplies, materials, specimens

At previous Unesco meetings of a similar character,[1] the suggestion arose that certain exchanges, especially of specimens, natural products, etc., of severely localized origin might be arranged. The answers provided to questions about this point indicate: (a) existence of a rich variety of materials; (b) existence of some severely localized and specialized materials; (c) a great willingness to engage in exchange; (d) the need to take a realistic view in order to ensure that the mechanism of exchange, operated between the universities, would be as efficient as and less costly than the use of commercial channels; (e) the desirability of extensive exchange of information as a preliminary to the exchange of materials; (f) the desirability of over-all planning of any such activity so that, through some degree of specialization, overlapping would be avoided and costs reduced; (g) while the need for supply agencies, especially in regard to the supply of natural products, biological specimens and the like, was recognized, there were differences of opinion as to whether or not universities themselves, or government departments, could effectively or economically sponsor them. The general position appeared to be that those who worked in the same fields of study might be able to effect certain exchanges, especially between institutions which were fairly close geographically, but operating in different climatic, ecological or biological conditions. It was also felt that the problem was more complex than it appeared to be on the surface. Nevertheless there was a general expression of readiness to engage in exchanges, where opinion was expressed, rather than any sign of inability or unwillingness to do so.

1. First Regional Science Seminar on Physics and Chemistry Training in Universities and Science Teaching at Upper Secondary School level. New Delhi, India. December 1960. *Report*, edited by T. L. Green, published by Unesco South Asia Science Co-operation Office, New Delhi.
   Regional Meeting on the Teaching of Basic Science in Universities of South and South-East Asia, Manilla, Philippines, 1961. Report, edited by T. L. Green. To be published by the Unesco National Commission for the Philippines.

Reports and studies

This section related not to the normal academic studies, to be expected in universities, but to the social and economic significance of science and its role in development. Material of this kind has an obvious significance for the strategy of developmental planning. The information obtained relating to the various points indicates that:

University science teaching, whether in general terms of planning or specific terms of performance, appears to have received very little critical thought. It has been the subject of study and report only in the older-established institutions. It may be taken that this emphasizes the value of the seminar under discussion which, by bringing together members of the newest and the oldest African universities, allowed the former to benefit from the experience of the latter.

School science, on the other hand, appears to have been given more attention, as a number of delegates referred to attempts which had been made, or which were in progress, to develop a new science syllabus. Reference has been made earlier in the report to discussions of the existence of problems in the relationship between school and university science teaching. The solution of these problems, though dependent upon many factors, is partly dependent upon greater co-operation between school and university in determining the purpose, nature and procedures of science education at high school and in the early university years. While this proposition was accepted by the seminar it is clear that much yet remains to be done to bring about such co-operation.

The economic significance of science has been clearly appreciated and the whole seminar, in every way, was a tribute to this appreciation. Despite this there are, it seems, few specific studies and only a single manpower survey was reported. It would seem that here an urgent need is disclosed; if science is to make the most effective contribution to development, such surveys which are basic to planning are essential.

National science councils

These, while of varying form, appear to be fairly well established, especially in those Member States with the longer histories. Six major organizations of this type were recorded, with others in process of formation.

Co-ordinating committees

University and government. As National Science Councils are, in effect, co-ordinating committees between university and government, the returns naturally included the six major organizations referred to above. In addition reference was made to other devices for co-ordination, the most common being the presence of government representatives on College Councils.

University and industry. The general state of non-industrialization in Africa has obviously conditioned the situation here. Thus there are few co-ordinating links between the university world and the industrial world. However contacts are being developed between the College Appointments Boards and industry.

University and secondary schools. These, which are so mutually interdependent, should work in close collaboration. However, formal devices for collaboration are little developed, although such devices as examination boards bring the two types of institution into contact.

ANALYSIS OF DIFFICULTIES

Any discussion of the problems of teaching science in the universities inevitably touches upon the difficulties encountered. A list of the nine difficulties which appeared to be most marked among those mentioned was circulated with an invitation to indicate relative severity on a rating scale—and to add others which had not been included. By using weighted scores from the completed questionnaires the following results were obtained showing the difficulties in order of rank.

1. Insufficient staff to teach science.
2. Lack of supporting technicians.
3. Lack of special services.
4. Too heavy a teaching load.
5. Limited budget.
6. Shortage of textbooks.
7. Shortage of apparatus.
8. Shortage of supplies.
9. Inadequate library.

In addition to the above a number of other difficulties were mentioned, for the most part extensions or derivatives of the items listed and none was mentioned by more than a single delegate. They are given below, as they are of some interest in helping to interpret the earlier list: inadequate commercial agencies; delays in the delivery of orders; inadequate facilities for expedition work; inadequate clerical assistance; insufficient number of research students; lack of senior staff; difficulty of supervising research; insufficient number of science students in early stages; very rapid change-over of staff; inadequate science teaching amenities in schools; lack of school science teachers.

It will be seen that many of these items are closely interconnected so that, in seeking improvement, an attack on a group of problems may be more effective than a piecemeal attack. The chief problem lies not in the material, but in the human field; it is the shortage of trained staff which will be most difficult to overcome.

EVALUATION OF SCHOOL SCIENCE TEACHING

Reference has been made earlier to the fact that while science teaching in the schools is the foundation for university science teaching there has been too little recognition of the interdependence of the two stages of science education. Improvement in either is definitely contingent on improvements in the other. Having attempted to diagnose some of the difficulties experienced at the university level it seemed only appropriate for the delegates, who were university teachers, to give their evaluation of school science. Using a simple rating-scale technique, the following results were obtained, in order of rank:

1. Insufficient general reading by students entering the university.
2. Insufficient practical experience.
3. Tendency to remember rather than understand.
4. Knowledge confined to the syllabus content.
5. Limited practical skills.

6. Limited critical ability.
7. Knowledge mainly theoretical.
8. Insufficient basic mathematics.
9. Inability to improvise.
10. Inadequate command of terminology.

Again there is a list of further comments which should prove of interest to all who are in a position to take practical steps in regard to the improvement of school science teaching. The points, each mentioned only once, are: rigidity of thought processes; lack of imagination and insight; lack of interest in the subject, only concerned about examination; inability to apply knowledge in new situations; no understanding of accepted ideas of causality; inadequate preparation for university work; low level of mechanical and constructional skills; insufficient command of French or English.

Criticisms of this kind are by no means confined to the African situation. They have, for example, been recorded in two earlier Unesco Conference Reports.[1] They are of particular importance because they suggest that the improvement of science teaching at the school level requires attention not only to the content of the curriculum, but also to the methods by which it is taught.

QUALITIES OF THE GOOD UNIVERSITY TEACHER

Despite the fact that there is so much talk about the 'good' university teacher, the qualities by which he is characterized have not been defined, still less agreed upon. This is not through any lack of attempts to reach a definition; the simple reason for their failure is that in relation to complex phenomena, criteria which are at once uniform and distinct are rarely found, especially where a subjective element is present. Indeed the subjective aspects of the situation were such as to lead several delegates to refrain from answering—not through any unwillingness to be co-operative, but because they felt that the situation did not permit a sufficiently objective answer.

There have been attempts made to define the qualities of the good university teacher, the criteria of good teaching and so on. These attempts have ranged from elaborate procedures[2] through the relatively simple[3] to the very simple—as here. In all cases critics have, in the past, felt that the whole is greater than the sum of the parts—and thus the essence of the 'goodness' of the teacher is lost in the face of attempts to characterize it in detail. However, as others have recorded,[4] though the direct outcomes of such attempts at analysis are usually very slender, whether the techniques adopted were complex or simple, refined or crude, the most valuable outcome has been the experience of participation, of having to attempt to diagnose and order qualities of an intangible kind.

It will be noted that the few remarks which follow were made by university teachers, and not students. It may be that sharp divisions of opinion exist between the two groups!

1. First Regional Science Seminar . . . op. cit., and Regional Meeting on the Teaching . . . op. cit.
2. J. W. Riley *et al. The Student Looks at his Teacher*. New Brunswick, N.J., Rutgers University Press, 1949.
3. B. B. Cronkhite, *A Handbook for College Teachers*. Cambridge, Mass., Harvard University Press, 1951.
4. First Regional Science Seminar . . . op. cit., and Regional Meeting on the Teaching . . . op. cit.

The respondents named thirty criteria. Some were mentioned but once, others more often, those most frequently mentioned being 'knowledge of subject matter' (nine times) and 'clarity of thought and exposition' (eight times). As the respondents had ranked their criteria in order of importance this ranking and the frequency of occurrence could be used as the basis of a scoring system. The various criteria were divided into categories with the results shown below:

TABLE 1. Qualities of the good university teacher[1]

Category	Examples	Weighted score	Rank
Intellectual qualities	Knowledge of subject Originality of thought Critical thought Interest in subject Control of methods	125	1
Attitudes to students and teaching	Interest in people Sympathy for students Desire to teach others	38	2
Personality qualities	Adaptability Humility Sympathy Honesty Patience	33	3
Miscellaneous	Knowledge of teaching methods	5	4

1. The respondents were scientists and their reference was to the science field.

Those who discuss the problems of university teaching are, on occasion, over confident in their analyses. To claim, for example, that the skills of teaching are entirely inborn may be to ignore the effects of experience. Similarly, those who think that training can solve all difficulties are ignoring the need for some inborn substratum of potential aptitude. The delegates, as befitting a group of scientists, were cautious in their responses to questions on these points. In general they believed that those qualities which are characteristic of good teachers are primarily inborn, may be improved by experience and can be improved by training.

A question was inserted concerned with lack of qualities, as opposed to possession of them. It is not intended to present the results, beyond referring to the three following points which were not covered in the more positive approach of another question dealt with above: (a) inability to make valid judgements of the relative ability of students; (b) inability to understand the basis of the difficulties experienced by students, and (c) inability to be free of prejudical pressure, religious or political. While this is a function of the situation rather than of the individual, it is nevertheless regrettable. Both points (a) and (b) are obviously significant for they become operative very frequently, first, in selecting students to follow sciences courses, and second, in helping them to do so. The interesting point arises here as to whether these particular abilities are the fruits of endowment, experience or education?

DESIRABLE AIMS OF THE GOOD UNIVERSITY TEACHER

Three delegates refrained from answering this question on the grounds that the setting was 'too subjective', although the intention of attempting to introduce some degree of objectivity was obvious. The answers obtained indicated a greater degree of agreement about aims, sixteen of which were mentioned with a total frequency of thirty-two mentions. Since each aim was given an order of priority this information was used for rating and the aims were grouped as appeared most appropriate. The results are shown below:

1. Knowledge, interest in and understanding of science: 77 points
2. Professional aims (produce scientists, science teachers, etc.): 21 points.
3. Formation of character, personality, attitudes: 17 points.
4. Social service by science to society: 7 points.

The emphasis on knowledge, interest, skill and understanding in the fields of science is perhaps to be expected. The majority of the respondents were academic scientists and they naturally see their role and task in terms of science. Allied to this is the second most widely accepted aim, that of producing professional scientists (professors, teachers, technicians, etc.). The less easily definable qualities which might be outcomes of education were rated lower, under such heads as character formation, personality and attitudes. Little reference was made to the aims of the good university teacher in social terms.

DESIRABLE ACTION AND OUTSIDE HELP

Three specific questions were asked in order to provide guidance to Member States and their universities in regard to action they might take, singly, collectively or co-operatively. and also to indicate to Unesco specific kinds of help that are needed.

1. *References and bibliographical data bearing on:*

   Tests of scientific aptitude: 86 per cent wished to receive such data.
   Studies of the nature of scientific ability: 90 per cent.
   Reviews of methods of science teaching: 94 per cent.
   Studies on science and its place in education: 80 per cent.
   Studies of the social significance of science: 78 per cent.

2. *Publication of a Unesco-sponsored handbook on methods of teaching at university level:*

   Of the respondents 75 per cent indicated that they thought such a text desirable, though a few stressed that it would be a difficult undertaking, requiring not only scholarship, but tact. Those opposed to the idea were very emphatic that such a book would serve no purpose, partly because it could not easily be written; and secondly, because the sceptical would not use it.

3. *Annotated bibliographies relating to:*

   Psychology of learning: 77 per cent wished to receive bibliographies.
   Reviews of new learning theories: 90 per cent.
   Books on programmed instruction: 80 per cent.
   Books about visual methods of instruction: 81 per cent.

It may be seen from the above that in a group where there is some degree of suspicion towards the professional educator there is, nevertheless, willingness to become acquainted with modern educational ideas, methods and findings.

DISCUSSION

While the data presented above, being based entirely on a few simple questionnaires, are of necessity insufficiently comprehensive and of a simple character, they help to fill in the details of the general picture. The contents of the discussions and the answers to questionnaires are found to be complementary and nowhere in serious conflict with each other. It may also be said that the findings, such as they are, reflect closely earlier findings of similar meetings held in Delhi and Manila.[1]

Two points may perhaps be referred to more fully, as both appear basic to the whole situation.

First, as noted in the previous section, the delegates have not given a high place in their statements of aims to the social outcomes of science teaching. It was made evident earlier in the report that some concern about the conditions of entry to the university was felt about the academic and often abstract character of syllabuses and the 'informational' type of examination paper. Yet, while these are the conditions of the academic world, those concerned with the acceleration of socio-economic development have given a high priority to science as an agent of social advance. Educationists have accepted this diagnosis of relationships and[2] are concerned about the remodelling of curriculum and methods. Here, it seems, is a point to which attention should be given in order that science teaching may make the maximum contribution to development.

Secondly, there does appear to be some degree of mistrust, if not of real suspicion, on the part of scientists towards the educational theorist. While it is certain that education has its fashions, as much as any other field, so also it is certain that some real, not merely apparent, progress has been made. From studies which have ranged from neurology to psychology, and from the simplest learning situation up to the design of computer circuits, ideas have accumulated which are of profound significance to all who are concerned with teaching and learning at every level. It is from these ideas that the new theories which underlie all that is comprised by the phrase 'programmed instruction' are now being distilled and they are remodelling the whole concept of teaching methodology. While there is some willingness to accept these ideas when presented as new theory, there is an undoubted resistance to their acceptance as the basis of new practices in teaching.

In conclusion, after examining the data provided in the information sheets and considering them in relation to the seminar, as analysed in the body of this report, four clear-cut needs were distinguished: (a) closer agreement between university and school worlds as to their respective social obligations; (b) closer co-operation between the university and the school worlds in regard to their academic functions; (c) wider appreciation of the value of the study of the educational process and its procedures and of the need to apply the results of such study to practical situations; (d) more emphasis upon the explicit evaluation of the social outcomes of science education.

Unless these needs can be not merely considered, but satisfied, success in other spheres, such as improving supporting services or increasing the supply of trained scientists, will fail to make a maximum contribution to social progress and human betterment.

1. First Regional Science Seminar . . . op. cit., and Regional Meeting on the Teaching . . . op. cit.
2. T. L. Green, *Education and Social Reconstruction.* Inaugural lecture from the Chair of Education, University of Malaya, 1960.

CONCLUSIONS

The information supplied by the participants and the discussions held at the seminar led to a number of observations and suggestions which might be summarized as follows:

Science has become an all-pervasive part of modern life.

Modern education must therefore give a very significant place to science.

Universities as centres of learning, teaching and research are of special importance in the field of science.

The outcomes of science education must go beyond information and skill into the fields of attitudes, individual and social.

For science education to fulfil its new task new conceptions of both its content and method are needed.

The content in particular must be more closely related to the needs of Africa.

The methods of education need to be reviewed and improved, especially in regard to the use of such new media as programmed instruction and teaching machines. In spite of their limitations all such methods also have potential value, for example, in regard to accelerating education.

The teaching of mathematics is very important as a basis for most, if not all other sciences. Physics which has undergone such great changes needs to be seen in new terms, and new relationships.

Chemistry may be of special importance to Africa, not merely in connexion with the exploitation of natural resources, but in its social significance in relation to health, agriculture and industrialization.

Biological science, for the same reasons, is also of prime importance to Africa.

Geology, little taught, yet, may in the future prove to be of extreme importance.

Difficulties have to be faced—the shortage of skilled and highly trained staff, the delays in obtaining materials and the lack of services essential to research and academic progress must be met and overcome.

Co-operation between African universities, at all levels, in the exchange of information, materials and skills will do much to overcome these difficulties.

Co-operation is needed between government and universities, between the economy (whether industrial or agricultural) and the universities, and between the universities and the schools.

Co-operation is needed also between the institutions of all kinds in Africa and the outer and international world and its agencies.

Attention must especially be directed to ensuring:

1. That universities have the autonomy and freedom essential for academic growth and fulfilment.
2. That university staff are required not only to teach, but enjoy conditions in which research is possible.
3. That research, though it may have an applied aspect, is to a large extent concerned with the pure and fundamental problems which form the bases of the various disciplines.
4. That staff, adequate in ability, training and experience are forthcoming.
5. That, while there must, perhaps for some time, be dependence upon others, the ultimate aim should be for the universities of Africa to be able to produce, train and employ their own African staff.
6. That the universities and the schools should collaborate in the task of improving science teaching.
7. That access to the university should be facilitated by sensible standardization of requirements and open to all with ability to profit from it.

8. That facilities, resources, amenities within universities be improved in all possible ways.
9. That teaching techniques, in particular at university level, be a matter for review.
10. That the modes of evaluating and examining be improved in all possible ways.

II. THE UNIVERSITY TEACHING OF MATHEMATICS AS A BASIS FOR THE EXPERIMENTAL SCIENCES

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INTRODUCTION

Whereas twenty or thirty years ago it was believed that industry would need a limited number of specialists and a large unspecialized labour force, the industrial situation today makes it clear that, in the very near future, if not now, the normal level of training will need to be quite high, and that the percentage of workers with maximum qualifications is steadily growing. This state of affairs makes it imperative to introduce new methods in university teaching whereby specialist personnel can be trained in less time and more easily.

Again, the rate of change in the methods used in industry and in scientific research is creating the need for a type of training quite different from the traditional. As lately as fifty years ago, it was enough to learn formulae and to know how to use tables. Today, the regular work of a chemist, a geologist or a biologist may lead him to use methods which had not yet been invented when he was a student. This makes it necessary not simply to teach the student how to use formulae or accepted methods, but to provide a sound and adequate grounding for applying new methods. It is here that the teaching of mathematics becomes a factor, since the importance of mathematics has been steadily growing in recent methods, and it is in this subject that shortcomings in teaching are hardest to make good.

In these circumstances, we need to reconsider the teaching of mathematics to 'non-mathematics' students in a wider context. Our situation is comparable to that of the manager of a factory making television sets who wants his labour to be skilled. He cannot just have his workers taught how to make the sets in current production in his factory: he must also have them given a thorough knowledge of electrical technology and radio engineering. Similarly, we cannot expect to get good results from the mathematics courses for 'non-mathematics' students unless they come to us with an adequate grounding acquired at secondary school and unless we contrive to find a satisfactory solution to the problem of teaching personnel and their scientific work.

SECONDARY SCHOOL MATHEMATICS

It may be a paradox, but it is a fact that the nature of primary and secondary school mathematics syllabuses and how they are taught are of little importance in teaching prospective mathematicians (as there is sufficient time at the university to make good any gaps in their knowledge) but of great importance in teaching mathematics to 'non-mathematicians'.

The primary aim of mathematics teaching at primary and secondary level is to drill the pupil in a limited range of problems. The parts of mathematics he learns before the baccalaureat or secondary school leaving certificate can be set out in a few pages in the case of arithmetic and algebra and in twenty or thirty pages in that of geometry. The pupil learns by rote in his first year that $2 + 2 = 4$ and, in his eighth or ninth year that the roots of the equation $x^2 + 2ax + b = 0$ are $x = -a \pm \sqrt{(a^2 - b)}$. It is thus of great importance that his mathematics 'drill' should include as much as possible of what will be necessary for the applied mathematics he uses, or will form a grounding for university studies. This is possible only if the pupil learns no more than is genuinely essential.

To the best of my knowledge, however, syllabuses in every country in the world are cluttered with material of merely historical interest and included only because tradition requires it—and it may be a very hoary tradition, dating back even to classical times. Thus, the theory of proportions was necessary for the deductive exposition of Euclid's elements, but today has no bearing on contemporary methods or applied mathematics. The same applies to the systems of higher-order algebraic equations (of less antiquity), or even to the geometrical applications of trigonometry, which are important only to geodesists. These and many other items in the syllabus need to be eliminated and replaced by those which will be useful to prospective university or polytechnic students or in employment. We need, for instance, to include the numerical and graphical solution of equations, the fundamental theory of determinants, and the 'formal' properties of the trigonometrical functions used in analysis.

We also need—and this is perhaps still more important—to introduce the rudiments of the theory of probabilities and of mathematical statistics, which today are essential for any member of a modern society, and, if there is still time to spare (which means in all countries where the course leading to the secondary certificate lasts twelve years), the elements of differential and integral calculus.

Such changes in the syllabus are meeting—and will continue to meet—with much hostility from secondary-school teachers, which is invariably expressed in the question: 'If we omit things like the systems of higher-order algebraic equations or the geometrical applications of trigonometry from the syllabus, what problems can be set for the baccalaureat?' This kind of reaction needs, I think, no comment. Reforms will perhaps be assisted by the great authority in the mathematical field of the group of scholars in France who have recently begun to press energetically for the modernization of mathematics teaching in secondary schools. I think, too, that in countries where secondary school traditions are less ancient than in Europe, these reforms should be more easily accepted. I have dealt with them at some length here because their implementation will have a beneficial effect, particularly on the possibilities of teaching mathematics to 'non-mathematics' students and because they will be carried out only if the universities ask for them.

DIFFICULTY OF PROFFERING ADVICE OF UNIVERSAL VALIDITY

In different countries, the length of primary and secondary education together may be ten, eleven or twelve years; standards vary widely from one to another; and syllabuses may be traditional, in the sense of the preceding paragraph, to a greater or lesser degree. There may therefore be enormous differences in the standards of knowledge of students entering the university and it is thus almost impossible to suggest anything which will hold good for all countries.

Yet another difficulty is that, on graduation, students from the same faculty or branch of a faculty may have widely different requirements in essential mathematics for their line of work. For instance, a chemist engaged on classical organic synthesis will need no more than the four arithmetical operations and perhaps the ability to use tables of logarithms, whereas the man in radiation chemistry will even have to make use of branches of mathematics which mathematics graduates do not know, e.g., the theory of operators in Hilbert space.

The principle to follow is that no special consideration is required for the needs either of the 10 per cent of pupils for whom the minimum of mathematics is enough or of the 10 per cent who should get as much mathematics as possible. For the former, the mathematics taught may come in useful one day, while the latter will need an adequate grounding to be able to teach themselves the branches of mathematics which will later be of interest to them; 'extra' courses can be arranged for them, which I shall discuss more fully later.

We have already laid it down as a principle that, in their future professional activities, students need to know how to augment their knowledge unassisted, which means that they must be given a sound grounding by the university. But the foundation mathematics for a non-mathematician are not exclusively differential and integral calculus and may indeed be quite another area of the subject. His foundation mathematics are the necessary knowledge to enable him to learn the required extra material for himself, and the methods to be selected for applying his results to concrete problems.

For a chemist, for instance, the foundation mathematics will comprise differential and integral calculus, the rudiments of probability theory, and an introduction to numerical methods, with a knowledge of their application to the results of experiments.

A few months back I happened to come across a striking illustration of the difficulties experienced in using known formulae on concrete problems. The question was about a toy, a 'hydro-pneumatic' rocket, worked by partly filling a 'fuel chamber' with water and compressing the air in the rest of the space by means of a bicycle pump; on opening a cock, the water is forced out of a nozzle and the rocket takes off. The problem was to determine the optimum water content, i.e. the quantity of water needed in the tank for the rocket to reach maximum height. The equations of motion for this problem are fairly simple, but cannot be integrated by simple methods. Some students whom the toy had interested were completely at sea over the problem, but the simplest and crudest numerical methods give the answer with an acceptably small degree of error, using extremely simple numerical calculations which can be completed in half an hour.

The problem of applying mathematical methods to practical problems is regarded by mathematicians as outside their purview, while the other members of the teaching staff obviously lack the full qualifications for dealing with it; and this situation, I think, constitutes the most difficult problem to be solved in mathematics teaching for students of the experimental sciences. The ideal would be for the mathematicians instructing such students to have a thorough knowledge of the particular experimental science concerned—chemistry, biology, etc.—but it is difficult to impose this requirement on mathematicians, and it is to be expected that the present state of affairs, with nobody responsible for the uses of mathematics in the experimental sciences, will continue for a long time to come and that it will be far from easy to find a satisfactory way out of the difficulty.

THE TEACHING OF OTHER SUBJECTS

It is a well-known fact that the teachers of other subjects than mathematics, e.g. physicists or chemists, do not know how to make use, in their own lessons, of what their mathematics colleague has taught their students. Scores of examples can be quoted of physicists or chemists who, instead of using mathematical findings which not only meet the requirements of scientific rigour but also shorten the calculations, go in for 'do-it-yourself', hammering out mathematical procedures of their own which are imprecise and extremely clumsy to use.

For examples we need take only the use of a series of infinitesimal increases instead of derivatives, or the very complex analysis of the flux of vector fields across surfaces approaching ideal surfaces instead of using the Gaus-Ostrogradski theorem. All this is not only a waste of time but also misses an opportunity to let students learn to put methods they know in theory to practical use.

In some countries, an attempt has been made to split the mathematics course into two parts—a basic course for first- (and sometimes also second-) year students and a supplementary course (let us call it an 'extra' course) for fourth- and fifth-year students. Something on these lines has also been tried in Poland, where I had an opportunity of examining chemistry students after an 'extra' course, which included the elements of the theory of simple differential equations, an introduction to the theory of the Fourier series and an introduction to differential geometry (theory of curves). The chemists were extremely unhappy about it and did not understand why they had been obliged to learn branches of mathematics which were absolutely no use to them. Simple differential equations could indeed have been useful to them, but only if they had been familiar with them earlier, when they were studying physics and physical chemistry, particularly chemical kinetics. This also applies to the Fourier series. The elements of the differential geometry of curves were obviously useless to them, though some parts of the theory of surfaces—if they had learnt them early enough—would have been useful up to a point in the theory of capillarity.

From the standpoint of the organization of studies, providing this kind of course for students in their last year is simply what we in Poland call 'serving the mustard after the dinner'. I also suspect that mathematics which students know and which could be useful but which they were not taught to apply when studying their own subjects, will never be used by them in their professional work.

THE POSTULATE OF RIGOUR

Mathematicians are often asked by experimental scientists to teach 'non-exact' mathematics. Yet only 'exact' results can be interpreted and applied with ease, particularly in the case of non-mathematicians. Even if we want really to teach mathematics (of a kind which could provide a basis for later studies), as opposed to a lot of heterogeneous formulae, 'exact' mathematics are easier to learn than inexact pseudo-mathematics. This is obvious, since it is easier to learn concepts which are clear even if the reasoning is complex, than to grasp 'woolly' concepts.

Of course, we must not go too far: a course of theoretical arithmetic by way of introduction to differential calculus for chemists, for example, would be not merely unnecessary but even harmful.

OUTLINE SYLLABUSES

We may, however, attempt to work out a few proposals for the mathematics syllabus for non-mathematicians. They will naturally depend on the standard of mathematics in the local secondary schools and on the type of syllabus laid down for the main branch of science studies, and hence also on the degree of specialization in that branch. Two sets of proposals are accordingly given below, for a minimum and a maximum syllabus respectively.

Biology

Minimum: Introduction to mathematical statistics.
Maximum: Elements of linear algebra (matrix theory). Elements of differential and integral calculus and introduction (but only an introduction) to the theory of simple differential equations. Elements of the theory of probabilities and of mathematical statistics. Numerical methods and their applications in the numerical treatment of experimental data.

Geology

It is perhaps most difficult of all to make practical suggestions for a mathematics syllabus for geology students, since 'geology' covers a whole collection of specialist fields requiring widely differing levels of mathematical training. For a palaeontologist, for instance, knowing that $2 + 2 = 4$ will be enough, but a geologist specializing in crystallography needs a good knowledge of certain branches of mathematics, including the elements of group theory.

Chemistry

Minimum: Fairly thorough introduction to differential and integral calculus. Rough outline of the theory of simple differential equations and some useful formulae. Essentials of group theory. Essentials of probability theory and of the theory of errors. Numerical methods and their application.
Maximum: Introduction to linear algebra. Fairly thorough course in differential and integral calculus. Introduction to the theory of simple differential equations. Outline of the theory of partial differential equations. Introduction to differential geometry. Essentials of group theory. Theory of probabilities, mathematical statistics and theory of errors. Fairly full course on numerical methods and their application to the numerical treatment of experimental data.

As some chemists will need a fuller mathematical background and there is little probability of their being able to broaden their field of knowledge sufficiently by their own work, the maximum programme should comprise not only a basic course but also an 'extra' course intended only for students proposing to specialize in certain branches. The 'extra' course should go straight on from the basic course and should comprise: the theory of partial differential equations, particularly second order, more about group theory, the theory of Fourier series and a fairly full course on the theory of linear operators in Hilbert space.

Clearly these proposals will not give the result sought unless the way the syllabus is taught is up to date. Here—*mutatis mutandis*—all that was said above[1] about the 'traditional' elements in the secondary school syllabus again applies. For instance, it is a frequent practice to include a few lessons on the rudiments of analytical geometry as an introduction to differential and integral calculus. Tradition requires that at this point the classification of quadrics be taught in full detail. In my own

1. See p. 47, 'Secondary school mathematics'.

view, the greater the detail, the more the time wasted. There will be no waste of time, however, if some workings of the classification are studied as examples of the application of the theory of specific values of operators. Even the most up-to-date syllabus is useless if it is not given on modern lines.

MATHEMATICS SYLLABUS FOR PHYSICS STUDENTS

The teaching of mathematics to physics students is a problem on its own. Physics needs the whole of 'classical' mathematics (except perhaps some sections of geometry) and much of 'modern' mathematics. However, prospective physicists have to learn not merely mathematics but also physics, and accordingly the mathematics syllabus for them must be meticulously selected and modified according to the branch in which the student is going to work. A theoretical physicist working in the field of atomic physics needs a different mathematical background from an experimental physicist working on acoustics.

A classification showing what specialist branches of theoretical physics require what branches of mathematics could even be made out:

1. Astronomy, electrical technology (simple differential equations).
2. Hydro-dynamics, rheology, electromagnetism, optics (partial differential equations).
3. Atomics (operators in Hilbert space plus partial differential equations and certain other branches of mathematics).

Fifty years ago mathematics and physics students did much of the course together—mathematical analysis, algebra, analytical geometry, experimental physics, etc. . . . Today, in almost all countries, the trend is to teach mathematics and physics students separately. In my own view, this is sound in principle but there are certain subjects (mathematical analysis, experimental physics) which can be taught in combined classes of mathematics and physics students for many years to come; the arrangement will be of advantage to both parties, for the physicists will learn mathematical rigour and the mathematicians will develop their insight into physical problems. Moreover in those countries where there is a shortage of trained personnel, combining classes will make it possible to give both groups the best teachers.

Mention may also be made of the well-known fact that teaching centres can arrange separate courses for physics students only if they have a sufficiently numerous mathematical faculty to create courses for prospective mathematicians.

THE TEACHING STAFF

It has already been emphasized that the non-mathematicians' mathematics teacher must run the course on up-to-date lines, and adapt it to the students' standard of knowledge and in any respects made necessary by developments in the other sciences and their teaching methods. He should also help his colleagues (biologists, chemists, etc.) to overcome the mathematical difficulties they may encounter in their own departments. It is obvious, in view of this, that the person required for this kind of post is a true mathematician and not simply a mathematics teacher, the latter term being used in this context, to signify someone who knows the subjects in the syllabus and is capable of teaching them to others, whereas the 'mathematician' can not only do all this but is also sufficiently gifted and sufficiently trained as a scientist to be able to produce original mathematical work.

The training of science staff is not an easy matter, and the fruits of Polish experience with mathematicians may probably be useful to others at present suffering from a shortage of such staff. Poland secured her independence in 1918, after 150 years of occupation. Before the First World War, the country had only two small universities with a few mathematicians in their faculties. Today, although Polish mathematics, and indeed all Polish science, suffered great losses during the Second World War, we have over two hundred mathematicians who have published original work, much of which is regarded by such journals as *Mathematical Reviews* and the *Zentralblatt für Mathematik* as an important contribution to the subject. At the time of the First World War, there was a discussion between the two eminent mathematicians, S. Zaremba and Z. Janiszewski, on the means which should be adopted for training mathematical staff in adequate numbers for the universities and polytechnics. Zaremba's suggestion was to promote the best secondary-school teachers to the university posts, but Janiszewski maintained that the only way to proceed was to send enough students abroad to give Poland its own 'mathematical milieu' on their return home, since only such a milieu could produce a mathematical progeny more numerous and more active than the first generation. Janiszewski's ideas were followed, with the admirable results for Polish mathematics already mentioned.

My view is that what proved good for Poland may be just as good for other countries which now find themselves in the same situation as Poland was half a century ago. What needs to be done, therefore, is to select a number of young people, preferably at or near the end of their university course, who show promise of developing into researchers, and to send them for a few years to a centre of mathematical learning. It might be in the Union of Soviet Socialist Republics, or the United States of America, in France or in Poland, in Britain, Germany or Italy, chosen quite possibly, not on scientific considerations, but for political or financial reasons, or on the score of linguistic difficulties or traditional cultural links. During their time abroad these young people will learn how to do research and will return home with a scientific approach to problems. They should go to their centres to specialize in a single branch of their subject and, on their return, will be able to bring up a new generation of research workers probably more numerous and hence able to cover a wider range of scientific interests. In their turn the latter must also be given the fullest facilities for contacts abroad.

ORGANIZATION OF A MATHEMATICS CENTRE

It is not an easy matter to build up a centre of mathematics, in the sense of the forms of organization in which all the mathematicians making up a mathematical milieu are comprehended, and the work inevitably takes time.

Each organizational unit (School, Faculty, Faculty Department) wants its own mathematical professorship, for such an arrangement is more convenient for the organization of the unit's work; but, in countries where the numbers of mathematicians are inadequate, it is not usually possible to fill all the mathematical Chairs with persons having all the required qualities. A possible remedy would be to establish an institute of mathematics to serve the whole school, or even an inter-establishment mathematical institute if a town has a number of schools where mathematics are taught. Such an institute was opened in 1945 at Wroclaw, and its faculty taught mathematics not only to the mathematics, physics and chemistry students of the university, but also in all the departments of the Polytechnic School. From the point of view of the standard of teaching, the experiment was conclusive, and the institute was split into two—university and polytechnic—after several years of fruitful work, only in deference to the secondary consideration of unified arrangements for all the polytechnics in Poland.

No mathematical centre or milieu where effective work is possible can exist without a suitable library, and this may be yet another argument in favour of an inter-establishment institute. A library costs much less than a modern laboratory, but needs regular, if relatively small, appropriations. Even so, it is difficult to procure back volumes of scientific journals; if they are available at all, prices are prohibitive. A microfilm centre will therefore be absolutely necessary.

The Mathematics Seminar of the Marie Curie-Sklodowska University of Lublin was established in 1945. Today, seventeen years later, we can appreciate how greatly we have benefited from the publication of a mathematical journal (*Annales Universitatis Mariae Curie-Sklodowska*, Section A—Mathematics). Obviously no such journal could contain the publications of the whole faculty, or let alone the whole school, but simply some papers on mathematics, even though they may run to no more than two such papers per issue, each twenty or thirty pages long. Publishing a journal of this type is a help towards the collection of a suitable library by exchange, and also enhances the status of the centre issuing it. Lastly, it serves to make the original work of faculty members known and thus also assists their advancement.

Universities might well have consolidated university presses publishing, as appropriate, works on mathematics, physics, chemistry, or other sciences. The press could also help in the publication of textbooks or duplicated lecture-notes.

TEXTBOOKS

It would be difficult to secure satisfactory results in mathematics teaching without adequate supplies of textbooks, duplicated lecture notes and collections of exercises, which must be readily enough available for each student to have his own copy, and be written in a language students know well, and in terms that they can understand.

The question of mathematics textbooks for physics students, like all aspects of mathematics teaching to future physicists, is a problem on its own, but is not of so much importance, since physics students must have a sufficient mathematical background to be able to read textbooks intended primarily for mathematics students.

The really difficult question is that of mathematics textbooks for students of other branches of science—chemistry, biology or geology. If the course given is to be 'up-to-date' or 'modern',[1] i.e. if it is to impart the maximum of information in the minimum time and so that it can be understood, it must be based on an 'up-to-date' or 'modern' textbook, within the grasp of the student. I have had some scores of mathematics textbooks for students of other branches than mathematics and physics through my hands, whose titles or sub-titles include the word 'modern'. Almost all show no trace of modern methods except in the printing, which may be rather more modern than that of the standard textbooks not qualified as 'modern'. So far as I know, there is only one attempt at a new presentation of the course of differential and integral calculus for non-mathematicians,[2] which has not yet quite finished its 'running in'. A definitive version of this tentative exposition would be an invaluable contribution for teaching, and not solely for teaching in the universities.

To have ordinary textbooks suitable for students of particular sciences is not the only necessity. 'Extra' course textbooks suitable for chemistry, biology students will also be required, for reference if need should arise. It is not easy for the non-mathematician to find, for example, just those processes he needs, in the regular literature of the subject; with workings under the theory of Fourier series, for

1. In the sense given to these terms on p. 50, 'Outline syllabuses'.
2. K. Menger, *Calculus—a Modern Approach*, Boston, 1955.

instance, a chemist will certainly not manage to find what he wants in one of the recognized monographs (e.g. in A. Zygmund's excellent book) as it is practically certain that the answer to his problem cannot be found in a form which he can understand and apply. This leads me to the view that such reference books for non-mathematicians (which we may call 'extra' courses) will be useful to those for whom they are intended only if they are written in the same mathematical style and using the same notations as the 'basic' textbook since we cannot ask chemists—and still less biologists—to have all mathematical notations at their finger tips.

Things will be easier in many respects if students are sufficiently well acquainted with foreign languages to be able to understand textbooks written in 'conference' languages (French and English, in particular). Inevitably, however, the moment will come when some countries will have to change over to textbooks written in the local languages, and this will undoubtedly be necessary when the universities' second-generation specialists, produced on the spot by their senior confrères, reach maturity.[1] It is not easy, however, to write an original textbook, and it will therefore be necessary to begin by publishing duplicated courses and translations of the best extracts from world literature.

CONCLUSIONS

To provide sound and useful mathematics teaching for non-mathematicians involves the satisfaction of a certain number of prior requirements:

1. To begin with, the secondary school syllabus must be modernized.
2. Mathematics courses for non-mathematicians should provide a groundwork for individual study and not a rigid mathematical canon.
3. A substantial part of the time allotted to mathematical studies should be set aside for the theory of probabilities, numerical methods and their applications in the numerical treatment of experimental data.
4. A satisfactory standard of instruction can be reached only if there are adequate numbers of research scholars.
5. These research scholars should have their own library and, wherever possible, their own journal.
6. Finally, students must have suitable textbooks available.

1. See p. 52, 'The teaching staff'.

III. ON THE TEACHING OF PHYSICS AS ONE OF THE BASIC SCIENCES AT UNIVERSITY LEVEL

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The assignment given to me by Unesco is both challenging and staggering. My task is made possible only by the fact that a detailed factual survey of curriculum practices, textbooks, etc., in all university physics teaching in the United States of America is being undertaken simultaneously by Dr. W. C. Kelly of the American Institute of Physics on behalf of both Unesco and IUPAP. The results of that survey should be soon available to us. My own discussion is intended to be complementary to that report.

Since I am dealing with physics as one of the basic sciences at university level, on the basis of personal participation in some current experiments in this field, I shall indicate those areas where there seems to me to exist a particular need for further innovation and discussion. To supplement my own views I shall refer and draw attention to relevant recent publications in our country on this topic, insofar as they either extend or contradict these views.

It should be particularly remembered that I am drawing on experience in the U.S.A. Local conditions there are clearly in many ways unique, and establish boundary conditions that do not necessarily directly apply to the experience in other countries. For example, one half of our graduates from secondary school go on to receive some form of college education, and about a quarter of our college graduates in all fields (and half of those in the better colleges) are now heading for higher degrees in graduate school; our university system is largely patterned on private rather than state-controlled initiative, and this has helped to encourage the co-existence of the widest variety of curricula; and while basic physics teaching in the U.S.A. until about five years ago was by and large a relatively undernourished and unimaginative field, we are now beginning to see the influx of more money, manpower, and the interest of ingenious and well-placed people, so that we feel now definitely to be in the early transition stages of a change in the teaching of all sciences. (How deep-going this change will turn out to be is by no means clear at present.)

Despite the necessarily local context of my discussion, I hope to single out those features of my broader topic which are not bound to local conditions. I intend particularly that these pages may be of some use in countries which have to compress the timetable for reaching the scientifically and technologically sophisticated stage best suited to their wider aspirations. For I hold that the largest part of the problem of 'developing' countries is precisely the nations' ability to compress this schedule;

and that ability in turn crucially depends on how well things go in the science classroom. Indeed, our meeting at Dakar will be successful insofar as we can suggest how to capitalize on the conditions in 'compressed-schedule countries' in such a way as to make an order-of-magnitude improvement in basic science teaching.

IN WHAT SENSE IS PHYSICS 'BASIC'

Of all the sciences, the physical ones are usually acknowledged to be the most basic. To the philosophical arguments for this proposition in the nineteenth century, ours has added practical and political ones. 'Physical sciences occupy the front place in natural sciences, and it is on their successful development that the progress of allied sciences and of national economy does depend. Further prospects of technical progress are determined at present in the first place by the achievements of the fundamental trends in physical science.'[1] While this citation has been ascribed to Chairman N. S. Krushchev, it might be equally well made by the head of any other modern state, or by most scientists, educators, or administrators the world over. The chairman of the influential national commission on college physics in the U.S.A. has recently elaborated on the basic role of physics, and some of the problems this creates:

'Sciences other than physics are requiring more and more of their students to take at least one year of physics. The growing importance both of physical instrumentation and of the use of theoretical physics concepts in engineering, biology, chemistry, geology, and meteorology is making extended work in physics more essential each year.

'Aside from the requirements of the adjoining sciences, more students in the humanities and the social sciences are and should be enrolling in introductory physics courses. The recognition of the role of physical science as a chief determinant of our culture, and the recognition of physics as a discipline having many of the educational values associated with the classics in the nineteenth century are contributing to this trend. Many institutions that recently required one year of natural science for the A.B. degree are now requiring a year each of physical and biological science, in recognition of the place of science as a liberal art.

'The community of academic physicists will be hard pressed to meet all the demands made upon it, yet it would be shirking its responsibility if it failed to do so.'[2]

In a completely analogous way, Professor A. S. Akhmatov of the U.S.S.R. delegation to the 1960 Unesco Paris Conference on International Education in Physics has stressed the basic place of physics both for the other sciences and for the general cultural requirements of educated men and women:

'The theoretical and experimental development of physics during the last thirty years, unprecedented in the history of science as regards its scope and successes, and the beneficial effect of this development in almost all branches of theoretical and applied knowledge, put physics in the forefront as a powerful means of comprehending nature and as a powerful lever of technical progress.

'It is clear at present to everybody that it is precisely the progress of physics that determines the possibilities of development in a very wide range of sciences, from

1. Quoted in: S. C. Brown and N. Clarke (Eds.), *International Education in Physics*. Proceedings of the International Conference on Physics Education, Unesco House, Paris, 18 July to 4 August 1960. New York, The Technology Press and John Wiley and Sons, 1960. p. 132.
2. 'Progress Report of the Commission on College Physics', *Am. J. Phys.*, vol. 30 (October 1962), p. 17.

cosmology to biology and medicine. It is physics that determines to a large extent the foundations of our outlook as well as the possibilities and limits of our practical activities. One cannot be called a specialist or, for that matter, an educated person unless one is familiar with a certain range of ideas and facts in the sphere of physics.'[1]

THEORETICAL FRAMEWORKS AND OBJECTIVES FOR CURRICULA

These remarks serve to remind us of the enormously wide and varied spectrum of purposes which basic physics university curricula must fulfil. The physics courses must deal with the elementary materials and laws that structure the universe: they are doors through which other sciences are entered; they are prototype examples of rigorous scientific thought; they prepare the future physicist or other scientist, or physicians, the engineer, the administrator, the citizen in a technologically oriented society. Moreover, the basic physics course is usually one of the few links that help to couple secondary school preparation with later specialization, physics with other sciences (e.g. chemistry, biology, astronomy), scientific with technological sophistication, scientific knowledge and the rest of the cultural tradition.

Each of these tasks separately is as complex as it is important; and all of these together amount to an assignment that is overwhelming. For students who take only one high school *or* college physics course—as is still the case with the majority of students in the U.S.A.—this course carries an impossible burden. In setting a theoretical framework for basic physics curricula, we should see that the basic university physics course is meaningful only when it is regarded not as an entity in itself, but as a bridge between prior science education in secondary school on the one hand and later education in the university and beyond on the other hand.

For example, I would urge that the university must bring pressure to bear on secondary schools to assume that students come in with at least the necessary minimum of preparation, and that in particular the basic university physics course in future be constructed on the enforceable assumption of the student having passed prior physical science school courses along the lines excellently described in the report of N. Clarks's International Committee on the Teaching of Physics in Schools.[2] Precisely because it is an ambitious programme, this is one of those instances where a compressed-schedule country, in which large-scale changes are being introduced with a will and with good planning, can hope to accomplish what is practically impossible to do in more 'advanced' societies with self-satisfied, entrenched educational systems. To reinforce the urgency of this theme of necessary interaction and mutual help of college and secondary school, I attach the relevant Resolutions of the International Conference on Physics Education, 1960, as Appendix A.

As on the input end of the basic course, so also on the output end: the student who has passed through the course, whether a future scientist or not, should find available to him further courses that build on the competences he has acquired in accord with his particular further educational aims.[3] To do less than this, to think

1. Cited in: S. C. Brown and N. Clarke, op. cit., p. 129.
2. Ibid., p. 12-21 (also in *Physics Today*, vol 14 (January 1961), p. 30-8). See also the discussion on p. 136-7.
3. For example, the 'Progress Report . . .' (see footnote, p. 57), which points out on p. 3 that the introduction of more junior and senior courses to prepare college students for graduate work in modern physics 'may do more harm than good unless the necessary groundwork for such courses has been laid carefully in the freshman and sophomore years . . .'.

of the basic course alone rather than in the context of the total educational programme, would be as futile as building a stretch of highway that terminates in a jungle at either end.

The recent discussion of introductory courses in the U.S.A. has been marked by a great liveliness, large scope and frequent meetings—as well as by generous subventions for financing the meetings and the reports, obtained from the General Electric Company and from the National Science Foundation. Over the past seven years, more than a hundred physicists and educators in physics, as well as administrators and research scientists in industry, have participated in one or more of nearly a dozen separate, large multi-day meetings, called especially to consider some aspects of the physics curriculum. Nobel laureates, presidential advisers, prominent textbook authors, and dedicated researchers and teachers have all been equally involved. Since 1960, a national seventeen-man Commission on College Physics has been hard at work on further improving physics teaching in the U.S.A.

Over the recent years, a concensus has been forming on many matters which should be of interest everywhere. One cardinal conclusion is the importance that has to be attached by physicists, educators and administrators precisely to the *introductory* or basic university physics course. As the recent Progress Report of the Commission on College Physics stresses;

'Physics departments are rated by most physicists in terms of their research productivity, the quality of their graduate programmes, and their success in producing undergraduate majors, with the weighting favouring the first of these. *Yet a strong case can be made that the most important work being done by any physics department is that involved in the teaching of introductory courses.* The numbers of students enrolled in these courses is usually greater by orders of magnitude than the number of majors. For many of the students, one introductory course may well represent the only contact that they will ever make with physics.

'Most of us believe that a knowledge of the physical world, of the methods that have made possible the rapid growth of this knowledge, and of the nature of the process of physical inquiry are essential ingredients of the cultural 'mix' suitable to the twentieth century. It follows we have almost unlimited responsibility to those students who will be the business and professional men and women, the intellectual leaders, and the statesmen of a coming generation. The fact that one course gives us our single chance with such students demands that this course be as typical of the best of physics as is any other course that we offer. The achievement of this end is not easy; real ingenuity and inventiveness are required to present honest physics to students with a minimum background in mathematics and, often, a lack of interest in thoughtful observation and in logic.'[1]

These are some of the external boundary conditions for any discussion of curricula. Internal boundary conditions should also be examined before turning to specific curricula, methods, time allotments, and level. No doubt the most important of these conditions are the objectives which the basic course is to serve. Over the past few years the aims and the curricula of basic university physics courses have been discussed at a number of the related, nationwide conferences mentioned above. The reports of these conferences reflect the judgement of the overwhelming majority of physicists interested in these matters in our country, and the aims and curricula proposed there have stood up well under scrutiny and experiment. For this reason I shall cite relevant sections of the two most influential of these reports with respect to objectives and curricula. I should also mention that, as a participant in the drafting of the reports, I had found with some astonishment that agreement was relatively

1. *Am. J. Phys.*, vol 30 (October 1962), p. vi (our italics).

easy to obtain within the drafting groups that had been arranged to represent faithfully the existing variety of points of view.

The first report to be mentioned was the outcome of a widely representative conference of university physicists held at Carleton College in Minnesota (and hence referred to usually as the Carleton report); it was published in the *American Journal of Physics*[1] in its October 1957 issue—a significant coincidence with the date on which the space age began.

The report asked at the outset that 'the objectives which the course is intended to achieve should be clearly and explicitly formulated'. Despite the fact that this plea has a trite and familiar ring, it is in fact a task that is difficult, and rarely performed with clarity and lack of self-deception. The report continues:

'Good introductory physics courses have always been designed to give students an acquaintance both (a) with physics as a process of inquiry and (b) with some parts of the body of knowledge and of concepts that have been collected through that process. One cannot accomplish either of these aims without directing some effort toward the other. The relative importance of the two must be determined in accordance with the needs, the interests, and the future plans of the students and with the availability of teaching staff, laboratory facilities, and instruction time. The fraction of the course that is explicitly and consciously directed toward either goal is not necessarily proportional to the extent to which the corresponding effect is produced.

'It was the opinion of the conference that each instructor should try to decide on the relative extent to which he should direct his energies, and those of his students, toward the achievement of each of these and of other aims that seem relevant to the course. *Physics teachers have not devoted as much conscious thought to the establishment of specific goals as is desirable.*'[2]

There followed a list of suggested objectives meant to be applicable to all types of physics courses—wether they are what I shall call Type A (namely, courses for physics majors and engineering students), Type B (courses for majors in other sciences and for pre-medical students), or Type C (courses for non-science majors, e.g. liberal arts students). This list, repeatedly re-endorsed since, has been made somewhat wider in a recent closely related version, published in the second report to be cited here. That one was the result of a large and thorough set of meetings, supported by the National Science Foundation and sponsored by the American Association of Physics Teachers (AAPT), published in September 1960 under the title 'Report of a Conference on the Improvement of College Physics Courses'.[3] The list of six general objectives adopted for all college courses is worth studying in detail—particularly with a view to the question whether our current courses do indeed fulfil these aims, and if so, at what point, to what depth, and with what testable evidence:

'(a) The college course in physics should stimulate the interest of students in nature, in natural law, in the developing field of physics, and in the applications of physics to technology.

'(b) It should familiarize beginning students with the elementary technical vocabulary of physics, with its basic principles, concepts, and techniques. Not only is such knowledge an essential foundation for the future work of all scientists, but it is likely to be of practical value even to the non-scientist and is certain to help him to understand the world in which he lives.

1. *Am. J. Phys.*, vol. 25, no. 1 (October 1957).
2. *Am. J. Phys.*, vol. 25 (October 1957), p. 419 (our italics).
3. *Am. J. Phys.*, vol. 28, no. 6 (September 1960).

'(c) It should develop the mental capacities of students by stimulating them to accurate and meaningful thinking about scientific questions, and by providing them with a basis for critical judgements over a wide range of subjects. It should help them to acquire a high respect for disinterested inquiry and a flexible and experimental attitude towards problems that can be approached scientifically.

'(d) So far as possible the physics course should give students a living scientific experience that will enable them to understand scientists and their activities. It should be the constant aim of the instructor to communicate as much as possible of the spirit of scientific inquiry. This he can do both by emphasis on the unfinished character of scientific knowledge and by occasional interpolations from the history of science.

'(e) There is, we believe, a growing realization among physics teachers of the fact that a physics course can and should give its students some appreciation of both the historical interaction between science and philosophy and the role of science in the social ferment that pervades all cultures today.

'(f) Finally, the teacher of college physics should be perpetually interested in the conservation of scientific talent. To this end he should make every effort to stimulate the creative faculties of gifted students without neglecting the cultivation of sound learning among those of lesser ability.

'These general objectives are not equally feasible, nor are they equally relevant to the traditional conception of the function of a course in physics in an American college. Few, however, would question the desirability of any of these objectives if it can be attained without serious detriment to the others. The items in the list are in some respects less specific than those presented in the AAPT report on "Improving the Quality and Effectiveness of Introductory Physics Courses"[1] in several respects they build on and go beyond the aims listed in that report. Fundamentally, however, the two lists are in harmony.'[2]

A specific point to elaborate is the perhaps unexpected emphasis in items (d) and (e) on the history, philosophy, and sociology of science. In the U.S.A. this attitude has been growing during the last seventeen years. While I shall return to this topic when we examine the proposed curricula themselves, it is well to cite the discussion in the report on this point because it is not tied to specific curricula implementations:

'There is a new demand for more rigorous formulation of the basic physical concepts, for more sophisticated discussions of the nature and function of physical theories, and for a critical account of the processes by which scientific knowledge is advanced and tested. In part, because of the intimate connexion between the philosophy and history of science, there has been increased interest in the latter subject as well. This trend appeals strongly to the non-scientific members of university faculties and to all those concerned with problems of general education. Instruction in science through an historical and philosophical approach has a strong potential appeal to many non-scientific liberal arts students because it makes connexions with their other studies. It has value for scientific and non-scientific students alike, because it readily brings to light the sociological relation of science to the rest of our culture and points up the central role of science in the intellectual

1. *Am. J. Phys.*, vol. 25 (1957), p. 417.
2. *Am. J. Phys.*, vol. 28 (September 1960), p. 571-2. The equivalent list of aims in the Carleton Conference Report was most recently endorsed again in the Report of the Summation Committee of the Denver Conference, *Am. J. Phys.*, vol. 30 (March 1962), p. 156.

history of mankind. By placing the development of physics in the context of other intellectual activities, it is better able to bring out the spirit of science and to communicate some of that spirit to students.

'The urge to give added depth to courses in physics by giving them greater philosophical sophistication and the urge to tie up the description of today's physics with the social and historical context in which it arose are closely connected. They are not the same thing, however. So one can say that there are three principal varieties of internal pressure that can influence the conscientious and enthusiastic teacher of today who wishes to improve the quality of his instruction. These are, first, the desire to bring into his course more atomic and nuclear physics, more quantum theory and relativity; second, the desire to give added meaning to his teaching by persistently asking the question "How do we know?" and by subjecting the concepts and laws of physics to a somewhat more philosophical scrutiny than heretofore; and third, the desire to present his science in an historical and sociological context. . . .' [1]

CURRICULUM CONTENT — GENERAL

When we now come to the heart of the matter, the choice of subject matter for the one-year (or two-year) basic university physics course, we find in recent representative thinking two widely accepted 'principles of parsimony' (in the sense of Occam's Razor) that should be of particular interest to all compressed-schedule efforts: (a) the range of individual topics to be treated should be kept to a minimum in favour of increased depth, and (b) the number of qualitatively different types of physics courses (for different audiences) should also be reduced as far as possible. Here, as in physics itself, unnecessary proliferation is to be zealously shunned.

The discussion of content as approved by the Carleton Conference has here also stood up very well; it has been incorporated into texts and courses, and reaffirmed on review. These recommendations are so clearly and succinctly put that I believe we can do no better than study them directly and in full, particularly since I see my task to provide not a sample syllabus—which would be hardly defensible—but an assembly of the best reflections on the bases for making syllabuses.

'The selection of content determines in large measure the success with which physics teachers and students will achieve the above goals. The conference felt most strongly that physics teachers must reduce drastically the number of topics discussed in introductory physics courses. A more critical and parsimonious selection of content would permit a pace that encourages both reflection on the part of the student and a proper regard for depth and intellectual rigour.

'Physics, as a body of knowledge, is now far too extensive to receive adequate general coverage in an introductory course. The instructor must not sacrifice depth and understanding by attempting to cover too many topics in encyclopaedic fashion. As one of our colleagues has well said: "Let us uncover physics, not cover it".

'It was the opinion of the conference that a satisfactory introductory physics course could be constructed around the following seven basic principles and concepts, and the material leading up to them:

'1. Conservation of momentum.

'2. Conservation of mass and energy.

'3. Conservation of charge.

'4. Waves.

1. Ibid., p. 572-3.

'5. Fields.
'6. The molecular structure of matter.
'7. The structure of the atom.

'Furthermore, these seven principles and concepts outline the minimum content which any introductory course must encompass in order to provide a satisfactory treatment of present-day physics.

'Lest this list appear too brief, we point out that the discussion of such topics as Newton's laws of motion would ordinarily be included in the development of the principles of conservation of energy and of momentum at an introductory level.

'To provide illustrations of the ways in which these topics may be incorporated into a course, the conference requested three of its members to prepare syllabuses that would indicate the scope of possible courses, the level of discussion, and the latitude allowed the instructor within the proposed framework. The authors were requested to prepare these syllabuses [1] on the basis of existing introductory courses designed for different student groups.

'Few instructors will wish to limit their material to the bare minimum of topics. Most will wish to enrich the course by the use of additional topics, chosen from classical and modern physics. The instructor's own interest and special competence, as well as the interests and needs of his students, will best guide him in his choice. Some examples of such topics are:
'1. The electromagnetic theory of radiation.
'2. The second principle of thermodynamics.
'3. The special theory of relativity.
'4. Quantum theory.
'The instructor should select sparingly from these topics or from other enriching subjects and should introduce into the course only that material which he can discuss adequately in the available time.

'In treating the basic principles and concepts listed above, and in determining additional topics to be included in the course, the instructor may follow various procedures. For example, he may use a historical approach, he may give special consideration to the pre-professional requirements of the students, or he may select topics of particular importance in the development of an understanding of contemporary physics.

'It is apparent that differences in content and approach can and should exist among courses. However, whatever the content selected, it should:
'1. Consist of sufficiently few topics so that each can be treated with thoroughness and intellectual rigour.
'2. Present both classical and modern physics as growing subjects, having present-day frontiers in all areas.
'3. Contribute to an understanding and appreciation of the unity of physics. [2]

Three other general principles that have emerged are noteworthy. One is that so far as possible the basic course should reflect the unity of science rather than be the repository of unconnected pieces of scientific information. A second is that modern material and examples should be introduced as widely as possible from the very beginning of the course (though this does not by any means imply that a basic course must necessarily begin with atomic and nuclear physics!). And a third is

1. 'Syllabus for the One-Year College Course in Physical Science', by Gerald Holton, *Am. J. Phys.*, vol. 25 (October 1957), p. 425-9; 'One-Year Introductory Course in a Liberal Arts College', by Walter C. Michels, *Am. J. Phys.*, vol. 25 (October 1957), p. 430-2; 'Three-Semester Introductory Course for Engineers and Science Majors', by R. M. Whaley, *Am. J. Phys.*, vol. 25 (October 1957), p. 432-5.
2. *Am. J. Phys.*, vol. 25 (October 1957), p. 420-1.

that, at least in the U.S.A. context, we encourage not one or a few solutions, but as many individual different solutions as can claim respect. At the conference setting up the College Commission on Physics, this was strongly stated:

'This conference has taken a strong position against the endorsement of any single course. In fact, it is evident that there is no content structure which would satisfy the requirements of all instructors and all institutions. There is, on the contrary, room in our university system for a broad spectrum of structures to serve the needs of a variety of personal inclinations in a variety of environments. The potentialities of new and unconventional structures should not be ignored. Individuals and groups who embark upon projects of this kind should be given every encouragement. Only through such activities can we expect to maintain both the variety and the high quality which our aims demand.'[1] This point is ideologically typical in the American context. The traditional way of achieving excellence has been through pluralistic, individually competitive efforts, rather than through one or two monolithically organized attempts. I suspect that it becomes very difficult to follow the former rather than the latter model when the timetable of intended achievement on a national scale is severely compressed and particularly when manpower is in short supply. Nevertheless, even under such conditions the risks inherent in monolithic rather than competitive intellectual enterprises must be carefully pondered.

CURRICULUM DEVELOPMENT—PREDOMINANTLY TYPE-A COURSES

In reviewing the best thinking in the U.S.A. on specific curriculum contents of the basic university physics courses, it is well to distinguish between the three types of courses (A, B, and C), and to direct attention to the development of ideas as expressed in recent publications over the past few years in so far as they appear to me to reflect generally held views.

Concerning the Type-A course, i.e. the basic physics course for physics majors and engineers, it was thought by the Carleton Conference Report of 1957 that the typical existing one-year introductory course with laboratory offers sufficient time to fulfil the *minimum* objectives for these students. 'An additional year of physics should be provided for engineers, as has already been recommended by the AIP Committee on Engineering Education.[2] Students majoring in mathematics and students planning to teach physics in the secondary schools should be advised to take this (Type-A) course.'[3] To give substance to the description of a 'minimum-objective' Type-A course as currently offered in the U.S.A., I attach as Appendix B the result of a valuable statistical survey of current practices, made by Dr. L. W. Phillips in 1961. It includes details on total class time spent per year (ten semester hours of credit corresponding roughly to one-quarter of a student's available time for one academic year), timing of the course, mathematics requirements, average enrolment, division of time between large demonstration lectures, smaller discussion sections, and laboratory work, etc. It will be seen that the new trend in Type-A courses is for a striking upgrading of the level, e.g., toward a two-year introductory course, using calculus from the beginning.

Among the number of course syllabuses published in recent years to implement general objectives congruent with those of the Carleton report listed above, I would direct the attention of the serious investigator to the following articles, most of which represent considerable co-operative achievements.

1. *Am. J. Phys.*, vol. 28 (September 1960), p. 569.
2. *Physics Today*, December 1955.
3. *Am. J. Phys.*, vol. 25 (October 1957), p. 422.

Arons, Arnold. 'Structure, methods, and objectives of the required freshman calculus-physics course at Amherst College', *Am. J. Phys.*, vol. 27 (December 1959), p. 658-66.
A one-year course with both rigour (e.g., simultaneous development and use of the calculus) and breadth (e.g., historical discussions), compulsory for all students at Amherst College. Combines Types A, B, and C.

Michels, W. C. 'One-year introductory course in a liberal arts college', *Am. J. Phys.*, vol. 25 (October 1957), p. 430-2.
Applicable to a one-year course for a small college in which students in science and mathematics share the course with all others. It is therefore also a combination of Types A, B, and C.

Whaley, R. M. 'Three-semester introductory course for engineers and science majors', *Am. J. Phys.* vol. 25 (October 1957), p. 432-5.
Designed for a large university as a specifically Type-A course.

Akhmatov, A. S., in S. C. Brown and N. Clarke, op. cit., p. 137.
Sequence of course syllabus for a technical college in the U.S.S.R. There is a close parallel between this syllabus and those for corresponding colleges in the U.S.A., for example.

Fuller, E. C.; Palmer, R. R. 'Beloit Conference on teaching physics and chemistry in a combined course', December 1961.
Copies available from authors, Beloit College, Beloit, Wisconsin, U.S.A. The result of a National Science Foundation sponsored conference for investigating whether and how to teach introductory physics and chemistry together in one course. With syllabuses, texts, etc., of courses in eleven colleges and universities as given at present. Some of these are combinations of Type A, B, and C courses.

Because this is a novel and apparently viable development, and in line with the injunction to oppose proliferation of courses, I attach as Appendix C the discussion of two main points, taken from that report.

Lodge, John I. 'Report of the Denver Conference on curricula for undergraduate majors in physics' and essays by some of the conference speakers, *Am. J. Phys.*, vol. 30 (March 1962), p. 153 f.
This set of essays deals not only with the basic course, but with the whole problem of the science education of physics majors in four-year colleges. A more balanced and useful account of this conference, particularly with respect to the basic course, is contained in the full report of the papers delivered and the group summaries obtainable in lithoprint editions, two volumes, from the Conference Director, Byron E. Cohn, Department of Physics, University of Denver, Denver, Colorado, U.S.A.

Among the points of interest for the Type-A course here is the insistence that 'the introductory course, whenever possible, should begin in the freshman year preferably in the first term'; that 'the course should use the concepts of calculus and should emphasize care and rigour in the presentation of a reasonable number of topics rather than attempt encyclopaedic coverage...'; that 'topics from "modern physics" should be included in the course and ... well integrated throughout'; and that 'there should be a sequential development such that the essential unified nature of physics becomes apparent to the student as early as possible'.[1]

1. *Am. J. Phys.*, vol. 30 (March 1962), p. 156-7. A number of thoughtful and specific recommendations are contained in the paper by R. A. Reitz and in the three group summaries of Groups AI, AII, and AIII (in the lithoprint edition cited above).

Crane, H. R., 'The First Ann Arbor Conference on curricula for undergraduate majors in physics', lithographed edition, Edwards Brothers, Inc., Ann Arbor, Michigan, 1962.

Analogous to the Denver Conference, but of representatives of university physics departments (rather than four-year colleges), concerned with matching undergraduate work to graduate school needs.

Michels, W. C., 'Progress Report of the Commission on College Physics', *Am. J. Phys.*, vol. 30 (October 1962).

Some parts have been quoted above. Two examples of 'radically new' approaches to introductory physics courses which are now being developed are briefly discussed. One is a one-year Type-A, -B, and -C course at Washington University, St. Louis, Missouri. It starts with classical particle mechanics, but draws heavily on twentieth-century physics; similarly, wave motion is introduced with classical equipment but soon connected to electron diffraction. The other is a two-year Type-A course at California Institute of Technology, with lectures by Richard Feynman, which from the start place great emphasis on the quantum-mechanical nature of modern physics.

CURRICULUM DEVELOPMENT—PREDOMINANTLY TYPE-B AND TYPE-C COURSES

Several factors combine to assure that there will usually be more than one basic physics course offered on U.S.A. campuses. From the point of view of the pure mechanics of running the course, we have to deal with the great spread of interests in the student body, the natural maximum in the number of students that can be handled in a demonstration lecture, their very varied preparations (because of the absence of nation-wide standards of secondary school curricula or performance), not to speak of the preferences of the instructor for dealing with a certain group of students rather than with others. Small colleges may not be able to afford giving more than one basic course, and other colleges may—at least for a time—pursue a fine experiment involving their very best lecturers in one joint basic course; but by and large, the pattern of basic physics courses at present seems to be stabilizing around two or three types: The pre-professional course discussed above (Type-A) lasting three or four semesters; a one-year course for premedical and other non-physics science students (Type-B); and a one-year course for liberal arts students, sometimes called a General Education or Integrated Education course (Type-C); or one serving both as Type-B and Type-C together.

Apart from the mechanical reasons for this pattern, there are important differences in the educational function of basic physics courses designed for students who will not continue in the physical sciences as against those who will. I insist that the main subject matter of Type-A, Type-B, and Type-C courses can and should be the same, despite the necessary differences in detail (e.g., mathematical sophistication, additional material beyond the list of 'minimum' topics given in the Carleton Report, etc.). But the basic university physics course offered to non-physical science students (Types-B and -C, or B + C) should take particular care to do its share toward the total orienting process of the young student which is the true function of the college as an institution for education rather than merely for training.

This point is so basic that it merits discussion.[1] The total orienting process of the college student has, it seems to me, at least five goals. If he is to emerge as an educated and sane person from our educational institutions, the student should

1. This passage is based on a paper presented at a Conference on Science in General Education at Michigan University, Oakland, Michigan, May 1962.

be well on the road to recognizing which are his own talents, whatever they may be; second, he should know enough about his physical home, this universe, not to feel either overwhelmed by it or a total stranger in it; third, he should know how to be in fruitful relationship with his fellow men; fourth, he should know what the past means and what the probable future may be; and fifth, he should know the difference between, and the relative functions of, his mind and his soul.

The study of science can obviously not contribute equally, or even predominantly, to every one of these goals. But my fundamental claim is that, particularly, the student who will not go on in scientific studies can and should have science courses which attempt to contribute meaningfully to each of these general goals of education. This does not mean in the least that such courses have to be soft and simple; on the contrary, precisely because of their ambitious goals they surely will have to make as taxing demands on the student (and, it should be added, on the instructor) as any he will ever encounter.

To do justice to the first goal would mean seriously challenging, helping, testing, watching the student, to enable him to discover his abilities in scientific work, including the laboratory, whether he himself had known of any such abilities or not. The second goal implies the all-but-impossible attempt to teach him, in the limited time available, enough basic and substantive material to show that the natural universe is fundamentally knowable. To do this right would require at a minimum, in my view, a year of selected work in physics, with elements of the calculus developed separately or as one goes along—and with excursions into elements of astronomy and chemistry—and then a second hard year of selected work in chemistry and biology. The third goal implies that he should hear at least on occasion about the social activity called 'science' (which is not at all identical with the textbook content also called 'science'); indeed, in such a course we have a striking opportunity to show the magnificent plurality of roles of the individual—as a transformer of accumulated knowledge, as a member of a chain of teachers and students, as a collaborator in teams and social groups.

The fourth goal implies such courses will not shrink from showing at the proper time that science has its historic tradition as well as its characteristic way of growing and, as it were, of anticipating the future. For on the one hand, science grew not by the destruction of old knowledge and rebuilding on totally new lines, but rather like a tree, ring by ring, where the inner layers are invisible though nevertheless still responsible for the strength of the whole structure of which only the outer part is seen. And, on the other hand, scientists do differ from most other scholars in the degree of optimism and future-directedness, a quality that at its best is the proper antidote to the existential despair so fashionable elsewhere.

The fifth goal would require us to tell our students—or have them read—at least on occasion what has been thought to be the philosophical meaning of scientific knowledge; this is, of course, often said to be an unnecessary preoccupation, particularly by scientists—with the significant exception of the really great ones, from Aristotle to Kepler, and from Newton to Niels Bohr.

It should be immediately obvious that I am not in favour of throwing the non-science student into the introductory departmental specialty course directed primarily to an audience expected to make physics or engineering its profession, as is still often done. In such a course, the orientation function is necessarily a narrow one. Here, the classroom usually resembles a training ground at the foot of a large mountain that is to be conquered stage by stage by selected students in later years. Here, next to the student with lungs that naturally accommodate themselves to high altitudes and who was born with climbing boots on his feet, there sits by administrative edict the eternal lowlander, the stolid farmer or congenital subway rider, and the dreaming sailor, or even the adventurous deepsea diver. Silently do these listen and exercise the mass of technical instructions guaranteed to pay off in the exhilarating climb in which, alas, they themselves will, of course, never take part.

These remarks provide the theoretical background against which I would suggest one views the practical solutions, the design of Type-B or Type-C course curricula.[1] The pure Type-B course is so old and so standardized that very few recent publications exist—or are needed—that describe it. A number of pure Type-C courses are described in a recent book, *Science in General Education*, edited by R. R. Haun.[2] In line with the principle of parsimony enunciated earlier, I prefer to draw attention here to the newer, combined Type-B and -C course, which should be of special interest to condensed-schedule efforts that have to work with a short supply of trained manpower. An article entitled 'Syllabus for the one-year college course in physical science', commissioned from this author by the Carleton Conference to illustrate operationally how the recommendations of the Carleton Report may be implemented in a course for students not intending to major in the physical sciences, was published in 1957[3] and has been in use at Harvard College, among others. As Appendix D, I attach the description, syllabus, reading, experiments, etc., given in that article, updated to take into account recent developments in this Type-(B + C) course. As in the Type-A course, the rapid change in the state of physics has forced a severe reassessment of what should go into such a course, and helps to explain why many topics held to be sacrosanct some ten or twenty years ago no longer appear in the syllabus at all.

For the consideration of this Unesco conference I would particularly suggest that the discussion concentrate on two aspects of the basic university physics course:

1. The two-year Type-A course closely linked with (a) previous training in science and mathematics, (b) concurrent further mathematics training in other college courses, and (c) subsequent science courses expected to be taken by the pre-professional physics or engineering student, and
2. The combined Type-(B + C) one-year physical science course, closely linked with (a) previous training in science and mathematics, (b) concurrent further mathematical development as required in the same course, and (c) a subsequent one-year natural science course continuing the science education into more chemistry and biology. While other types of courses will continue to exist, in so far as is possible students should, in my view, be channelled more and more into one or the other of these. In so far as this twofold scheme represents a saving of high-level staff and of manpower that otherwise might be more fragmented among larger numbers of physics courses, it should be possible to insist that these courses are given and supervised by the most talented and eminent department members who can be persuaded to assume the important and difficult task of introducing large numbers of students to our beloved science.

RECENT WORK ON LABORATORY AND APPARATUS

The role and suitability of laboratory work in basic physics courses has been vigorously discussed since that novel idea was introduced. Among recent contributions to this subject in our country I suggest study of the following items:

1. A few courses seem to have achieved satisfactory results under local conditions with all three types of students, as listed in the last section under items (a), (b), and (e).
2. W. C. Brown Co., Dubuque, Iowa, 1960.
3. G. Holton, *Am. J. Phys.*, vol. 25 (October 1957), p. 425-9.

Brown, S. C., 'A survey of elementary physics laboratories', *Am. J. Phys.*, vol. 21 (1953), p. 411 f.

A report on laboratory administration, instruction, and grading in twenty-five colleges and universities.

Overbeck, C. J., editor, *Proceedings of the Northwestern University Conference on the Training of College Physics Laboratory Assistants*, photo-offset edition, Northwestern University, Evanston, Illinois, 1954.

A lively and useful compendium on an often-neglected problem, reflecting the varying experiences of over forty participants. Such training is, of course, important not only for the health of the course itself, but also is perhaps the best way of instructing future physics instructors.

Michels, W. C., 'Laboratory instruction in general college physics', *Am. J. Phys.*, vol. 25 (October 1957), p. 436-40.

Summary of Proceedings of the Connecticut Conference on *Laboratory Instruction in General Physics*, which was published under this title in photo-offset edition at the University of Connecticut, Storrs, Connecticut, 1957. The longer report contains also an annotated bibliography of articles on the subject.

A strong plea is made to make the laboratory meaningful to the course objectives and challenging to the student. The whole range of devices—from entirely 'free' laboratory to rigid 'fill-in' forms—is discussed, showing how closely the laboratory part of a course is coupled to the course's history and the instructor's temperament.

Michels, W. C., 'The role of experimental work', *Am J. Phys.*, vol. 30 (March 1962), p. 172-8; and Neher, H. V., 'The role of experimental work', *Am. J. Phys.*, vol. 30 (March 1962), p. 186-90.

These were part of the Denver Conference (see above); comments from three study groups at that conference are given in the report cited on p. 19.

Michels, W. C., 'Progress report of the commission on college physics', *Am. J. Phys.*, vol. 30 (October 1962).

Notes the general 'agreement that the laboratory needs improvement more than does any other portion of physics teaching. These opinions echo those of a great majority of teaching physicists. . . . At least one of the causes of the general dissatisfaction with laboratories and demonstrations lies in the fact that new apparatus has not been made available to match the changes that have been taking place in the content and tone of physics courses. Although needs have been recognized for many years, most of the commercially available equipment consists either of slightly modified versions of old items or of apparatus that has been designed for other purposes and whose educational function is an accidental by-product. At the present time we are badly in need of as sweeping a change as was introduced in the late nineteenth century and that made available the calorimeters, linear expansion apparatus, and the other items that still crowd many of our stock rooms. Such a change can be brought about only if physicists exercise considerable inventiveness and if ways can be found to clear the bottlenecks that impede production and distribution.'

I can select here only a few topics for brief comment. The first is, again, the formulation of aims. If there is relatively little time for the laboratory, as is the case in most U.S.A. college courses, one must tailor one's hopes to manageable proportions. The primary purpose of laboratory work in the introductory physics course is the teaching of fundamental concepts and principles. Only if there were enough time could one hope to do more (e.g., create research atmosphere, develop experimental skills in a serious manner, etc.). Therefore, I have come to see that one should select for the laboratory exercise those concepts, principles, and devices (e.g., uncertainty of measurement, mass, conservation of energy, electronic circuits, radioactive half-life) which students can more easily and clearly grasp when the discussion in lecture and conference is supplemented by actual experience in the laboratory. Thus, laboratory work plays the role of a *teaching aid* in the design of the whole course.

In addition, we can hope even in a brief laboratory to give each student a chance to expose himself to the problems of experimental inquiry—to learn how to plan the attack upon a physical problem, how to recognize when things go well, and how to help oneself when they do not, how to evaluate the reliability of observations, and how to get the most information and enjoyment out of a job well done.

In many cases, a subject can be covered just as well in the laboratory as in lectures (e.g., geometrical optics). This is worth trying, for it not only frees precious lecture time, but also gives the student extra motivation for the laboratory. [1]

Manpower and money are clearly the main difficulties with many laboratory courses. The tendency must be strenuously resisted to let the laboratory become the stepchild of the course. The assistants should be the best and the best trained graduate students or, preferably, higher faculty members. In any large course a good part of one physicist's time should be reserved for watching and improving the laboratory; for example, one or two experiments should routinely be jettisoned each year to make room for newer and more up-to-date physics and apparatus. This is expensive and time-consuming—but unless one insists on it, one will soon find the course to have settled into a state of petrification.

The unavailability of good, inexpensive, ingenious apparatus is another road block, as indicated in the quotation above. Hence, one of the aids a course head must have is accessibility to and budget for machine shop, supervisory personnel, trained curators, etc. Among the publications of tested ideas for laboratory and lecture experiments, I single out the following:

Kelly, W. C., *Apparatus for Physics Teaching: Reprints of Articles from the American Journal of Physics*, published by the American Institute of Physics for the Committee on Apparatus for Educational Institutions of the American Association of Physics Teachers, 335 East 45 Street, New York 17, New York (September 1961).

Apparatus Drawing Project prepared by R. G. Marcley for the American Institute of Physics, New York, and published by Plenum Press, Inc., 227 West 17 Street, New York 11, New York.

Contains detailed description of and professional shop drawings of thirty major pieces of laboratory and demonstration equipment, many on the basic physics course level. The material had been published during the past two years in part in the *American Journal of Physics* as a project that is continuing. The apparatus for many of these experiments has been constructed on the basis of these drawings, and is available in relatively inexpensive kit form from the Ealing Corporation, 33 University Road, Cambridge 38, Massachusetts.

Brown, T. B., Editor, *The Lloyd William Taylor Manual of Advanced Undergraduate Experiments in Physics*, Addison-Wesley Publishing Co., Reading, Massachusetts (1959).

Among the many experiments described here, one can find good hints for improving basic physics experiments.

1. A laboratory manual with this point of view has been prepared by the author for his courses under the title *Experimental Physics* (Harvard University), Department of Physics, Cambridge, Mass., 1956.

'Apparatus notes', 'Apparatus drawing project', 'Reviews' of new apparatus, and other such articles, appearing regularly in the *American Journal of Physics*.

Eaton, V. E., *Proceedings of the Wesleyan University Conference on Lecture Demonstrations*, Wesleyan University, Middletown, Connecticut.
A discussion of all aspects of lecture demonstrations, under the headings: value of demonstration lectures, demonstrations, demonstration techniques, television, space and equipment, inexpensive and simple apparatus, developing skilled demonstrators, problems of curator and assistants. The main recommendations are given in the article 'Wesleyan Conference on demonstration lectures', *Am. J. Phys.*, vol. 28, September 1960, p. 539-41.

There are other efforts that are very promising and to which in such a brief article adequate justice cannot be done. A Science Teaching Centre has been set up at the Massachusetts Institute of Technology in Cambridge in which distinguished faculty members, on time released from teaching duties, are helping to develop systematically new and interesting teaching apparatus, films, kits for doing laboratory work in the student's own room, etc. This excellent idea should be more widely copied and supported by academic administrators. A number of other kits for home and laboratory work are being prepared at the Educational Services, Incorporated (ESI) in Watertown, Massachusetts (in addition to the vigorous film developments of this group, which has now expanded from secondary school curriculum aids to college as well as elementary school levels). And a group of physicists at Rensselaer Polytechnic Institute in Troy, New York (under R. Resnick and H. Meiners) are making an intensive attack to locate and describe all new and improved pieces of lecture demonstration equipment for college physics, to be published in a year or two in a book that is planned to supplement the long established book on this subject by R. M. Sutton.[1]

FILMS, TELEVISION AND OTHER NEWER TEACHING AIDS

It is clear that these newer teaching aids are going to loom large in the United States in the near future, but it is also evident that few people or organizations are sure about the direction and potential of the course of development. At present, interesting developments at a number of places are being watched with care by all who are concerned with the teaching of physics. As more money is becoming available for physics teaching, and as the staffing problem continues to mount, there is no doubt that a break in tradition is coming. It may well be that ten years from now no good physics lecturer, particularly for large groups, will want to do without the substantial use of film and closed-circuit television. When planning and building, we should anticipate that day even now.

Some resource discussions for these newer media are contained in the following publications:

Brown, S. C.; Clarke, N., 'The use of television and films in physics teaching', Chapter 9, op. cit.
Contributions by H. E. White, W. C. Kelly and others, mainly concerned with United States practices.

Cassirer, Henry R., *Television Teaching Today*. Unesco, 1960, Chapters 1 to 10, particularly p. 99-113.

1. R. M. Sutton, *Demonstration Experiments in Physics*, New York, McGraw-Hill Book Co., Inc., 1938.

Though mainly concerned with teaching below the university level, this book contains careful data and stimulating suggestions for all levels.

Weber, R. L. 'Films for students of physics', *Am. J. Phys.*, vol. 29 (April 1961), p. 222-33, and Supplement I, *Am. J. Phys.*, vol 30 (May 1962), p. 321-7.

Excellent catalogues of selected available films, with sources, costs, etc., for teaching basic university physics, including those prepared by ESI and the Visual Aids Committee of AAPT. A number of problems and plans in connexion with the use of film are discussed in Michels, W. C. (p. 69, 'Progress report...' of this essay).

Tendam, D. J.; McLeod, R. R.; Snow, R. E., 'An experimental evaluation of the use of instructional films in college physics', *Am. J. Phys.*, vol. 30 (August 1962), p. 594-601.

Presents data in support of assertion that (1) 'presentation of lecture-demonstration experiments by film is as effective instructionally as the conventional method of presentation, and (2) student achievement is independent of the distance up to 60 ft.' from the demonstration for 'both methods of presentation'.

'Resource Letters'. Initiated by the author of this report, and developed with the backing of the United States Commission on College Physics, a new teaching aid has begun to be available recently. In the Commission's Progress Report (see p. 69) this is decribed as follows:

'Although the commission is placing emphasis on co-operative efforts in course development, it recognizes that the success of any course must depend primarily on the instructor. Very few instructors are able to limit their teaching to the subjects in which they can keep abreast of all current developments. Hence the commission, in its early deliberations, saw the need for regularly issued bibliographies, each designed to place in the hands of college teachers references to significant books and articles dealing with some one part of physics. This concept was developed . . . into a plan for 'Resource Letters' which include not only [critical] bibliographical references but also lists of films and apparatus, with sufficient comment to aid the instructor in his search for the most suitable materials for his purpose. . . . On behalf of the commission, three Resource Letters were prepared during 1961-62:

"PL-1. Polarized light". Prepared by William A. Shurcliff. Published in *Am. J. Phys.*, vol. 30, p. 227-30 (1962).

"PP-1. Plasma physics". Prepared by Sanborn C. Brown. Published in *Am. J. Phys.*, vol. 30, p. 303-6 (1962).

"SRT-1. Special relativity theory". Prepared by Gerald Holton. Published in *Am. J. Phys.*, vol. 30, p. 462-9 (1962).'

The American Institute of Physics, which has distributed the first three Resource Letters to all teaching physicists in the U.S.A., is now preparing packages of reprints to go with all future Resource Letters; titles scheduled for early offering are 'Quantum and Statistical Aspects of Light', 'Mössbauer Effect', 'Kinematics and Dynamics of Satellites'.

Inexpensive books to supplement a student's course reading. The rise of paperback books in the U.S.A. has had its effect on the physics course also, first in the Science Study Series (Doubleday and Co.) for secondary schools, and now in a number of newly starting series on the next-higher level, including the Momentum Books of the Commission on College Physics. In certain sciences (e.g., biology), enough good, inexpensive, short books have been published so that an instructor can 'mix' his own textbook for his class from existing parts. This may well become not at all unusual in basic physics courses in the future. Special topics and newer engineering applications of science will certainly find their way soon into our courses by this device.

FURTHER PROBLEMS AND CHALLENGES

Further beyond the horizon are a number of other problems and challenges which do not yet appear to be on the way to solutions. Among them is the possible use of teaching machines to supplement instructors; the use of small groups of interacting students, as in reading or 'research' seminars in the basic physics course; the neglected possibility of co-operative relationship with other academic departments (not only mathematics, engineering, chemistry, and astronomy, but also biology, history, and philosophy) in order to make all their basic courses more meaningful; and, most strikingly, the preparation of useful and validated tests for the selection of students, for the course itself, and for the evaluation of curricular changes. [1]

On the other hand, one can see everywhere signs of an increased awareness that the physics teacher has learned a technique for amplifying his effectiveness which has been of great and increasing help to the physics researcher for over thirty years. He is learning that the older model of isolated teachers in isolated systems can be supplemented by the newer trend of rising strong, businesslike, non-bureaucratically oriented organizations—to help set standards, to exchange ideas, to collaborate with similar groups elsewhere, to keep self-examination and innovation before us, and to help raise money for better instruction and experiments. We need good, flexible organizations, controlled by the concerned instructors themselves, on the local, national, and international level. Groups and organizations such as a local Science Teaching Centre, a national Association of Physics Teachers, and a section of Unesco or IUPAP can and should aspire to these several functions. Particularly, the rapidly developing regions need the strength and stability of such organizations. This, I have no doubt, is an essential point to consider at this conference for every one of the sciences represented here.

This list of unmet challenges turns my thought back to the specific problems of the compressed-schedule efforts, particularly those in developing countries. In the teaching of basic university physics, as in so many other contexts, our aim must be to bring about immediate and striking increases in the slope of the curves plotting the number of trained teachers, the number of well-prepared and well-motivated students, the amounts of money available for better and more assistants, buildings, apparatus and other teaching aids, etc. In addition to numerical increases, we look to striking increases in quality.

How shall all this be achieved? We have only three general methods at our disposal. One is dedicated work on the level of the aided invididual, e.g., the gifted instructor who is being given incentive and time to work up a good course. The second is the level of organized activity on a large scale, e.g., through a national or international Commission on College Physics. But both of these will inevitably tend to develop only existing ideas and fall into well-established traps unless they embrace the third method, on which probably everything depends: It is the ability of some individuals and some groups to invent short circuits across existing problems (e.g., in the U.S.A., where science teaching centres can hope to by-pass the reluctant and tariff-protected apparatus manufacturers who have been a roadblock to better science teaching for decades).

Here, I think is the real challenge before each of our countries and each of us as

1. The repeated and inconclusive discussion of tests recorded in: S. C. Brown and N. Clarke, op. cit., shows that this is an internationally prevalent problem.

individuals: How to free both our minds and our physical or financial circumstances, so that we may be ingenious, bold (and, if necessary, agressive) enough to invent short cuts by which to turn our liabilities into advantages. This is the philosopher's stone with which one can hope to make striking qualitative and quantitative changes in the existing methods of teaching basic university physics to the ever-increasing number of students which the future is putting into our hands.

APPENDIX A

PERTINENT RESOLUTIONS OF THE 1960 INTERNATIONAL CONFERENCE ON PHYSICS EDUCATION[1]

The conference has accepted, without dissent, the following resolutions. Some of the comments and recommendations concerning education in physics may apply to education in other subjects, and we are particularly aware that similar consideration might profitably be given to the teaching of chemistry and mathematics, subjects which need to be taught effectively if the efforts of even the best physics teachers are not to be seriously impaired. However, since this conference has been composed exclusively of physicists, we have limited our comments and recommendations to the subject on which we may claim to speak with authority.

I. In our view, physics is an essential part of the intellectual life of man at the present day, and the study of physics provides a unique interplay of logical and experimental disciplines. The study of physics and the physicist's methods of acquiring and evaluating knowledge should therefore be regarded as a necessary part of the education of all children.

II. In many countries, education in physics, both for non-specialists and for future specialists, is unsatisfactory. In all countries, improvement is essential at some levels of teaching. Experiments have been initiated in some countries to try to find ways to make improvements; we welcome and encourage such experiments. They are particularly necessary and important at the level of secondary schools or their equivalent. Experiments and solutions will probably take different forms in different countries.

We should like to see one or more international institutes established, among their functions being the devising and carrying out of experiments of this kind.

We recommend to the International Union of Pure and Applied Physics that it should take appropriate action, possibly in collaboration with other international organizations, to establish an international committee of professional physicists to accept responsibility for:

1. The collection, evaluation, and co-ordination of information and the stimulation of experiments at all levels of physics education.
2. Suggesting ways in which the facilities for the study of physics at all levels might be improved in various countries.
3. The collection and evaluation of information on methods used for the assessment of standards of performance of students of physics and for the evaluation of the qualifications and effectiveness of teachers of physics.
4. The giving of help to teachers in incorporating modern knowledge in their courses.
5. The promotion of the exchange of information and ideas among all countries by methods that would include the holding of international conferences.

III. We stress that efficient instruction in physics requires specialized teachers who can keep abreast of developments in a rapidly growing subject. We are alarmed at the present shortage of such teachers, particularly in view of the growing demand for physics education. The shortage is likely to become more acute in the years ahead.

In our opinion, steps should be taken to improve both the efficiency and the attractiveness of physics teaching as a profession. Insofar as the realization of these aims requires action by governments and universities, we recommend that these bodies should consider the following general conclusions:

1. In schools of secondary and higher levels, physics should be taught by physicists, that is, by men and women who have received a professional training in physics. Teachers must be encouraged to keep their professional experience up to date. The experimental nature of physics places an added burden on the teacher, and this must be recognized and adequately compensated by a reduction of his teaching hours and in other suitable ways.

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1. From S. C. Brown and N. Clarke (Eds.), *International Education in Physics*, Proceedings of the International Conference on Physics Education, Paris, Unesco House, 18 July to 4 Agust 1960; New York, The Technology Press and John Wiley and Sons, 1960, p. 1-3.

2. To make teaching careers more attractive, improvements of salary and status are necessary in some cases, but most important are better conditions of work. For example, technical assistance and liberal provision of apparatus are vital, and facilities should be provided for all students at all levels to carry out experiments. Secondary school teachers should have conditions in which they can feel that they form an integral part of the development of physical knowledge.
3. Universities and comparable institutions should accept their responsibility to establish close relations with secondary school teachers, to assist in solving the problems of instruction in schools, and to provide refresher courses. These courses would require extended periods of study leave for teachers.

APPENDIX B

DATA ON CURRENT INTRODUCTORY TYPE-A COURSES IN THE U.S.A.[1]

INTRODUCTORY COURSES IN PHYSICS

In those institutions offering more than one introductory course (see Table VIII), there is usually no specific requirement that students intending to major in physics take a particular introductory course, although it is the normal pattern for one of the courses offered to be designated as the one recommended for physics majors, and for that course to be the primary avenue through which students move to the physics major programme. The data below are based on the courses, one at each institution, which normally (or most often) serve as the introductory course for physics majors.

TABLE VIII. Percentage of schools offering only one introductory physics course[1]

School size	Number of schools reporting	Percentage offering only one introductory physics course
200-499	13	77
500-999	70	56
1 000-1 999	77	30
2 000-4 999	50	18
over 5 000	21	10
	—	—
TOTALS	231	36

1. This does not include Ph. D. degree-granting institutions.

SURVEY OF PHYSICS CURRICULA

Table IX supplies some information about these courses—duration in semesters (or the equivalent) and course credit in semester hours (or the equivalent)—the tabulation broken down by school size and by type of institutional support. The table lists the number of schools in each category offering courses of the indicated duration and with the indicated number of credit hours.

1. Excerpted from L. W. Phillips, 'Some results of a survey made in preparation for the Conference on Curricula for Undergraduate Majors in Physics', *Am. J. Phys.*, vol. 50 (March 1962), p. 210-13.

TABLE IX. Number of schools versus introductory course duration and introductory course credit

	Total number of schools	Length of course (semesters)				Credit in semester hours			
		<2	2	3	4	<8	8	10	>10
By school size									
200-499	13	—	11	2	—	1	6	4	2
500-999	70	2	63	3	2	3	38	22	7
1 000-1 999	77	1	69	4	3	5	36	28	8
2 000-4 999	50	—	39	10	1	2	11	26	11
over 5 000	21	—	14	7	—	—	2	15	4
By type of support									
State-supported	68	—	55	13	—	1	16	37	14
Private, denominational	119	—	107	8	4	3	57	46	13
Private, nondenominational	44	3	34	5	2	7	20	12	5
TOTALS	231	3	196	26	6	11	93	95	32
Percentages	—	1.3	85	11	2.6	5	40	41	14

From the data in Table IX and from replies to other questions not tabulated here in detail, one gets a rough description of the 'average' introductory physics course now offered, in this group of institutions, to students going on into a physics major programme. The average course carries about 4.3 semester hours of credit per semester and runs for about 2.2 semesters—a total of about 9.4 semester hours of credit. Almost always (nine exceptions out of 231) laboratory work is an integral part of the course. In eight of the nine exceptions, laboratory work is taken concurrently as a separate course; in only one case is the course strictly a lecture-recitation course with no accompanying laboratory.

About 58 per cent of the courses are intended primarily for sophomore registration, some 28 per cent for freshmen or sophomores, and about 16 per cent are designed specifically for freshmen. If one considers only those institutions at which a single introductory course is offered, the 'freshman' to 'freshman-sophomore' ratio is almost inverted: 55 per cent of the courses are for sophomores, 27 per cent for freshmen, and 18 per cent for freshmen or sophomores. In general, it appears that, at somewhere in the neighbourhood of one-fourth of the institutions, students intending to major in physics get their introductory college physics in the freshman year.

Out of 199 schools supplying specific information about mathematics requirements, 21 (11 per cent) indicate the calculus (or a mathematics course which, though it may be listed under a different title, includes some calculus) as a prerequisite to the introductory course, and an additional 90 (45 per cent)require concurrent registration in calculus. About 10 per cent have no specific mathematics requirement, although college algebra or trigonometry are often listed as 'recommended'.

The average enrolment is about 75 (ranging from 5 to 500), the median is very close to 45, with a total course enrolment of 20 or less in 33 of the schools reporting, and 10 or less in 8 of them. Clearly, there are many in which the total enrolment is too large to be handled as a single unit, and the class is therefore broken down into 'sections' of manageable size. There is little uniformity in the ways in which this breakdown is accomplished, but they may be characterized as of two basic types, or combinations thereof:

1. The class is divided into sections of a given size (say 25 students) and each section is carried, almost completely isolated from all other sections in the course, through all phases of the instructional programme—lectures, class discussions, problem-solving sessions, laboratory work, and examinations.

2. The instructional programme is separated into three parts—formal lectures, recitation or discussion sessions, and laboratory work—and the students are assigned to sections in each of these categories, with sections of the size most appropriate or most convenient to the particular kind of instruction. For example, a course of 100 students may be handled as a single unit for formal lectures and separated into four sections of 25 each for recitation, discussion, and problem solving, and into five sections of 20 students each for laboratory work.

One quite common technique, a mixture of the two above, involves separation of the class into sections of one particular size for laboratory work and into another group of sections, usually somewhat larger in size (and sometimes the entire class), for combination lecture and recitation-discussion periods. Sometimes certain periods are designated for formal lectures and others for recitation-discussion; in other cases, no such distinction between lecture and the less formal recitation-discussion type of instruction is made.

TABLE X. Number of schools with enrolments of indicated size in courses, in recitation-discussion section, and in laboratory sections

Enrolment	Total course	Number of schools with enrolments of indicated size in:	
		Rec.-disc. section L and RD[1] separated	Rec.-disc. section L and RD[1] not separated
1-10	8	2	6
11-20	25	29	33
21-30	36	26	44
31-40	31	12	29
41-50	26	8	12
51-60	14	6	6
61-70	11	2	—
71-80	13	—	4
81-90	11	—	—
91-100	5	—	2
100-150	25	—	1
151-200	10	—	—
over 200	14	—	—
Average size	75	27	31
Median size	45	24	27

Enrolment	Number of schools with indicated laboratory section enrolment		
	Sectioned	Not sectioned	Total
under 10	6	1	7
10-14	35	12	47
15-19	39	12	51
20-24	46	9	55
25-29	14	7	21
over 29	12	26	38
TOTALS	152	67	219
Percentages	69	31	100
Average size	19	28	22
Median size	18	24	20

1. L and RD: Lecture and recitation-discussion.

For example: at one institution, with a total course enrolment of 40, the students meet as a unit for three 'lectures' per week, and the class is broken into three sections for one 'recitation-discussion' period per week and into five sections, each meeting for one three-hour period per week, for laboratory work. At another institution with a total course enrolment of 140, there is no sectioning; the class meets as a unit three times each week for a combination of lecture and recitation-discussion, and there is no laboratory work. Of five institutions with course enrolments of between 91 and 100, three break the class into smaller sections for both recitation or discussion and laboratory, while two, though sectioning for laboratory, handle the entire enrolment as a unit for the other parts of the instructional programme. In general, about 70 per cent of the institutions break the class down into smaller sections for laboratory work, and about 40 per cent section the class for non-laboratory work. Enrolments and section sizes are given in Table X.

Where there is a distinction made between 'lecture' and 'recitation-discussion' periods, there seems to be a general tendency toward more lecture periods and fewer recitation-discussion periods per week, probably as a device for more economical use of staff time. About 35 per cent of the institutions make this distinction, and in them the (lecture: recitation-discussion) time ratio is as shown in Table XI.

TABLE XI. Lecture: recitation-discussion time ratio

Lecture: rec.-disc. time ratio	Number of institutions	Percentage of institutions
1 : 3,[1] 1 : 2, or 2 : 3	8	12
1 : 1, or 2 : 2	9	14
3 : 2, or 2 : 1	21	32
3 : 1, or 3 : 0	27	42

1. Numbers recorded here are actual numbers of periods per week.

Length of class periods, for lectures and for recitation-discussion sessions (and for the combinations when no distinction is made) is almost universally from fifty to fifty-five minutes. In a few institutions, laboratory sections meet twice each week (usually for about two hours per meeting), and two institutions report laboratory sections meeting every other week, but in over 97 per cent of the cases one laboratory meeting per week is the normal schedule. Duration of the laboratory period varies quite widely, as indicated in Table XII.

TABLE XII. Duration of laboratory periods[1]

Length of laboratory period[2] (minutes)	Percentage of institutions
100	10
110-120	44
150-165	16
170-180	28
195-210	2

1. Includes only institutions in which labs meet once each week.
2. Average laboratory period is 140 min.

In 6 per cent of the institutions, students work alone in the laboratory; in 73 per cent they work in pairs; in the remaining 21 per cent, in groups of three or four, or in a few cases, five. In 31 per cent the laboratory runs on an 'even-front' scheme, all students in a section working on the same experiment; in 69 per cent, several experiments are in operation at the same time—usually four or five, but in a few cases as many as ten. In almost all cases, the students do one complete experiment at each laboratory meeting. Written reports on all experiments performed are required at 89 per cent of the schools; the other 11 per cent either require reports on only some of the experiments, or substitute examinations, oral reports, or the keeping of a 'research-type' laboratory notebook for formal written reports. Of those requiring formal written reports, 53 per cent characterize them as 'complete', 29 per cent as 'brief', and 18 per cent as 'some complete, some brief'. The report, whatever its magnitude, is written during the laboratory period in 34 per cent of the institutions; outside of the laboratory period in the remaining 66 per cent.

Averaged over all schools in this group, about 80 per cent of the students registered in the course at its beginning complete the course with a passing grade although the percentage varies over wide limits from one institution to another. Of 189 institutions supplying information on this point, there are ten (and these are not always, though usually, in courses with low registration) at which one hundred per cent of the students usually complete the course successfully. At the other end of the scale, twelve institutions expect the successful completions to amount to about 50 per cent and one expects it to be as low as 42 per cent. Table XIII gives the number of institutions at which the percentage of students expected to complete the course with a passing grade is as indicated in the left-hand column.

TABLE XIII.

Percentage of registrants passing the course	Number of schools with indicated percentage passing	Percentage of registrants passing the course	Number of schools with indicated percentage passing
100	10		
95-99	14	65-69	10
90-94	43	60-64	22
85-89	20	55-59	0
80-84	21	50-54	12
75-79	15	45-49	0
70-74	21	40-44	1

APPENDIX C

ON TEACHING PHYSICS AND CHEMISTRY IN ONE COURSE[1]

1. What areas of knowledge usually included in modern introductory physics and chemistry can be taught more effectively in a combined course than in two separate courses?

The study of classical Newtonian mechanics, which introduces the student to the concepts of force, mass work, kinetic and potential energy, and a variety of conservation principles, is basic to the entire field of physical science. This foundation enables the student to gain a deeper insight into the kinetic theory of matter and a sounder understanding of the kinetic-molecular model of matter. The concepts of work and mechanical energy, of the conversion of mechanical energy into heat, of heat as a mode of motion, and of the relation between temperature and the kinetic energy of molecules help him to interpret the changes in thermal energy accompanying changes of state and chemical transformations. Studying the nature of static and of flowing electricity enables him to understand more clearly the involvement of electric energy in electrolysis and the chemical reactions taking place in galvanic cells.

1. From the Report of the Beloit Conference of 1961 on Teaching Physics and Chemistry in a Combined Course, p. 15-17.

Studying the nature of magnetic and electric fields enables him to comprehend more clearly how charged particles moving in such fields behave and how a study of these has led to our contemporary model of atomic structure. Knowledge of atomic structure is prerequisite to understanding contemporary interpretations of the periodic table, the nature of chemical bonding, and the relations between particle size and geometric configuration and the chemical properties of atoms, molecules, and ions.

2. Are there pedagogical or philosophical values in teaching physics and chemistry in a combined course?

There is merit in exposing students to both physics and chemistry in their first year of college in order to enable them to make a wise choice of a major. Since several topics are commonly taught in both physics and chemistry courses, teaching them only once in a combined course saves time for studying other topics. One college reported that almost half a semester in a four-semester sequence of physics and chemistry was gained in this way. The combined course is especially valuable in the curriculum for preparing students to become secondary school science teachers, since they are often expected to teach both sciences. Alternation between the mathematical approach used in physics and the phenomenological approach used in chemistry widens the students' outlook on science and how it develops. They learn something about the difference in 'style' between the physicist's and the chemist's approaches to nature. Students planning to major in chemistry get started in physics at an earlier stage in their education; the opposite is true for students of physics. Students with a strong background in chemistry are able to use this in coping with the physics in a combined course to better advantage than when physics of the same degree of difficulty is taught as a separate course. Their chemical knowledge 'helps them over the humps' in a combined course; the opposite is true for students with a strong background in physics. Applying a given concept (e.g., kinetic-molecular theory) to both chemistry and physics strengthens and deepens a student's understanding of the concept and its usefulness.

Working together in a combined course broadens the outlook of the faculty involved. It is an exhilarating experience to teach such a course; it forces the teacher to choose among the sacred cows of chemistry and physics. The rather drastic changes of approach engendered by a combined introductory course require that the faculty think through and revise the whole curriculum for the major by changes in the course offerings which follow the combined course. Co-operation in the teaching of upper level courses is also encouraged.

Disadvantages in the combined course have been encountered: postponing a well-motivated student's deep and rapid penetration of physics or chemistry; confusing a poorly prepared student by switching from physics to chemistry and vice versa, when care is not taken to integrate the work; increasing the difficulty of co-ordinating a student's work in college with what he had in secondary school—particularly if he had 'advanced' courses in school; complicating problems of administering the course, since more staff members are involved and need to be consulted when decisions are made on staffing, sectioning for lecture and laboratory groups, scheduling examination, etc.; the lack of a wide selection of suitable texts; the difficulty of 'coverage'—the instructor is prone to select too much subject matter from the wealth of material available. It was generally felt, however, that these disadvantages are outweighed by the advantages of integration.

APPENDIX D

SAMPLE SYLLABUS FOR THE ONE-YEAR, TYPE-(B + C) COURSE IN PHYSICAL SCIENCE[1]

Aims and approach

This one-year course is directed to students in the liberal arts and the non-physical sciences. My principal aims are the sound presentation of key concepts and theories of physical science, and the development of intellectual tools for the student's orientation in an age where science has become a dominant cultural force. Physical science is therefore studied both as a body of rigorous knowledge and as a living process of investigation.

The centre of the course lies in physics, although connexions are made to other physical sciences whenever appropriate. Instead of adhering to the ancient but rather arbitrary division of physics into rigid categories (e.g., mechanics, heat, etc.), I let the historical and philosophical development of science suggest the organization and unification of the material. Like others who have tried it, I have found that this approach has several advantages. Occasional well-chosen references to the original work of great scientists can provide the excitement of looking over the shoulder of the originator at his work. A careful study of the meaning of fundamental concepts brings out that feature of science which has made it the proverbial model for effective thinking. And the occasional analysis of procedures and tools of working scientists may help to formulate the student's attitude toward problem situations in general.

However, the main strength of any science course lies in its scientific subject-matter content, and the most important experience we can give a student comes when he finds that he can enjoy and solve a difficult but important problem in science, although it be on the introductory level. This is the prerequisite to an understanding of the physical universe. And if the student does not reach this stage first, attempts to teach the 'meaning' or nature or structure of science can hardly succeed. Therefore, I avoid following the historical line wherever it does not help to clarify the scientific content. In short, in this course the history of science is necessarily thought of neither as a science nor as the subject of main concern, but as a pedagogic aid.

Encyclopaedic coverage—the great stumbling block in elementary courses—has also been discarded; instead of giving a general (and therefore often shallow) survey, I have elected to spend the time on a more careful study of a number of key topics. This choice need not imply a set of unconnected cases; they can be arranged to form a continuously developing story from early beginnings to contemporary research, from Galileo's law of free fall to thermonuclear reactions.

The guiding principle in the selection of subject matter for this form of block-and-bridge course is that each main topic should fulfil two purposes: it must be of interest and importance in its own right, and it must have important links with the rest of the story. For example, the laws of projectile motion are discussed first in connexion with Galileo's contribution to kinematics, but are taken up again several times later: as examples of vector addition; as a special case of motion under Newton's law of universal gravitation; and in connexion with the motion of charged particles in the cathode-ray tube and the mass spectrograph. The same selection principle gives one courage to omit many topics which usually have been regarded as indispensable in the classic type of pre-professional physics course (e.g., photometry, lens aberrations).

Length and level

The course is intended to be taken in the freshman or sophomore year; it meets three hours a week for demonstration lectures, once a week for one and a half hour discussion in smaller groups, and about every other week for a three-hour laboratory session. (This distribution of time is dictated not by some inherent necessity, but by our local circumstances.)

1. Based on article by G. H olton, *Am. J. Phys.* vol. 25, (October 1957), p. 425-9.

Some special features of the course are considered important:

Mathematical level. No special mathematical prerequisite or aptitude is required of the student. But the elements of the calculus are developed and used as the course proceeds, and students who already know the calculus are able to use and extend this knowledge in special sections.

Laboratory work. The laboratory is so designed that it covers material not otherwise elaborated upon in the course; thereby each experiment is endowed with additional validity and student interest, and more lecture time can be given to other topics.

Moreover, if the course is to serve a double purpose, the specific experiments can concentrate on topics which one expects a premedical student to be familiar with (e.g., geometrical optics, electric circuits). Consequently, this course can be considered as one way of fulfilling the premedical physics requirement for students who subsequently decide to apply for admission to medical schools.

Basic topics. The Carleton Report requests that every course which attempts to provide a satisfactory introduction to present-day physics should be constructed around and must encompass a stated set of 'seven basic principles and concepts and the material leading up to them'. In addition, four more topics are given to illustrate how the course content may be enriched if time is available for this purpose after a sound presentation of the basic topics. These specifications are perhaps more difficult to fulfil in the type of course here described than in other physics courses, but I agree that the same basic image of the field of physical science can and should be presented in all courses in which physics is taught. I regard it as axiomatic that there is only *one* physical universe for all of us, not one for physicists and engineers, another for premedical students, a third for liberal arts majors, and so on. It should be possible to meet the special needs and pedagogic problems of each student group without sacrificing the fundamental unity of the subject.

Topics for lectures and discussion periods

The time allowance indicated below for each of the eight parts of the course is only approximate. I have indicated by asterisks those topics which might be discussed in abbreviated form if the local situation should make it necessary to prune the content even further to permit a lengthier treatment of the rest.

Part A. Kinematics (three weeks):

1. Speed and acceleration. (Measurement and 'errors'; motion with constant speed; instantaneous speed; equations of motion for constant acceleration; mathematics and the description of nature.)
2. Galileo and the kinematics of free fall. (Qualitative vs. quantitative science; free fall; experiment and theory.)
3. Projectile motion. (Simple trajectories; vector algebra; general projectile motion; Galilean relativity*.)

Part B. Dynamics (two weeks):

4. Newton's laws of motion. (First law; force; second law; mass and weight; third law; Mach experiment*.)
5. Rotational motion. (Uniform circular motion; centripetal force; absolute and relative space*.)

Part C. The astronomy and dynamics of the planetary system (three weeks):

6. Greek astronomy*. (From Plato to Ptolemy.)
7. The Copernican theory. (Heliocentric system; what is a good theory?)
8. Kepler's laws. (The universe as mechanism; the three laws.)
9. Galileo's contributions to astronomy. (What is scientific evidence? Interplay between philosophic position and scientific theory.)
10. Newton's law of universal gravitation. (Newton's 'rules of reasoning'; derivation of the law; tests.)
11. Some consequences of Newton's work. (Value of G; mass of celestial bodies; shapes of planets*; tides*; 'I frame no hypotheses'; the effects of the great synthesis outside physical science.)

Part D. The conservation principles (four weeks):

12. Conservation of mass.
13. Conservation of momentum. (Collision; explosion*; open and closed systems; angular momentum*.)
14. Conservation of energy in mechanics. (Work; energy; application to previous topics.)
15. Heat phenomena. (Temperature; fluid theory of heat*; specific heat capacity; change of state.)
16. First principle of thermodynamics. (Joule's and Mayer's work; applications.)
17. Second principle of thermodynamics*. (Entropy; direction of heat flow; efficiency of heat engines.)

Part E. Origins of the atomic theory (three weeks):

18. Laws of gases. (Laws of Boyle, Charles, Gay-Lussac; gas models.)
19. Atomic theory in chemistry. (Dalton*; law of multiple proportions*; atomic weights; Avogadro's hypothesis.)
20. The Periodic System of elements. (Valence; Mendeleeff's work; the modern table of elements.)
21. The kinetic theory of matter and heat. (Plausibility arguments; derivation of pressure formula; meaning of temperature; other successes; failures of the theory.)

Part F. Theories of fields in electricity and magnetism (four weeks):

22. Origins of the concepts of field and charge. (Fluid theories*; force-distance law; Coulomb's experiments.)
23. Electrostatics. (Electric field strength; potential.)
24. Electric currents. (Ohm's law*; electrolysis; magnetic fields; current field interaction.)
25. The electron. (Cathode rays; e/m measurement; measurement of e; determination of Avogadro's number.)
26. Electromagnetic waves. (Wave motion in general; electromagnetic waves; Hertz's experiments*.)

Part G. Quantum theory of light and matter (five weeks):

27. Some optical principles. (Light; Huyghens' principle; interference; continuous spectra.)
28. Quantum theory of Planck and Einstein. (Blackbody radiation; photo-electric effect; measurement of h; photon-wave dilemma.)
29. Discrete spectra. (Emission; absorption; Balmer series and others.)
30. Rutherford's atomic model. (Scattering experiments; nuclear charge and size.)
31. Bohr's theory of the atom. (Energy levels; atomic size; emission and absorption spectra; correspondence principle; periodic table; valence; anomalous specific heats*; X-rays*.)
32. Matter-waves and indeterminacy. (De Broglie matter-waves; electron diffraction; reinterpretation of electron orbits; particle-wave duality; complementarity concept; indeterminacy relation*.)

Part H. Nuclear atom and nuclear energy (five weeks):

33. Radioactivity and isotopes. (Discoveries of Becquerel and the Curies; nature of alpha, beta, and gamma radiation; radioactive series; half-life; isotopes; mass spectrography.)
34. Nuclear model. (The proton; artificial transmutation; neutron; induced radioactivity.)
35. Mass-energy equivalence. (Exothermic and endothermic processes; elements of special relativity theory; conservation principle of mass-energy; pair formation and annihilation*; neutrino*.)
36. Nuclear energy. (Discovery of fission; fusion; binding energy; nuclear forces; recent models of the nucleus*; reactors and other applications.)
37. Retrospect. (Conditions for the growth of science; science and the bases of our culture.)

Reading

The textbook on which the course is based (Gerald Holton, *Introduction to Concepts and Theories in Physical Science*, Addison-Wesley Publishing Company, Reading, 1952; or Holton and Roller, *Foundations of Modern Physical Science*, Addison-Wesley Publishing Company, Reading, 1958) contains additional material on the conceptual methods of physical science, which may be assigned as independent reading for interested students.

It is also very instructive to make supplementary reading assignments on specific technical topics in other introductory physics texts (e.g., Sears and Semansky). For further historical and philosophical background material I have found selections from the following references of particular interest and use to students: Herbert Butterfield's *Origins of Modern Science*, E. A. Burtt's *Metaphysical Foundations of Modern Science*, J. H. Randall's *The Making of the Modern Mind*, Lewis Mumford's *Technics and Civilization*, P. W. Bridgman's *Logic of Modern Physics*, and Philipp Frank's *Einstein*.

Laboratory experiments

The Carleton Report recognized that 'physics, as a body of knowledge, is now far too extensive to receive adequate general coverage in an introductory course'. Space for the programme outlined above has been won by giving little or no attention in lecture or discussion to a number of traditional topics (and favourite, hard-won lecture demonstrations)—for example, hydrostatics, thermal expansion, musical sound, lenses and mirrors, magnetostatics, alternating currents, vacuum tubes. For some students, high-school courses in physics will have covered this material. But whether or not such a background can be assumed, the laboratory experience can well concentrate on some of these topics. The following fourteen experiments in this physical science course correspond to experiments usually found in the repertory of the traditional type of college physics course. In the laboratory manual we have developed, the theory of each topic is presented in a fairly self-contained manner: motion with constant acceleration: free fall—Newton's laws: reaction-car experiment—the laws of statics: the crane—rotational motion: centripetal force—conservation of momentum and of energy: ballistic pendulum—the mechanical equivalence of heat—vibration of strings and air columns: wave propagation—electric currents: the potentiometer—the cathode-ray oscilloscope—alternating current circuits—electronics: the triode—lenses and optical instruments—spectroscopy—radioactivity: half-life of thoron, statistics of counting.

IV. A DYNAMIC APPROACH TO UNIVERSITY CHEMISTRY TEACHING

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INTRODUCTION

The classical curriculum in chemical teaching comprises rather voluminous introductory courses in inorganic chemistry, organic chemistry, and physical chemistry. Parallel to these courses, laboratory work is done. In inorganic chemistry it concentrates around qualitative and quantitative analysis, mainly following classical schemes. Inorganic preparations are rather neglected. In organic chemistry much time is devoted to organic syntheses. This synthetic programme is sometimes supplemented by exercises in qualitative organic analysis. Experiments in physical chemistry are usually done in a separate institute and often do not bear any relation to the students' particular work in inorganic and organic chemistry. As a rule, the chemical teaching is supplemented by elementary physics and mathematics.

Advanced students complete their knowledge by attending special courses which treat special subjects such as quantitative inorganic analysis, inorganic co-ordination complexes, nature of the chemical bond, stereochemistry, mechanisms of organic reactions, chemistry of natural products, chemistry of colouring matters, chemical technology of inorganic and organic compounds. The time devoted to such supplementary courses is in most universities comparatively small. The advanced student works mainly in the laboratory in order to get a Ph.D. degree; he has to submit a thesis containing results of research done by himself.

The time required for studies in chemistry varies greatly. The minimum is from five to six years, the average may be seven years. A duration of eight or even nine years is not as rare as one might expect. The duration of his studies is in part controlled by the student. Properly chosen examinations can therefore be a great help to him. The lower limit, however, is set by the amount of knowledge which he is supposed to absorb during his studies, and by the way in which that knowledge is presented to him. A comparison between different universities reveals that teaching systems and required knowledge vary greatly.

The point which counts, however, is not the teaching system. It is instead the yield of the teaching. Today's problem is not so much how to produce good chemists, but how to produce good chemists in a reasonable time. In view of the ever-increasing rate of the development of chemistry, an appropriate choice of teaching subjects becomes all-important. No teaching system can follow the steady accumulation of facts. However, from accumulating facts new principles may emerge, and they do emerge. Teaching must concentrate on such principles.

This means that historical barriers between subjects will gradually disappear. The classical subdivision of chemistry into inorganic, organic, and physical chemistry becomes obsolete. While most university teachers are aware of this fact, old traditions very often prevent a reorganization. In European universities, this constitutes a very serious problem. Young countries thus have an advantage. Every effort must be made to treat chemistry as one subject presenting different aspects and every effort must be made to offer to the student frequent comparisons among these different aspects.

A CURRICULUM IN CHEMISTRY

What is chemistry and what is a chemist?

It is profitable to ponder on that question before setting up a programme of chemistry teaching. Chemistry belongs to the realm of natural sciences. Nevertheless, it is in many ways more an art than a science. To a large extent, chemistry is based on empirical rules. Progress is even nowadays more due to accidental discovery than to logical reasoning. Trial and error play a great role in every chemical achievement. It is true that modern theories on the nature of chemical bonds and on reaction mechanisms are a great help for the design of experiments. This help should not, however, be over-emphasized. There are pitfalls in many cases, because our understanding of chemical events is not good enough. Often the chemist cannot really rely on the theoretical predictions. The very great merit of modern theoretical concepts is seen elsewhere. It is especially seen in the fact that these concepts enable a rational classification of experimental chemical knowledge. The importance of this other side of the picture of theory cannot be overemphasized, neither in practice nor in teaching.

Strangely enough, another aspect of chemical theory, i.e. physical chemistry, is—especially by the organic chemist in continental Europe—very much neglected. This subject may be less glamorous than the electronic theory of organic chemistry. However, physical chemistry offers laws instead of speculations. Every chemical experiment is subject to these laws. The chemist can expect immediate profit if he is willing to eliminate from his work that part of empiricism which can be eliminated by thoroughly applying physico-chemical knowledge. Modern development of analytical methods offers a convincing example of the vast possibilities which physical chemistry offers to the practical chemist. It cannot replace trial-and-error experiments but it can reduce their number.

A further reduction of the number of necessary experiments is rendered possible if the chemist becomes acquainted with a new branch of statistics which has to do with the design and analysis of experiments.

So it becomes apparent that chemistry, while still being essentially an empirical art, is much aided by a certain knowledge in physics and mathematics. Indeed, chemistry may be regarded as applied physics, or at least there is no doubt that physics constitutes one root from which chemistry is growing. However, as a rule, physics only explains facts which have been first empirically observed. It rarely helps to discover new chemistry. Maybe it could do so, but usually the chemist's mind is not comprehensive enough. He must rely mainly on imagination or on his good luck. This is a serious handicap. The modern chemist's situation would indeed be rather awkward, were it not for the fact that he had at hand a most experienced teacher—life. The chemical achievements of life compensate for all the lack of comprehension and imagination in the chemist's mind. He must just be willing to learn from them. Thus life constitutes the second root from which modern chemistry develops. Classical chemical teaching recognized the importance of supplementary courses in physics and mathematics. Modern chemical teaching must recognize the importance of supplementary courses in biochemistry and biology.

Now, what is a chemist? What sort of a student is willing to devote his life to chemistry, which extends on one hand from physics to preparative or analytical laboratory work and further to chemical engineering and large-scale industrial production and, on the other hand, from biology to biochemistry and further to medicine and agriculture? A student of chemistry must have a keen and continuous interest in natural sciences, he must be willing to study physical chemistry, physics and even mathematics, and at the same time he must be willing to admit that his own science, chemistry, is to a large extent empirical. In a way there must evidently be two souls in a chemist's breast. This quality is not frequently found among students. There are many chemists, but comparatively few good ones. We all know the type of person who denies the role of empiricism, and we all know his counterpart who does not accept anything but empiricism. Both of them are wrong and neither one should have started his studies in chemistry. They probably did start their studies because they did not know and were not told in time what chemistry really meant. Sometimes the view is held that the student of biochemistry is more entitled to pure empiricism than his colleague of organic or inorganic chemistry. This is completely wrong. Good modern biochemistry is impossible without very good modern chemistry and all its auxiliary disciplines. A good chemist must at the same time be very critical and very imaginative. He must be able to apply logic where logic can be applied. He must be willing to apply trial and error when trial and error must be applied. He must be prepared to subject his ideas to most severe experimental tests. He must have the imagination to devise such tests and he must have the manual ability to do the respective experiments. Finally he must never tire of repeating such experiments as long as repetitions are seen to be necessary. Students of this kind can only be selected by trial and error. At the very beginning of their studies, one must give them a chance to find out what chemistry means and whether they like or dislike it. The best means to achieve this end is an introductory course.

Introductory course: basic general chemistry

In this title the emphasis is on the word 'general'. The course includes lectures as well as laboratory work.

Obviously, the beginning of such a course must demonstrate everyday life in the chemical laboratory. The student must become acquainted with simple laboratory equipment, with chemical language, and with the chemicals on the shelf. Such acquaintance is best made by using the equipment and experimenting on the properties of the materials at hand. Excellent texts for this purpose are available. Pertinent topics are: general laboratory manipulations, states of matter, atomic and molecular weights, atoms and molecules, electronic charge and radiochemistry, stoichiometry (gravimetric and volumetric), thermochemistry, preparations and syntheses (some inorganic and some organic preparations, fermentation and isolation of ethyl alcohol), kinetics, chemical equilibrium, solutions, electrochemistry, qualitative analysis, viscosity, absorption, diffusion, osmosis, catalysis, photochemistry, colloid chemistry. Each experiment must be accompanied by theoretical considerations. In such a way applied theory is introduced as a part of the experiments. The student thus learns physical chemistry and physics as a by-product. This is a very important point. The student's interests in physical chemistry and physics must originate from his own laboratory work. Only then will he be prepared to accept and to appreciate the more abstract treatment of advanced physical chemistry.

Of course, the process of acquiring theory in such a way takes time. But there is plenty of time. It is only necessary that the student be given physical chemistry in small rations—from the very beginning to the very end of his studies. If it is offered to him as a daily theoretical supplement to his laboratory and seminar work, he will have the opportunity to digest it, and without any effort physical chemistry will for him become an integral part of chemistry. Today's practice is, at least in continental Europe, very different. Physical chemistry is taught within a comparatively short period as an isolated subject. The result is not very satisfactory: to many students physical chemistry becomes a nuisance. The young universities must and can avoid this state of affairs.

Laboratory work in general chemistry must be supplemented by lectures in general chemistry. Starting from the laboratory experience, the lecturer will broaden the student's views, both with respect to facts and theory. Available texts on general chemistry give very good hints to the possible scope of such lectures. They often include a wealth of pertinent questions which may form the basis of frequent and severe examinations. A preparatory course must be tough, because the chemist's profession is a tough profession. The student must find out whether his mental attitude toward chemistry is correct, he must feed his mind with chemical reasoning and he must find out whether he likes or dislikes it. Examinations are considered to be helpful in this process.

It seems advisable to incorporate into the preparatory course lectures on physics and mathematics. Physics is necessary as a supplement to physical chemistry and also in view of the ever-increasing role of instrumentation. For obvious reasons, lectures in mathematics should include differential and integral calculus, vector analysis, some matrix algebra, and some statistics.

The time devoted to this preparatory course may be limited to one year. Students who are definitely not interested in chemistry will have found out by then. It is quite clear that a course of this type demands professors and instructors of high quality and in sufficient number. It should be realized that competent elementary teaching of a broad subject is much more difficult than advanced teaching of a strictly limited subject! At this stage in the educational programme the teacher must not only inform the student; above all, he must form future chemists.

Intermediate undergraduate courses

After the preparatory course, about two years should be devoted to descriptive chemistry and related laboratory work. However, a certain theoretical background must be kept in sight. This will be much easier if parallel lectures are given on the nature of the chemical bond and on stereochemistry. Titles for other lectures might read:

Descriptive inorganic chemistry, and some theoretical background.
Descriptive organic chemistry, and some theoretical background.
Qualitative analytical chemistry (inorganic and organic).
Quantitative analytical chemistry (inorganic and organic).

Supplementary subjects are: introduction to crystallography; general biology; exercises in foreign languages (English, German, French, and Russian).

Laboratory work during these two years should comprise: inorganic and organic preparations, inorganic and organic analysis.

The experiments may be selected in such a way as to offer continuous opportunity for physico-chemical considerations. Pertinent examples are distillation, crystallization, precipitation, extraction, adsorption, countercurrent procedures, chemistry of solutions, electro-chemistry, chemical equilibrium, reaction rates. This programme offers also an opportunity to demonstrate the use of instrumentation and—especially in chemical analysis—the application of statistics.

The general purpose of such an undergraduate course is seen in the accumulation of a certain knowledge of descriptive chemistry and in the development of an understanding of the importance of theory. It may also prepare students for the following studies, again in the field of general chemistry.

A concluding undergraduate year

Main topics are: advanced general chemistry; introduction to biochemistry; advanced laboratory work.

The student is now prepared to appreciate advanced lectures on thermodynamics, reaction rate, kinetic analysis, reaction mechanisms, general aspects of molecular interactions, chemistry of co-ordination complexes, chemistry of macro-molecules, spectroscopy, radiation chemistry.

Laboratory work may be devoted to advanced studies in any desired direction. It will, however, be profitable to include experiments on polymerization and poly-condensation, and experiments in biochemistry.

It seems appropriate here to make a general remark on the type of laboratory work conducted by the students: there are, for example, schools for organic chemistry where the student is supposed to make some thirty to forty organic preparations. Some teachers want him to do as many type reactions as possible. This tendency seems somewhat strange. The student, no matter how long he works, will never acquire a complete knowledge of type reactions. There is no reason why he should study more than a few of them. The art of experimentation remains the same. So does the general chemical reasoning. It is therefore much more profitable to study very few reactions very thoroughly than many of them in a superficial manner. Once a student has got the spirit of chemical experimentation, he will be able to perform any experiment whatsoever, regardless of whether or not any particular experiment had been demonstrated in school. Experiments should rather elucidate the application of physico-chemical principles than merely illustrate reaction formulae.

The purpose of this final course is to give the student the finish necessary to embark upon graduate work in a specialized field. Consequently examinations must show whether he has reached the necessary degree of maturity. If it is found that a student should preferably not continue his studies beyond this stage, he should nevertheless obtain some sort of a degree. That degree will show that he was able to study chemistry for four years and that he can be useful in many positions in research or industry.

The examinations may or may not comprise practical work. Usually a student is so well known to his instructors that too much emphasis on practical examinations does not seem to be warranted. It is important, however, that the student has learned to express himself clearly. Therefore a concise description of some experiments might well form part of the examination.

Graduate studies

The student now specializes in some field of inorganic, organic or physical chemistry, biochemistry or chemical engineering. The choice will not only depend on his abilities, but also on available teachers and on the possibilities of a future practical application of his knowledge. It will be an important function of his professor to give the necessary directions with respect to lectures and seminars to be attended by the graduate student. Two or three years should be sufficient time to complete a thesis. The final examination can well be restricted to the field in which he was particularly engaged.

It goes without saying that the undergraduate programme will certainly have left gaps that can be closed during the time of graduate studies. This last period of the studies is therefore again very important to the student. He is now sufficiently advanced and sufficiently formed to be given plenty of freedom. Lectures can largely be replaced by seminars.

The student now must also learn how to talk and how to write a chemical paper. Cultivation of his language is thought to be of utmost importance. The ability of expressing thoughts is just as important as chemical knowledge and experimental skill.

REMARKS ON LABORATORY EQUIPMENT

A student of chemistry spends the larger part of his time in the laboratory. Adequate equipment is very important. The usual glassware is furnished by well-known companies. On request catalogues are distributed. These contain all necessary information. Regarding instrumentation one may differentiate between necessary and desirable apparatus.

Necessary apparatus: pH-meter, spectrophotometers (infra-red, visible, ultra-violet), polarimeter, refractometer, apparatus for melting-point determination, polarization-microscope, gas-chromatograph, fraction collectors for chromatographic work, apparatus for liquid extraction, equipment for thin-layer chromatography and electrophoresis, centrifuges, balances, high vacuum pumps, constant temperature baths, apparatus for electrical conductivity measurement, machinery for shaking and stirring, iceboxes and a cold-room, equipment for organic micro-analysis, constant temperature room.

Desirable apparatus: Equipment to handle radioactive material, mass-spectrometer, nuclear magnetic resonance, X-ray, polarimeter for rotatory dispersion measurements, electron microscope.

Special equipment for classroom demonstrations seems less important. Classroom demonstrations can never replace personal laboratory experiments. In chemistry lectures to students of chemistry it can therefore be dispensed with. The few really indispensable experiments may equally well be conducted and demonstrated in the laboratory.

REMARKS ON TEACHING AIDS

The modern teacher of chemistry is increasingly discovering the usefulness to his work of the important aids to instruction such as concept films (of very brief duration), of three-dimensional models of molecules and atoms, and even of programmed instruction when this is designed carefully to save him classroom time with routine areas of the subject, such as equation-balancing rules, nomenclature, etc.

In the study of atomic structure, graphical representations can be of a very great help.

Examples are: 'The Electron Chart' by Jack W. Eichinger, Jr., published by Charts, Rt. 4, Box 412, Tallahassee, Florida, U.S.A.; or the 'Electron Locator' by N. D. Weis and J. S. Meek, which helps to find electron distribution in the elements. The 'Electron Locator' is distributed by Verlag Chemie GmbH, Weinheim/Bergstrasse, Germany.

Stereochemical studies are very much aided by atomic models. There are two types available: one type is the space filling model and the other one the so-called stereo model. The first reveals interference between neighbouring atoms. The other allows for studies of bond angles, bond lengths and all sorts of geometrical isomerism. An example of the first type is 'The Courtauld Atomic Models' (Griffin and Tatlock, Kemble Street, Kingsway, London WC2), an example of the second type is 'Dreiding Stereo Models' (W. Büchi, Glasapparatefabrik, Flawil, Switzerland).

The situation with regard to teaching aids is more favourable in the case of laboratory instruction. All general laboratory manipulations, such as recrystallization, distillation, filtration, glassblowing, etc., must be demonstrated by instructors. Such personal instruction could easily be replaced by films, accompanied by written or recorded instructions. Such films do not yet exist, but they could be easily produced and would help to: [1] (a) achieve a wide distribution of competent laboratory technique, and (b) replace a great number of instructors.

At places without equipped laboratories, motion-pictures could even replace practical chemistry teaching. This would not be an ideal solution, but it could considerably speed up the spread of chemistry teaching.

PROBLEMS OF PRACTICAL APPLICATION OF THE KNOWLEDGE OF CHEMISTRY

In fully developed countries chemists go into teaching, research, or production. Young countries first of all need teachers. Not every student, however, can become a teacher. Those who are not needed for teaching will have to start production. At this early stage very few will find themselves in a position to do pure research work.

For obvious reasons, production should be based as much as possible on local resources. It will find much stimulation, if it tries to answer local demands.

Of course, local resources differ widely from country to country. Generally speaking, one might visualize products from mining, wood, agriculture and fishing, and a conceivable power source would seem to be hydroelectricity. Possible products are minerals—including fertilizers, fuel and petrochemicals, processed food, fermentation products from straw and starch. Under favourable conditions some simple pharmaceuticals might also be produced.

As a conclusion it would seem appropriate for universities to offer the possibility of advanced studies in technology of heavy chemicals, of fermentation and of food.

Stimulated by problems of production there will automatically arise a need for applied research. In a process of evolution this will sooner or later end up in pure research and thus create the basis for new industrial development.

The process is, however, a slow one. Its speed depends very much on the personal and technical qualities of the teachers who start to build up a school of chemistry.

1. I have since learned that a motion-picture of this type is available: The Geschäftsstelle der Gesellschaft Deutscher Chemiker (Frankfurt a.M. Karlstrasse 21) offers the 'Farbtonfilm' on 'Laboratoriumstechnik der organischen Chemie' by Professor Dr. L. F. Fieser, Harvard University, Cambridge, U.S.A. Probably an English version is also available.

V. GEOLOGY TEACHING AT UNIVERSITY LEVEL[1]

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The development of society and its productive forces calls for the development of mining, and mining production and the exploitation of mineral deposits in turn require a knowledge of geology. Hence the development of geology as a science, and the training of the necessary staff of specialists, are closely related to the level of the productive forces and needs of a given society or country.

The first mining schools in Russia were opened at the beginning of the eighteenth century, and by the end of that century the mining industry had developed to such an extent that institutions had to be set up to train mining specialists—i.e. to organize specialized training in mining work. I believe I am right in saying that the first advanced school of mining technology in Europe was the High School for Mines set up at Ostrava (in present-day Czechoslovakia) in 1716. Somewhat later—in 1766—a Mining Academy was opened at Freiburg, in Saxony. In Russia, the High School for Mines was opened in St. Petersburg in 1773, and is now known as the Leningrad Mining Institute. Other mining schools were opened subsequently—in Ekaterinoslav (now Dnepropetrovsk), Tomsk and Novoeherkassk. This is one avenue for advanced training in mining and geology which future mining engineers may follow.

Another avenue is by way of the universities, where the emphasis is on broad training in natural history. By the end of the nineteenth century and beginning of the twentieth, a number of universities (Moscow, Kazan, Kiev, Kharkov, Rostov, Saratov and others) had established faculties or departments which provided training for future specialists in geology rather than in mining.

Prior to 1917, Russian higher educational establishments trained very few specialists in geology or mining engineering. One result of the October 1917 revolution was the radical reorganization of public and higher education. In the first place, the number of higher educational establishments was increased. Whereas, in the academic year 1914/15 there were 105 higher educational establishments in Russia with 127,000 students, in 1962 there were no fewer than 725, with 2,396,000 students, or 19 times as many (1961/62).

Thus, at present there are about 400,000 scientific workers in the U.S.S.R., and about 135,000 of them hold academic diplomas or degrees. The number of post-graduate students in geology and mineralogy is about 1,300.

1. Based on data relating to higher educational establishments in the U.S.S.R.

In respect of geological education specifically, the far-reaching changes also, since 1917, have been apparent: there has been a steep increase in the number and improvement in the quality of educational establishments offering courses. The following three distinct avenues for specialist training have emerged: (a) the geological faculties of the universities, whose main function is to provide a thorough course of training for geologists, giving them a sound knowledge of natural history, physics and mathematics so that they will be capable of undertaking both practical and theoretical work in geology, geo-chemistry and geophysics; (b) geological prospecting institutes, which train specialists capable of carrying out geological surveys and investigations and prospecting for mineral deposits; (c) specialized institutes of mining technology (dealing with the mining industry, oil industry etc.), which train specialists qualified to undertake prospecting and to exploit mineral deposits, including the complete cycle of underground operations.

In all, specialized training in geology is provided at twenty-two universities, nineteen institutes specializing in geological prospecting, mining and oil extraction, and eighteen polytechnical institutes. In addition, there are about forty *technicums* which offer training in geological prospecting for middle-level specialists (collectors, mining technicians etc.).

In 1960/61 there were 51,5000 students attending higher educational establishments providing training in the fields in question.

A total of some 100,000 geologists, who have had a higher or secondary education, are now working in the U.S.S.R. They are mainly concentrated in the regional geological administrations of the U.S.S.R. Ministry of Geological Survey and Mineral Wealth, at research institutions and production plants of other ministries, in pits and mines, and at scientific establishments, academies of sciences and higher educational establishments.

Below, by way of illustration, the curriculum is given of the Faculty of Geology of the Moscow State University for the course on 'Geological surveying and prospecting for mineral deposits', with particulars of the structure of the faculty.

The course is a five-and-a-half years one, with two semesters a year, autumn and spring, and examination sessions at the end of each semester. Four (or five) examinations must be taken at each session, and the same number of tests. In the summer, apart from a two-month vacation, the students do practical field work and take part in expeditions.

The following list shows the subjects covered by the curriculum, with a breakdown for each year:

First year (thirty weeks): general geology, 126 hours; higher mathematics, 120; general chemistry, 144; physics (Part I), 72; geodesy, 78; zoology, 60. The first year's lectures are followed by practical work in geology (four weeks) and geodesy (four weeks).

Second year (thirty weeks): physics (Part II), 90 hours; botany, 54; crystallography, 72; physical and colloid chemistry, 120; palaeontology, 162; historical geology, 120. After completing the second year, the students take part in expeditions.

Third year (twenty-seven weeks): mineralogy, 151 hours; petrography (Part I), 168; geological cartography, 140; geological prospecting, 108; geomorphology, 66; palaeozoology, 70; geophysics, 80; industrial safety measures, 22. After completing the third year, students engage in production practice as trainees in geological surveying (eight weeks), drilling practice (two weeks), and specialized practical work according to the various subjects (two weeks).

Fourth year (twenty-eight weeks): petrography (Part II), 80 hours; petrography of sedimentary rocks, 112; geology of the U.S.S.R., 140; charting of magmatic and metamorphic rocks, 64; geology of quaternary deposits, 60; hydrogeology, 60; interpretation of geophysical data, 64; minerals (Part I), 60; methods of stoping, 96. On completion of the fourth year, the students engage in thirteen weeks production practice (expeditions).

Fifth year (twenty-six weeks): minerals (Part II), 156 hours; mineral prospecting, 60; geochemistry, 56; engineering geology, 56; geotectonics, 72; organization and planning of production, 24; history of science, 48; methods of stoping, 156. On completion of the fifth year, the students do eighteen weeks of pre-diploma practical work (on expeditions).

Sixth year (twenty-one weeks): preparation and defence of diploma thesis (report on the pre-diploma practical work); state examination.

In addition to the subjects listed above, the students study a foreign language—English, French, German or Spanish (first to fourth years); social and political subjects—history of the Communist Party of the Soviet Union, political economy and philosophy (first to fifth years); and attend classes in physical training (first and second years). In the fourth and fifth years there are a number of elective courses (320 periods), including structural petrology, vulcanology, tectonics of the quaternary period and seismotectonics, dynamic palaeography, practical palaeontology, study of facies, marine geology, glaciology and terrestrial physics. There are also optional courses in such subjects as motor mechanics, photography and cinematography, principles of scientific atheism and methods of occupationally useful sports.

In the five-and-a-half years of their course, geology students attend lectures for a total of 2,369 periods, do practical work in laboratories and workrooms for a total of 2,536 periods, and attend seminars for a total of 285 periods. They spend 20 weeks in practical work in the field, take part in working expeditions lasting 31 weeks, and take 43 examinations, defend three course-papers and write their diploma thesis (covering 21 weeks). The course of instruction culminates in the defence of the thesis and the State examination.

The subjects covered in the curriculum for the special second course given by the Moscow State University's Geology Faculty on 'Geological surveying and prospecting for mineral deposits' may be classed in several groups as follows:

General education—mathematics, physics, chemistry and the study of a foreign language.

The study of the physical composition of the earth—crystallography, mineralogy, petrography, lithology and geochemistry.

Biology and stratigraphy—zoology, botany, palaeontology, palaeozoology, historical geology and regional geology (geology of the U.S.S.R.).

Dynamic geology—general geology, geomorphology, geology of quaternary deposits, engineering geology, hydrogeology, geological cartography and geotectonics.

The study of mineral resources—geology of mineral deposits, mineral prospecting and geophysical prospecting methods.

Subjects in the socio-political group—philosophy, political economy and history of the Communist Party of the Soviet Union.

A curriculum of this kind, which covers different branches of science and provides a broad and thorough general education in the natural sciences, enables the future specialist to deal familiarly with special methods and have sufficient confidence to tackle the complicated problems met with in geological research. And this, in our opinion, is the main purpose of a university education.

The teaching work is organized by the teaching section of the geology faculty administration, and is carried out by the various departments.

The faculty has thirteen departments as follows:

1. Geology section: department of dynamic geology; department of historical and regional geology; department of the geology and geochemistry of mineral fuels; department of palaeontology; department of the geology and prospecting of mineral deposits.
2. Geochemistry section: department of crystallography and crystallochemistry; department of mineralogy; department of petrography; department of geochemistry.
3. Engineering geology section: department of hydrogeology; department of engineering geology and soil science; department of cryopedology.
4. Geophysics section: department of geophysical methods of research on the earth's crust.

Each department is provided with a number of workrooms and laboratories, with the necessary equipment and teaching aids.

An important point to be noted is that the higher educational establishments try to relate the students' classroom work as closely as possible to research work. This is done in two ways—the students take part in the research work done by the department, including expeditions, and also in the work of the students' scientific societies. The Moscow State University's Geology Faculty, for example, sends scores of expeditions to all parts of the country every year and most of the senior students serve on them as collectors and prepare terminal papers and diploma theses on the field data collected, this giving them their first experience of independent scientific production work.

The student will thus have acquired, by the end of his course, a certain stock of theoretical knowledge in the field of geology, familiarity with specialized research methods, and some experience of independent practical work under field and laboratory conditions.

The Moscow State University's Geology Faculty trains specialists in: geological surveying and prospecting for mineral deposits; palaeontology; geology and prospecting for non-metallic minerals; geology and geochemistry of oil and gas deposits; geology and geochemistry of coal deposits; crystallography and crystallochemistry; mineralogy; petrography; geochemistry; hydrogeology; engineering geology; soil science; cryopedology; gravimetric and magnetic prospecting; seismological prospecting; electrometric prospecting.

Experience shows that the graduates in geology, like the graduates of other geological higher educational establishments, are adequately equipped to undertake independent work in geology.

The vast African continent is remarkable for the variety and complexity of its geological structure and the wealth of its mineral deposits. The emergence of a large number of sovereign States in Africa in recent years will obviously make it necessary in the near future to expand geological services, especially by training qualified national staff. It will be most gratifying to us if our experience of geological education at universities is of use, even in a small degree, to universities in the African countries.

We should like to stress, however, that African geologists have carried out a great deal of most interesting research, and we should find it most interesting and instructive to learn more about what they have done and about the methods adopted at geological institutes and universities in African countries.

VI. TEACHING OF BIOLOGY AT UNIVERSITY LEVEL IN AFRICA[1]

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INTRODUCTION

The recent conquests of science have thrown into relief the importance of scientific and technical studies and, in so doing, have focused attention on education as a worth-while investment. While the imagination is struck by the huge advances made in the mathematical, physical and chemical sciences, advances perhaps less spectacular, but no less remarkable have been made in the sphere of biology. It may be that these are exerting an even more pervasive, though subtler, influence on our daily life and will help in the solution of major problems such as that of malnutrition, so grave in many parts of the world.

The natural sciences are changing and their scope is constantly widening. In highly organized countries as well as in underdeveloped areas, governments are having more and more to enlist the help of biologists and technicians in occupations related to biology. This applies particularly to the new nations of Africa whose economy is based on agriculture, fishing, stock-farming and forestry. They will therefore have to agree—mainly in the rural sectors—to substantial investments in education.

But the biological sciences are conditioned by the local situation, by the characteristics of the country where studies take place—differing in this respect from the so-called exact sciences, which are not dependent (or far less so) upon geographical circumstance. Rules and techniques have to be adapted to the flora, the fauna, and the vegetation. This points up, if it were necessary to do so, the fundamental responsibility devolving upon African university institutions engaged in the study of the environment.

In this connexion, I should like to quote the words of Djibril Sene, agricultural engineer, which, though they apply to agricultural research, could well be extended to biological research in general: 'We should not lose sight of the fact that agricultural research must be conducted in the place where the results are to be applied.

1. It was difficult, in the time allowed for the preparation of this report and having regard to our other obligations, to assemble full information on the teaching of the biological sciences at university level in Africa. For this reason, the report is based mainly on our own experience and on the teaching provided in the French-speaking University Centres of Africa and Madagascar. These centres are organized on lines similar to those of French universities.

Accordingly, research workers whose efforts are intended to benefit tropical countries must be on the spot so as to gain a clearer insight into the resources afforded and the difficulties presented by the environment. Expert missions are, of course, valuable in providing opportunities for a profitable interchange of views, for a renewal of ideas, but we must not suppose that with one wave of a magic wand they will produce the solution for every problem, since all that the members of missions have time to do is to draw conclusions from the ideas put forward in the course of their tour.'

Teaching at university level will be provided in the light of: (a) The vast need of the African States for secondary school teachers and for research workers—agrostologists, foresters, physiologists, geneticists, oceanographers, etc. . . .[1] (b) The value of teaching the corresponding subjects, if not wholly at least partly, on the spot, relating them to the physical and human environment.

The objectives sought are therefore of four kinds:

1. Training of secondary school teachers—courses leading to the degree qualifying for teaching.
2. Training of research workers to explore the problems of basic research—courses leading to the degree qualifying for research work and to postgraduate diplomas.
3. Training of specialists in various subjects—courses leading to the third cycle certificates and doctorates.
4. Training of technicians—courses leading to the recently created *diplômes d'études supérieures techniques* (diplomas of higher technical studies) or (of older standing) to the doctorate of engineering.

In what follows we shall include under the term biological sciences subjects often considered as belonging to the natural sciences.

ACCESS TO THE UNIVERSITY

The majority of students come from secondary schools and, to accede to higher education, they must have the *baccalauréat* certificate. However, exemptions are granted to candidates possessing certain other diplomas or certificates. These are usually former students of the French *grandes écoles* (State higher professional colleges), among which mention may be made, in relation to biology, of the *Écoles supérieures d'agronomie* (Higher Agricultural Colleges) (former *Institut national agronomique, Écoles nationales d'agriculture, Instituts agricoles* of Nancy and Toulouse), the *École nationale d'horticulture* (National Horticultural College), etc. Some foreign certificates are also accepted as equivalents.

In addition, with the object of broadening access to higher studies and, as it were, democratizing university education by making it available to deserving students who have not been able to follow the normal course of secondary education, a special university entrance examination has lately been instituted. This measure will help in providing a larger number of trained personnel, of whom the country stands in need. By way of illustration, it may be noted that, in 1961, out of 413 candidates sitting, in France, the special entrance examination for the faculties of

1. By way of example, we give below the recruitment requirements of the Republic of Senegal for the next four years, according to documents prepared by an ILO expert and which were kindly communicated to us.
Agriculture: 10 rural works engineers; 2 waterways and forestry engineers; 20 agricultural engineers; 20 agricultural technicians; 7 oceanographers; 20 veterinary surgeons; 10 animal husbandry research workers; 15 animal husbandry technicians; 2 specialists in the study of soils; 3 agrostologists; 15 other specialists.
Education: 20 university and secondary school teachers.

sciences, 237 passed, the proportion of successful candidates being thus over 57 per cent. The average age was from 28 to 30 years.

But efforts to bring in the best elements have not been confined to the above action. Arrangements are also being made for a second type of university entrance examination, under the 'social advancement' scheme, for the benefit of persons of 24 years of age and over with two years' experience in their occupation. Africans, who often have an inborn aptitude for the natural sciences, will be enabled, by means of these new facilities, to develop their talents and give their country the benefit of their experience.

ACADEMIC LEVEL AND BENT OF STUDENTS ON ENTRANCE

It is well to have information not only on the diplomas held by the student on entering the university, but also on the real level of his knowledge, his psychological make-up, his preferences and natural bent. The training he received in primary and secondary school will influence his subsequent behaviour. The methods used in secondary education are often too passive, due chiefly to the heavy syllabus to be covered and not to a lack of merit or quality in the teachers. This over-academic approach is particularly regrettable in the case of the natural and the experimental sciences. On arrival at the university, the new student is generally nonplussed by the different teaching methods he finds there; he tends to go on absorbing his mental pabulum just as it is put before him. This inclination towards parrotry, towards learning by rote, must be combated. During the first practical sessions it is not unusual to find a student drawing not what he sees but what he thinks ought to be seen.

The student should develop a consciousness of the importance of the part he will be called upon to play in the future. Yet his choice of subjects is rarely determined by a vocation for a particular profession; it is often determined rather by the desire to advance in the world, the hope of immediate material gain (Dufour).

Africans, as was said above, have an acute awareness of nature; they have inherited an astonishing sum of ancestral lore. We might therefore expect to see quantities of students wishing to enrol for biology. Curiously enough, however, the number reading for the certificates in the natural sciences is comparatively low, as is shown by the figures in Table 1 from the Dakar Faculty of Science:

TABLE 1. Student enrolment figures for the Dakar Faculty of Science, 1960-62

Year	Total enrolment	*Licence* (Degree course)	Botany	Biochemistry, Microbiology, Plant physiology	General biology	Zoology	Animal physiology	Natural sciences total
1960	298	109	9	10	13	17	15	64
1961	343	116	17	10	13	5	9	54
1962	317	109	11	9	9	6	14	49

There are several reasons for these relatively low figures, the chief among them, in my opinion, being misappreciation of the career opportunities available to graduates in the biological sciences; belief that the only profession open to them is teaching; the over-academic tendency referred to above, which results in a preference, on the part of African students especially, for occupations unrelated to agriculture—the latter being doubtless considered as having less prestige value, as Boubakar Ba observes: 'Students opt more readily for law and medicine owing to the social status they confer'.

STAGES IN THE TEACHING OF BIOLOGY

In a system of the French type—and this is the type prevailing in the university establishments of the French-speaking African States—several possibilities are open to the student. However, the studies leading to a *licence*, of whatever type, begin with a preliminary cycle which, in the case of the biological sciences, generally leads to the Certificate of Physical, Chemical and Natural Sciences (*Sciences physiques, chimiques et naturelles—SPCN*)[1] but may also lead to the Certificates of General Mathematics-Physics (*Mathématiques générales-Physique—MGP*) or Mathematics-Physics-Chemistry (*Mathématiques-Physique-Chimie—MPC*).

Once the student has gained the preliminary certificate (*certificat de propédeutique*), he has a choice between several courses, leading to the *licences d'enseignement* (teaching), *de recherches* (research), *de spécialisation* (specialization), each consisting of several certificates.

The organization of the teaching of biology may be summarized under the following heads:

First cycle

Preliminary certificates—*SPCN*, *MGP*, *MPC*. One of these three certificates (or the equivalent) is required for admission to the second and third cycles.

Second cycle

Licence d'enseignement: (a) natural sciences: honours in biological sciences; (b) natural sciences: honours in earth sciences; (c) chemistry—physiology.

This degree consists of five or six certificates, of which the following pertain essentially to biology: botany, zoology, general biology, biochemistry-microbiology-plant physiology (BMPV), animal physiology. It qualifies the student to prepare for the *agrégation*, the *CAPES* (general secondary teachers' certificate) and the secondary level of teaching in general.

Licence de recherches or *Licence de doctorat d'état* (State doctorate). This degree consists of four of the above certificates, two advanced certificates (advanced botany, advanced zoology, general ecology and genetics), plus a certificate of the candidate's choice or a diploma of higher studies (*DES*). It qualifies the student for university teaching and research, particularly in the sphere of agriculture.

Licence libre (non-teaching diploma). This degree consists of five certificates of the candidate's choice; it offers fewer career opportunities.

Third cycle

Students taking the studies in the third cycle must: (a) obtain a third-cycle certificate (subjects: algology, cell biology, cryptogamy, biology of development, advanced genetics and physiology of reproduction, microbiology, neurophysiology, cell

1. Certain diplomas, or eligibility for entry to certain schools of higher education, are accepted as equivalents of the *SPCN*.

physiology, plant physiology, tropical botany, for example). In Paris and Dakar—tropical botany; (b) after obtaining the third-cycle certificate, prepare a thesis for a third cycle doctorate. This qualifies the student for technical secondary teaching, for university teaching as associate lecturer (*maître-assistant*) for research mainly in agriculture, and for work in private laboratories.

Diplomas of Higher Technical Studies (Diplômes d'études supérieures techniques—DEST)

These are awarded at the end of a two-year course following the preliminary cycle:
First year—a certificate of technology in the subject chosen and the appropriate *licence* certificate.
Second year—training period in a laboratory or an industrial concern.
This organization affords considerable scope for adaptation and choice. It is therefore proving valuable and effective, more especially as it is supplemented by other diplomas the main purposes and characteristics of which are listed below.

DIPLOMAS OTHER THAN THE 'LICENCE'

Diploma of Higher Studies (Diplôme d'études supérieures—DES)

This diploma is awarded on the results of not less than one year's research work in a laboratory, and following the maintenance of a thesis. There is no restriction as to age, academic status or nationality. The subject is at the candidate's choice, even if it is not directly related to one of the courses given in the Faculty. However, in exercising this option, the candidate must be guided by the advice of the Director of Studies who will arrange for him to defend his thesis.

For people wishing to take up scientific research, this initiation into laboratory work forms a necessary part of their training; it is also useful for students who mean to make their career in the private sector; while, for intending secondary school teachers, it fits them better to provide the practical teaching they are required to give parallel with theoretical teaching (the *DES* is, moreover, required of candidates for the *agrégation*).

Doctorate of Engineering (Degree of Ingénieur-Docteur)

Candidates for this degree must possess, in addition to a preliminary certificate and three certificates of higher studies at their own choice, a diploma of a school of engineering; they must also submit, in the form of a thesis, the results of two to three years' research work. An engineer's degree awarded by an *École supérieure d'agronomie* exempts the candidate from the above-mentioned certificates. The degree of *Ingénieur-docteur* is highly valued in industry, where it is not uncommonly found. Holders of this degree are also eligible for inclusion in the list of persons qualified to teach in universities as associate lecturers.

University Doctorate

The University Doctorate is not a diploma; it represents the recognition by a university of the value of research work undertaken independently. As a rule, it is necessary for the candidate to hold one or more *licence* certificates; but exemptions may be granted, and persons possessing neither the *baccalauréat* certificate nor a *licence* certificate may successfully submit a thesis for the doctorate.

Third-cycle doctorate

This is the final examination of the third cycle (see above). The purpose of the third cycle is to give students a thorough grounding in a particular branch and to initiate them into research work. Third-cycle students do not have to attend lectures on methodology. They are taught through practical work and example the methods and techniques exactly suited to the subject of their choice. In small groups, they learn to work as a team and they develop a spirit of inquiry. The studies extend over at least two years, at the end of which those candidates that have successfully maintained an unpublished thesis on their special subject are awarded the doctorate degree.

At Dakar, there is now a third-cycle certificate in tropical botany. Close contact is maintained with the French universities, and, more particularly, with the University of Paris. Arrangements are made to enable students of the various branches of biology to prepare at least part of their third-cycle doctorate in Africa on subjects likely to be of interest to the governments of the regions in question.

State Doctorate (Doctorat ès sciences—Doctorat d'État)

The diploma awarded for the most advanced research is the State Doctorate, which is also the highest university degree. Candidates for the *doctorat ès sciences* must be holders of a *licence* (*licence de recherches*). They are required to submit two theses, one of which—the main thesis—is the outcome of original research over a long period.

The above-mentioned diplomas are of notable value, if only on account of their variety. They are designed for persons of widely differing educational background. For instance, the Diploma of Higher Studies and, to some extent, the University Doctorate can be obtained by persons who, although their general education may be incomplete, can show that they possess real qualities as research workers, that they have a definite gift for certain subjects. In Africa, especially, these diplomas should enable latent talents to be brought to light, thereby allowing their owners to take a share in the development of knowledge in their country. Instances could be cited of young African botanists, passionately devoted to their profession, who have been helped in this way to go forward with their excellent scientific work. Bents of this kind are often apparent in young Africans who have remained in contact with nature and whose powers of observation have not been blunted. African governments would do well to take greater advantage of these diplomas for purposes of the promotion of certain studies.

CURRICULA

The curricula for the preliminary certificates and the *licence d'enseignement* have been standardized and are identical for all French universities and all university establishments observing the same principles. This was a necessary measure, since the knowledge imparted here is of a general character, not specialized, and none of the more important biological subjects can be neglected completely. However, within the limits thus imposed, teachers are free to use their own judgement in dealing with the prescribed subjects.

For the *SPCN*, the curriculum is of course very broad. It enables students to acquire a reasonable scientific grounding in a number of subjects. Those who wish to proceed to the biological sciences will have to take, in addition to biological subjects, the courses in physics, chemistry, geology and mathematics.

In animal biology, the teaching bears on cytology, embryology, histology, the main divisions of the animal kingdom, heredity and sexuality, and the evolution of living organisms. In plant biology, the main subjects taught are general morphology of vascular plants, cell biology, sexual reproduction, the biology of the most representative lower and higher plants. Some of these subjects will be dealt with more thoroughly at the *licence* stage, but most of them constitute the generally accepted foundation for future studies.

There is now a tendency—and a gratifying one, in my view—to place greater emphasis, in the *SPCN*, on the physical, chemical and mathematical sciences. Mathematics, which used to be optional, have become compulsory. The descriptive stage, though far from finished, is diminishing in importance. The teaching of biology is assuming an increasingly practical character. The intrusion of the other sciences into the sphere of biology is thus a phenomenon that is likely to spread; but those sciences should then be taught from the biological standpoint. However, the fullness of the syllabus (twenty-four half-hour lectures and practical work per week), the liability of students to forget, the value of proceeding in an orderly manner from one well-mastered step to the next, all point to the necessity of spreading the *SPCN* course over two years. *Licence* certificates curricula are broadly as follows:

Botany—systematic, morphological and biological study of the main plant groups from the viruses and bacteria to the *Angiospermae*, together with the elements of plantecology and phytogeography.

Zoology—study of the main animal groups, with due regard to their biological, palaeontological and practical importance.

BMPV—one hour's lecture per week on biochemistry, half an hour on microbiology and two hours on cell and plant physiology (nutrition, metabolism, growth and development).

General biology—the main subjects are cytology, reproduction and sexuality, causal embryology, genetics, problems of evolution, general ethology.

Animal physiology—the main subjects are concerned with the functions of nutrition and the internal environment, endocrine glands, metabolic equilibrium, reproduction, the unity of the organism and the main regulatory systems.

We have found these curricula very comprehensive and conducive to the acquisition of a broad knowledge of the main branches of biology.

The curricula for the advanced certificates and the third-cycle certificates are less rigid, and teachers have more liberty in working out their programmes. In contrast to the previous certificates, in connexion with which the object was to cover a great deal of ground, the purpose here is more formative; the studies prescribed are therefore more detailed, more specialized and more closely adapted to specific needs.

CURRICULUM TRENDS

Curriculum trends should be determined in the light: (a) of their adaptation to the African environment; and (b) of the aims to be achieved.

In regard to the adaptation of curricula to the African environment, several aspects have to be considered, including that of the subjects to be taught and that of the persons for whom the teaching is intended.

Adaptation of curricula to the country

For biology teaching in Africa there is a risk, on the one hand, of not being sufficiently rooted in African life and, on the other, of paying too little attention to what is not African.

It is unthinkable that as many examples as possible should not be taken from the local environment; this would be all the more regrettable in view of the wealth and variety of African flora, vegetation and fauna. For instance, large families of *Angiospermae* are poorly represented or even non-existent in temperate lands; and a number of problems—philogenetic, among others—cannot be solved or even properly grasped unless these families are studied, with their morphological, biological and physiological characteristics. Where animal life is concerned, R. Godet observes that Africa is fortunate in possessing, in its highly differing regions, species of animals which are at the very parting of the ways in their racial evolution. Mention need hardly be made in this connexion of the *Dipneusti*, the large reptiles which form the link between the lower and higher vertebrates, the mammals whose great numbers and special characteristics fire research workers with enthusiasm.

We should be at fault not to make use, for experimental purposes, of this plentiful and often unusual material and not to draw attention to the major problems it raises. Study of the complex and luxuriant equatorial forest, the tremendous expanses of desert, and all the areas between them; the problems of dormancy, of bush fires, of water—so vital to our regions—these are matters which it is impossible to overlook, with all their practical implications, for the most part of national importance: reclamation of arid lands especially on the fringes of the desert, control of epiphytic diseases, malnutrition, nature conservation, etc.

Conversely, some 'taxa' of importance for the understanding of evolution are non-existent or poorly represented in Africa; this is the case with the Gymnospermae, which cannot be passed over in silence. At the same time, a great deal of research work, especially physiological research, has as yet hardly taken shape in Africa, and reference has to be made to work done elsewhere.

In short, the teaching of biology in African university establishments should, whenever possible and without prejudice to its universality, take its examples from the material at hand in tropical Africa.

Adaptation of curricula to the students of biology

Discussing, in Ghana, the problems of education, B. H. G. Chaplin states that only a perfect knowledge of the intellectual potentialities of African children, students and teachers can provide a sound basis for determining the lines on which education should be developed.

Reference may be made in this connexion to an opinion expressed by Professor G. Mangenot, whose experience in Africa is of long date—an opinion which I fully share: 'Africans are particularly talented for all research based on observation. For atavistic reasons they are well fitted to become botanists, ethnobotanists, zoologists, agronomists, veterinarians or physicians, pedologists. They possess precisely those natural gifts whose development is most necessary to the advancement of their countries.' On the other hand, it would seem that many students—with a few brilliant and noteworthy exceptions—have less of a bent towards other subjects, such as, for instance, cytology or physiology. This is no doubt due to the fact that, 'intellectually gifted young Africans and equally intellectually gifted young Europeans, faced with the same problems, have recourse to different methods of association, comparison, representation and reference' (Morgaut).

The condition *sine qua non* for profitable teaching is that it be based on concrete examples, that students be given a great deal of personal experience by hand and eye of every step of the process, and that these experiences occur in logical order (Chaplin). The student will discover the facts in a practical manner and will thus more easily understand the scientific explanation. The teacher's role is to direct the student's own discoveries. This method, while undoubtedly more profitable, is also much slower.

Determination of trends in the light of the aims to be achieved

In this connexion, three main objectives must be borne in mind:

1. Training of future teachers: the curricula for the *licence d'enseignement* should be brought more closely into line with the instruction that the candidates will later be called upon to provide as secondary school-teachers.
2. Training of future technicians and specialists: in the case of the former, especially, the curriculum should take maximum account of specifically African situations. Here, mention must be made of a serious deficiency in the French-speaking university centres: African countries, which are essentially agricultural, have no facilities for the teaching of agriculture. This deficiency should be made good by the institution of special certificates to be taken by intending specialists. The certificate of higher studies in tropical botany, which includes some phytogeography and phytosociology, plant ecology, botany, genetics and the improvement of the main cultivated tropical plants, is in line with this objective. Other certificates ought, however, to be instituted, such as, for instance, a certificate of agricultural and medical entomology, a certificate of tropical animal physiology, etc.
3. Training of future research workers: by taking subjects for diplomas and theses from African life, and seeking to ensure that this choice fits in with local needs and the wishes of governments (though without thereby detracting from the freedom and disinterestedness that characterize basic research), the African university will assert its individuality and fulfil its vocation.

Fortunately, one of the main characteristics of the university is a considerable flexibility. There is therefore no need for the African university to be an exact replica of the French university. Its structure may be similar, enabling it to benefit from a body of tradition and a long and learned experience, but it will be in a position to adapt its curricula by introducing local examples and having regard to local requirements.

TEACHING: THEORETICAL AND PRACTICAL

The method of formal lectures has for some time past come in for criticism—often severe—on the ground that this method tends to develop, rather than the habit of thinking, the ability to store up facts in the memory. How can theoretical teaching be made profitable?

Firstly, in preparing his lectures, the teacher's aim, far from turning his audience into a live encyclopaedia, should be to train his students to grasp the problems arising from the study of a given branch of biology, to perceive the way to set about their solution, to cultivate their critical faculties and a nimbleness of mind. Teaching that follows these lines can no longer be static or remote.

Secondly, to strengthen the dynamic character of the teaching, it should be supplemented and illustrated by practical work, excursions, student exposés, study groups.

Of all these activities, only practical work is compulsory. This brings the student into touch with live facts and offers him concrete examples to illustrate some of the theoretical points made in the lectures. It is organized and directed by associate lecturers and demonstrators (*chefs de travaux*). The proportion of practical to theoretical teaching is at present as shown in Table 2.

TABLE 2. Relative proportions of theoretical and practical teaching (in hours per week)

Certificates	Theoretical teaching	Practical teaching
Botany	3	6
Zoology	4	7
BMPV	3½	3
General biology	2	4
Animal physiology	3½	4
Tropical botany	3	6
SPCN	9	15½

The associate-lecturers have also to explain any parts of the lecture that may not have been fully understood, or to provide additional explanations; their classes are always small so that they can follow the progress of the students individually.

Student exposés and study groups are among the best ways of accustoming the student to engage personally in analysis and synthesis. The teacher has recourse to them at his own discretion.

The scientific and pedagogical value of exposés is beyond question, as I have found from my own experience. The students are diffident at first about addressing their contemporaries formally, but they soon come to appreciate the advantages of the method; they learn to compile a bibliography, to draw up a report, to express clearly a somewhat complex problem. The criticisms offered by their fellow students—who are expected to take an active part in the discussion following the exposé—and by the teacher, necessitate on their part the utmost exactitude, with regard both to form and to substance. This interchange of ideas brings out previously undeveloped qualities, such as concentration, the ability to draw unexpected analogies, openness and alertness of mind. In addition, the students lose their shyness and gain self-confidence. The first exposés are usually clumsy, the last often brilliant.

Study groups serve a similar purpose, with all probably participating more actively. They offer the further advantage of paving the way for team-work, the teacher or associate lecturer playing neither a passive nor a dominant part but acting as guide.

Exposés and study groups can only be really profitable if the number of students taking part is not too large. Fortunately, the overcrowding which is such a feature of academic life in Europe has not yet assailed the university centres in Africa, where the teachers are still in very close touch with their students. It is interesting to note, in this connexion, a remark made by Keita Moussa: We must 'resist the African student's natural tendency to submissiveness, due to that respect which is accorded to the teacher in Koranic schools'.

The efforts made by their teachers do not always meet with a response on the part of students, many of whom prefer, through natural passivity or as a result of up-bringing, to have knowledge meted out to them. In the words of one African student: 'as children we ask no questions, we have no right to do so; what our parents, our teachers or books say is the truth'. To guard against the student's absorbing a mass of knowledge which he cannot properly digest or acquiring a mere fleeting erudition, an endeavour should be made:

To provide a balanced theoretical teaching that will throw into relief the essential facts, the march of ideas and the successive stages of progress. The role of the teacher is not so much to transmit a body of knowledge, a cultural heritage, as to help young people to rediscover for themselves the significance of this knowledge. In systematics, the bugbear of some students, it will probably be better to lay stress on the main laws of evolution, on the complexity of structures from the virial nucleoproteins to the higher plants and animals, than to recite lists of characteristics which will be deadly dull for the student and which are to be found in textbooks.

This brings us to the question whether students should be provided with mimeographed copies of lectures. The question is controversial. Mimeographed copies can be useful in giving details which are necessary but which would make oral lectures complicated and difficult to follow. At the same time, however, they may encourage students to stay away, to use their mimeographed copies instead of attending the lectures.

To give a larger place to practical work, aimed at developing the students' faculties of observation and improving their manual skill. Though students need not become artists, they should learn to make accurate drawings. Dissecting and the assembly of apparatus afford excellent opportunities for inculcating the principles of scientific method, for enabling students to grasp and solve problems and, if need be, to draw up practical work schemes.

To increase the number of exposés and study groups.

In the words of a former President of the Union nationale des étudiants de France: 'information must be made subsidiary to training'.

SUPPLEMENTARY EDUCATIONAL FACILITIES

Films and photographs

In the biological sciences, the study of forms is essential, whether we think of the forms in themselves or as the setting for the physiological functions of organisms. Illustration is therefore an integral part of the teaching of these subjects. Audio-visual media are of undoubted assistance in teaching, even at university level. The image with commentary is a valuable source of information, able to rivet the attention of the student audience by mitigating the possibly over-abstract character of a lecture. Projectors for slides, films and microscopic preparations, and an epidiascope, are useful. But this equipment alone is not enough; it is also necessary to have films and slides illustrating the subject of the lecture.

Films on mitosis, embryology, plant and animal movement, and also sets of photographs concerning species belonging to families represented only slightly or not at all in Africa, and of plant types, animal and plant ecology, etc., render undeniable services. But any image is fleeting; it can only have its full effect if it serves to illustrate the lecture proper.

The foregoing media are exceedingly useful. However, too much should not be expected of them. It is interesting in this connexion to note that our students prefer that the diagrams illustrating the lectures be drawn in their presence rather than prepared in advance. It should also be pointed out that showings of pictorial material arranged, admittedly, for reasons of convenience, outside the normal teaching hours (in the evening, for example) are not well attended.

Excursions

These constitute an important adjunct to biology teaching. They bring the student into direct contact with nature and open up new horizons for him. With regard to botany, five or six half-day or full-day excursions are made in the course of the year. A longer excursion, continuing over several days, is also arranged whenever possible. The benefits derived are obvious, whether from the scientific or the human standpoint. Confidence springs up, new contacts are made, new bents come to light, older ones are strengthened. But there are difficulties in the way of these excursions: they can be arranged only for small groups, they involve a fairly large expenditure and they require transport. They are as beneficial for zoological as for botanical studies and in certain cases it would be useful for the two to be combined.

Botanical garden and animal section

The botanical garden, animal section, insectarium and aquarium are necessary facilities. They supply the appropriate laboratories with the research material they need, as well as providing the practical work rooms with the animals and plants required for observation and dissection. It is difficult to imagine experimental work without these indispensable ancillary facilities. Their drawback is that they are costly. Sufficient funds must be found for their installation and maintenance and for the recruitment of suitable personnel.

Library and documentation

In addition to the general library, there should be a specialized and adequately stocked library for each laboratory. For the students reading for the *licence d'enseignement*, a few basic works, a few of the most important learned reviews, would afford a reasonable foundation.

EXAMINATIONS

Under the present system, a *licence* certificate is awarded on the results of written, practical and oral tests. Each series—generally carrying a maximum of forty marks—is eliminatory. In this way the depth of knowledge is sounded over a comprehensive range, enabling the candidate's merit to be judged on a sufficiently broad basis.

In my view, examinations are indispensable. They constitute a powerful stimulus, spurring the student on to work. However, they present certain drawbacks, which can be mitigated by a series of corrective measures.

Students tend to leave the bulk of their work to the month before their examination. Regular, thorough work throughout the year is replaced by a last-minute rush, with everything then forgotten as fast as it was learnt. To avoid this risk of 'cramming', the main criticism levelled against examinations, the following would be helpful.

Firstly, the questions asked—especially in the written papers—should be general in scope. Knowing that he will be asked questions of this kind, the student will have to cease looking at problems as they are expounded at lectures, step by step; he will have instead to follow the subject through the successive steps. In this way, he will be forced to try to arrive at a general understanding.

Secondly, the defects of examinations could be palliated if they were supplemented by a few oral tests held, for example, one each term (though this is only possible with small numbers of students). These tests would act as partial examinations, and the marks obtained in them as well as in the practical work would be taken into consideration at the examination. The quality of exposés should also be taken into account.

Another advantage of examinations spread over a period is to oblige students to go over the same subjects several times, thus becoming thoroughly familiar with them. There is no doubt that the natural sciences call for a considerable effort of memory. Repeated revision will help to establish knowledge in the mind. One of my former teachers, R. Maire, the well known scientist, used to say—partly in jest, of course—that botany had to be forgotten six times before one could begin to know it.

DURATION OF STUDIES

There is much talk at the moment about accelerated training. This is not without its dangers; it is liable to lead to that 'second-rate' education which is so much resented by African students. However, in view of the increased needs of developing countries, such as the countries of Africa, there is justification for wondering whether something cannot be done to speed up the process.

The teaching of the biological sciences, which necessitate a long apprenticeship, is therefore faced with two inconsistent requirements: (a) the need to provide in the shortest possible time the senior personnel, specialists and technicians that the nation needs; (b) the need to ensure that such senior personnel, specialists and technicians are of real ability. But it is not desirable to sacrifice quality to speed. Though accelerated training undoubtedly has its advantages for the 'turning out' of technicians and, in a lesser degree, of specialists, it would be a mistake to overrate its virtues in the sphere of higher education.

RESEARCH AND TEACHING

At university level, research cannot be separated from teaching. This may seem a truism; it has sometimes been suggested, however, that the two branches be disassociated and entrusted to different groups of persons. Yet it is almost unthinkable that a university teacher should not at the same time be a research worker. He must himself be grappling with the problems of research, in order to be able to explain them, to help his students to perceive the difficulties they present and appreciate the subtle but manifest satisfactions they offer. Besides the lecture hall and the practical work rooms, there should be laboratories. It is in laboratories that the student's training is completed, that he becomes a research worker; and in laboratories that the most important work for diplomas and theses is done.

In the subjects studied, attention will be focused primarily on African aspects, and the subjects themselves will come within the province of basic research, which is essentially a concern of the university. Some prospect of practical application, in the near or more distant future, will be an advantage, without, however, any incursion into the domain of applied research, which should be left to the various specialized scientific establishments whose responsibility it is.

Regard must be had to the special conditions of work in Africa. The choice is wide—sometimes too wide—and there is a tendency for research to be dispersed over a vast field. Purely 'prestige' research, offering no corresponding advantage to the country, should therefore be avoided at a time when other, apparently less spectacular, studies can be more profitable. It is obviously better to carry out in Europe research demanding costly equipment which would not be fully used here, necessitating extremely delicate, fragile apparatus that is difficult to maintain away from the specialized centres, or requiring teams of workers that are difficult to assemble. 'For this reason, the extension of research in pure cytology, cell physiology, physico-chemical virology or even advanced biochemistry should not be encouraged in tropical lands for the time being' (G. Mangenot).

These considerations lead us to be on our guard against certain tempting but costly projects and to keep the available funds for the organization of laboratories for the pursuit of specific aims. To achieve these, it is necessary: (a) to install the supplementary facilities mentioned above; (b) to expand equipment; (c) especially, to increase the number of research workers; and (d) even more important, to increase the number of technicians—technical assistants, draftsmen, photographers, horticulturalists, prospectors, personnel required for the organization and maintenance of the experimental gardens and animal section, the herbaria and animal collections, the seed depots, etc.—necessary to the types of research contemplated.

At the present time, it is the human factor that offers the greatest obstacle to the satisfactory extension of research. As G. Mangenot points out, 'the recruitment of large numbers of staff is therefore the most pressing need of basic research'.

The programme of research is vast. It includes, on the one hand, inventory and observation work (inventories of flora and fauna, inventory of biocenoses, plant and animal morphology and anatomy . . .) and, on the other, experimental work (plant and animal ecology, study of the behaviour, growth and development of living organisms, flower biology, sexual and asexual reproduction, microbiology, animal and plant pathology . . .). 'Some of these studies condition the economic development of tropical lands, while others, yielding a less immediate material gain but of equal scientific interest, should for preference be conducted in hot countries because of the presence in those countries of many structural or morphological biological types about which little is as yet known.'

EXCHANGES, MISSIONS AND FELLOWSHIPS

Personal contacts are of prime importance. In Africa, the drawbacks inherent in isolation are apt to be accentuated by great distances. Documentation and exchanges of work help to palliate these drawbacks but without overcoming them. Consequently, it is advantageous to provide for missions, study tours and periods of work and observation in laboratories abroad.

These should benefit not only students but also research workers and members of the teaching staff; they should operate both ways—from Africa to the outside world and from the outside world to Africa—as well as between the various scientific institutions in Africa.

Where students are concerned, travel would be most profitable if a good cross-section could participate in it. The results would probably be best at the third-cycle level. Fellowships should be awarded to deserving young Africans and Europeans alike. This two-way movement would promote an interchange of ideas and increase the abilities of each beneficiary.

Fellowships should also be awarded to persons preparing theses, so as to enable them to add to their stock of information, learn new techniques, and finish their work in the places where scientific and technical innovations originate.

These aims are valid for research workers and teachers whose research work, in many cases, can only be finished after visits to European or other herbaria, libraries and laboratories. Exchanges of ideas and personal contacts with eminent colleagues in other countries cannot fail to be extremely beneficial.

So as to infuse new life into the teaching, it would, on the other hand, be an advantage if teachers from other universities could take a share in it, giving the students the benefit of their particular skill. Moreover, in this way more or less close links could be established between the laboratories. Research plans might be drawn up in common. The research would be shared between teams: some, in Africa, would collect observations and conduct experiments in the field, while others, in France or elsewhere in Europe, would deal with the points calling for advanced specialization and delicate equipment. A symbiosis of this kind would certainly produce excellent results.

But it is not enough for such connexions to be established with European laboratories concerned with African problems; they should also exist between research centres in Africa. They would make it possible to plan vast programmes of research into problems which can be solved only at the continental or international level—such, for instance, as those pertaining to the realms of phytogeography or zoogeography, which require the preparation of maps covering several territories.

CONCLUSIONS

What has been said above by no means exhausts this vast subject, on which we have been able to touch only by leaving aside certain aspects. The following are briefly our main conclusions.

Science is always a paying proposition. In the continent of Africa, where the economy is predominantly agricultural and where malnutrition deficiencies and under-employment are so common, the biological sciences are bound to play a very important part.

Modern higher education in the biological sciences is indispensable for the development of agricultural research which, in turn, is essential to the economic advancement of the African countries.

The structure of the African university offers many possibilities. It is based on the European university structure, which has stood the test of experience. It would therefore be well to maintain that structure in general, while adapting it to African needs, with such alterations or additions as may enable it to render the maximum service. In effecting this adaptation, the main lines of the European curricula for the *licence d'enseignement* would be preserved, but most of the examples would be chosen from the African environment.

Consideration should be given to the institution of certificates related to specifically African and agricultural problems. It is surprising that in African countries, where the main activities are agricultural, this situation should not be reflected in education. Certificates of tropical botany, agricultural and medical entomology, tropical animal physiology, etc. . . . would enable this defect to be remedied through the training of research workers who could contribute towards the development of those branches of science that are related to agriculture. The third-cycle certificates are those best suited to this purpose.

There is a great need for personnel, whether in secondary and higher education or in research. Arrangements calculated to broaden access to university studies are therefore excellent.

Accelerated training in biology is only conceivable in combination with high quality teaching. In practice, this involves two inconsistent requirements. While intensive courses can be justified for the training of technicians, it would seem more difficult to introduce arrangements for acceleration, apart from certain minor adjustments, in the sphere of higher education.

Africans are usually much attracted to research in botany and zoology. These subjects are in tune with their aptitudes, their predilection for nature and their inherited talents. They have perhaps less of a bent for physiological studies, presumably because these are more foreign to their early education in the family and at school.

Biology teaching must make allowance for a certain taste on the part of the African student for learning by rote. Consequently, it should proceed by gradual stages, from the simple to the complex, introducing practical examples, making extensive use of demonstration and practical work, of exposés and study groups, and developing everything that may contribute towards an understanding of the often complicated phenomena relating to life. In the curricula, then, training will be given pre-eminence over information.

At university level, there is a close relation between research and teaching. The various diplomas of higher studies and doctorates which are the outcome of university studies are valuable for the advancement of knowledge. Those African States that do not yet have trained research workers in sufficient numbers should encourage students to read for these diplomas by offering certain facilities to those who are prepared to do so.

Natural conditions in Africa are exceptionally favourable to biological research. In addition to its importance to the African countries themselves, this research is of interest to science as a whole. The plants and animals of the temperate regions alone can give no more than an incomplete notion of botany, zoology and biology in general.

Links should be established, maintained or strengthened between the various scientific and university establishments. The necessary contact with research workers in other countries can be provided by means of exchanges and missions.