

The Training of Students in applied Chemistry.

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My presence here in the position of President of the Chemical Section of the Indian Science Congress, while it is an honour which I recognise and sincerely appreciate, is due to the passing away of the esteemed teacher of chemistry Dr. Hill, Principal and Professor of Chemistry at the Muir College, Allahabad, whose experience of this country was much longer than mine and who would, had he lived, have occupied this position. I had not the pleasure of personally knowing Dr. Hill, but after 22 years of strenuous work he was greatly beloved by all his colleagues, students and friends and his loss will be keenly felt.

His researches range over a wide field and show that work in pure science does not preclude but rather assists more technical investigations. Thus while laborious and dangerous researches on the Electric Conductivity and Density of Solutions of Hydrogen Fluoride were published in the Proceedings of the Royal Society in 1909, he was engaged before his last illness on the purification, decolourisation and deodorisation of the common Indian vegetable oils.

We have to mourn another serious loss to our profession and to the Congress. I refer to Mr. J. H. Barnes, Principal, Agricultural Research Institute, Pusa, who died at Pusa on June 2nd 1917. In his case I can speak from personal knowledge having spent some pleasant hours in his company at the Congress meeting last year in Bangalore. I was greatly impressed by his keenness and the alertness of his point of view. He was awake to every aspect of the subject he was immediately considering. This is especially noticeable in his work on the methods of combating insects attacking stored wheat, where he was able to add valuable material to the subject of the chemistry of respiration. The reclamation of alkali soils led in his hands to further light being thrown on the conditions of nitrification and nitrogen fixation. I looked forward to many friendly communications as his line of interest in scientific work closely coincided with my own and the news of his death came as a

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personal loss. One felt that he was only at the beginning of things and was still rather feeling his way. It is satisfactory to know that the following up of the paths he only partly explored will be in the hands of such a sound and capable worker as Dr. Harrison.

In choosing a subject for an address one is often tempted to use the opportunity to discourse on something on which one may have vigorous opinions, but little knowledge. Thus I have strong views on the subject of indigenous dyes and especially on the question of natural as against artificial indigo which involves all sorts of criticisms on scientific control of industry, agricultural methods, economics and many other things. The whole subject of the relative importance of agricultural and manufacturing progress, whether *e. g.* an increase in the productive power of the soil does not outweigh in importance ordinary industrial development, is a fascinating theme.

But I have chosen one which, whether I am possessed of more knowledge than opinion concerning it, is, at any rate, my first business in life at present, *viz.*, the training of students in applied chemistry.

We shall find that even a brief handling of this subject involves the consideration of a number of important issues.

In the first place we may consider just where chemistry begins to find its useful application. Primitive industries even those involving chemical processes get on very well without applied chemistry. They are really arts. Thus to take an example with which I happen to be familiar the indigenous method of preparing shellac involves little or no capital expenditure. The raw material of this industry is stick lac which is an exudation produced by the lac insect (*Laccardia lacca*) on the twigs and thinner branches of certain trees. From it three products are obtainable—lac, lac-wax and lac-dye. It is possible for the workman to deal successfully with quite small quantities of stick lac. A few pounds can be washed by treading with water in a stone trough when the dye and some of the wax and finer portions of lac come away and are collected as a sediment, which is made into small cakes, dried and sold for a few annas per pound as lac-dye. The washed lac grains known as seed lac are dried in the sun, mixed with a little resin in a narrow cylindrical calico bag which is heated over a charcoal fire, and the molten lac squeezed out by twisting the bag. The molten lump of lac scraped from the bag is gradually and

cleverly flattened out and finally pulled into a thin even sheet by skill of hand and fineness of touch which a professional juggler might envy.

Such shellac, though the best brands maintain their quality, is never from the nature of the case an absolutely standard product, the lac dye as already described comes on to the market in cakes containing resin, wax and dirt in varying proportions, and pure lac wax is not to my knowledge on the market at all to any serious amount, although it has all the qualities suitable for purposes such as those for which bees wax is used.

If shellac, lac-wax and lac-dye are to be made of standard and uniform quality suited to various purposes, a different quality of lac *e. g.* being required for varnish from what is needed for hat making or for gramophone records, then modern methods of manufacture are called for, where a large quantity can be handled at once by one process. This involves expensive machinery and plant and hence we at once are met with the question of "critical output" *i. e.* the production of sufficient saleable material to pay for the expensive plant and machinery involved. It is at this point that modern industry begins.

I have chosen lac as a case with which I am personally familiar but of course these are many such. Immediately the jaggery maker gets away from his bullock mill and his pan on a charcoal fire, he steps into the modern industrial arena. When the maker of 'whole' soaps in a few tubs in a godown wishes to make a 'fitted' soap and recover glycerine he is at once faced with problems of capital, output and control.

My own view is that there is really no intermediate stage between the primitive method and the modern factory. I have myself tried to imitate the squeezed calico bag of the shellac maker by simple mechanism without much success, and from information available it would appear that even large expenditure on plant has not been quite successful. Radically different methods must be devised.

Again I think it may well be argued that the jaggery maker does better economically speaking with his pan over a submerged charcoal fire than if he used a boiler and allowed half his heat to be wasted by bad combustion, or faulty lagging and design of his steam pipes. But he has only a very imperfect control over the quality and composition of his product.

Standardisation then may be taken as the keynote of modern as distinct from primitive industry, and it is at this point that the student of applied chemistry is required.

What sort of man do we want for modern industry and how are we to obtain him? This brings me to the subject of my address.

I am old enough to remember when practical teaching in chemistry was largely a matter of a course of qualitative and quantitative analysis, when honours graduates in chemistry were numbered by units rather than by tens and when a short published research at the end of a fourth year at an English University or more likely a German one was looked upon somewhat as a crowning achievement.

Though chemical schools have multiplied and researches fill more and more pages of the journals and possibly increase in dullness with their number and bulk, it may still be questioned whether proportionately more real chemists are produced than formerly when the more restricted field gave opportunities for greater thoroughness both in thought and work.

Still more may it be doubted whether we are producing proportionately more of the kind of men who can successfully devote themselves to applied chemistry. At any rate to judge from the deficiencies revealed during the last three years, and the numerous consequent discussions, something is lacking, and such remarks as I have to make are with the hope of adding some results of actual experience rather than of making purely philosophic suggestions.

In this country the subject of applied chemistry, using this term in the widest sense, is of much more recent introduction than in Europe and its students labour under greater difficulties owing to the absence of numerous industrial centres where many general ideas can be picked up almost unconsciously. The need for definite and specific training in this direction is therefore the more necessary for those who are to take their place in the industrial developments to which all look forward hopefully in these days, and for which at any rate there is abundant scope.

On looking back over the progress of chemical education in England, it would seem that, as is so often the case, efforts have in many cases failed because there was not a quite clear idea of the type of man that was wanted

A good analyst is both useful and necessary in a works, but he is not necessarily an applied chemist. Experience in research is essential, but unless the right point of view has been reached a worker in an atmosphere of purely scientific research may be of less use in a works than a good analyst. To have been through a course of workshop practice and mechanical drawing may fit a student to be a handy man, but like the analyst or the pure research chemist he will not progress far or indeed really enter the field of chemical industry unless he is something besides these.

If asked what is one most important qualification for success in applied chemistry I should be inclined to say the possession of 'technical sense'.

Many apparently admirable propositions have failed because their sponsors though possibly excellent in the realm of pure science or in their own branch of it were yet quite lacking in this specially necessary qualification.

It must be remembered that pure scientific research may broadly speaking be considered as unconditioned, applied chemical research is always conditioned by the factor of *cost* in its various aspects.

I remember well an incident which impressed me with the fact that a man brilliant in his own line may yet be totally lacking in technical sense. In the early days of the discussion of the Manchester Sewage Disposal Scheme, very numerous inventions were considered by the responsible advisers of the Manchester Corporation, some more amusing than practical, but I was asked to interview a very famous Manchester surgeon who wished to discuss an important suggestion with me. He was a most charming and enthusiastic old gentleman and his specific was chloride of zinc. He had in his practice found it a most excellent antiseptic and on applying it to some samples of sewage which had been furnished him by the authorities he obtained most gratifying results in the direction of deodorisation and clarification. "You see", he said, holding up a graduated medicine glass full of sewage to the light, "I add a teaspoonful or half a teaspoonful of chloride of zinc to this sewage and you see the result." I said, "Yes Sir, that is excellent, but do you realise that whether you add a teaspoonful or half a teaspoonful means thousands of pounds at the end of a year?" "Does it really?" he said.

Of course in this case surgery was the old gentleman's proper business and not sewage disposal, but the incident illustrates clearly how a man rightly eminent intellectually and professionally may yet be wholly lacking in this necessary sense and so quite unfitted to become a leader of industry.

I use the word 'technical' sense rather than 'cost' sense. 'Cost' sense is an important and necessary part of 'technical' sense but not all of it. There is no more depressing person than the one who superficially looks into a set of figures in support of a proposition and says in five minutes "it can never pay". Such criticism may have its value in preventing many obviously foolish ventures from coming to birth but it is negative not positive.

The term 'business' sense it might be argued is what is required rather than simply 'cost' sense *i.e.* the quick appreciation not only of the methods of obtaining a product at least cost, including favourable buying of raw material, but also of marketing it to the best advantage.

In any large concern however the part of the work thus indicated is best undertaken by the business side of the management, leaving the chemist free to deal with more purely technical problems, though he should be of course in close and intelligent touch with the "office."

"Technical sense" then is something different from cost sense or business sense though it may, and often does, include these.

The history of the great successes in chemical industry, the Bessemer process, the sulphuric acid contact process, synthetic indigo, to take a few which readily occur to the mind, are all the history of continual failures and the patient overcoming of difficulties many unforeseen at first till the final goal is reached. Or to take an example from engineering, the output of steam turbines was practically negligible for ten years after the idea was first shown to be practicable, since which time of course the development has been phenomenal.

By "technical sense" then I understand the faculty of being able to recognise difficulties, but of distinguishing between those which are inherent and final and those which can be overcome by further research or adaptations of existing knowledge. It often happens that a process only becomes possible after some further progress has been made in directions that may be quite foreign apparently to the immediate problem. It was the internal

combustion engine which made possible the aeroplane. Cheap electrolytic chlorine facilitates the production of cheap non-inflammable solvents such as carbon-tetrachloride which stimulate improved oil and fat extraction processes and so on. A process useful in one industry for one purpose may be applied in another to an allied but different problem. The applied chemist with technical sense must be quick to see these possibilities and make use of them.

It must also be the aim of the applied chemist to effect improvement of yields and the utilisation of all by-products. The difference between a paying or non-paying yield of product will often depend on some small detail, often of a physico-chemical nature *e. g.* the right temperature for crystallisation, or the proper design and manipulation of a still. Instances of such details are met with *e. g.* in the manufacture of phenolic and nitroderivatives and in the distillation of oils, and recovery of sprits from solution of lac &c. The history of chemical industry abounds in cases where the recovery of by-products has saved an apparently hopeless situation. The classic instances of the Leblanc soda process and the recovery of chlorine, and the production of basic slag from the steel furnace need only be mentioned. The whole casein industry may almost be looked upon as a by-product of the creamery.

Further 'technical sense' is the faculty which enables its possessor quickly to translate a process from the laboratory bench to the works. A favourite question of mine is to ask a student who is washing a precipitate in a beaker by decantation and finally on a filter paper, how he would handle such a problem as separating that precipitate from the liquid, if the precipitate weighed a hundred tons and the liquid measured a million gallons.

The answer of course involves a knowledge of settling tanks, decanting valves, pumps, filter presses and so on, in fact leads directly into chemical engineering.

And here at once we come to the first important matter to be decided in the training of the applied chemistry student, how far is he to be trained as an engineer and how far as a chemist?

The question of the relationship between the chemist and the engineer raises issues in my view fundamental to the right development of chemical industry.

After 20 years of close association with engineers in attempting to solve problems in applied chemistry, I am clear that the two professions have their distinct spheres, and trouble is bound to arise either when the chemist poses as an engineer or perhaps still more when the engineer poses as a chemist. At the same time the chemist should know enough of engineering to know what it is reasonable to ask an engineer to do and the engineer should know enough chemistry intelligently to grasp the chemist's requirements.

Having said so much however I would add my further firm conviction that the chemist and not the chief engineer must be the captain of the ship.

It is true that in a big chemical works the engineer is everywhere in evidence, he puts up the blast furnace, the sulphuric acid plant and the gigantic gas holder and all the things that strike the eye, but all these things are only means to ends and if the active live directing thought is not chemical they will become a dead weight and a bar to progress. The engineer carries out, the chemist directs.

I speak with knowledge when I say that the directing intelligence in all the very numerous chemical works with which my former official position has made me familiar is chemical, and the higher the quality of chemical control the more successful the works.

Where the direction of a works is vested in the engineer rather than in the chemist, sooner or later there is stagnation and conservative inertia. I need only refer to the gas industry and the remarkable stimulus which war necessity has given to the recovery of by-products.

But on the other hand special qualities are demanded of our applied chemist if he is to take the place which is his of right. It is unfortunately true that many of the chemists trained in the ordinary schools are not fitted to deal with large practical problems demanding courage and initiative and the power of controlling men and machinery and so the responsibility passes into the hands of the engineer. To continue our analogy the captain may not be able to effect a repair in the engine room while under steam, but he must command respect of deck and engine room alike. I have discussed this question with engineers in a friendly way and the strongest argument for control being in the hands of the engineer has been that as he is trained professionally to handle material on the large scale, men place more

reliance on him than on the chemist and thus he can more readily maintain discipline. This, as I have admitted, is in a measure true, but it is a state of things which calls for alteration because, whatever the natural position of the engineer may be during construction and erection of plant he is not in his proper place in directing actual working. I consider that design of works and plant calls for the close collaboration of chemist and engineer, during actual erection of plant so designed the engineer takes the greater responsibility, for its operation the primary responsibility rests with the chemist.

But if he is to assume this last responsibility as he should, he must cultivate besides his scientific and technical knowledge and experience a knowledge of humanity. He must learn to understand and sympathise with the workmen who carry out his instructions. He must realise that although a workman may not be able to express himself in scientific language his daily contact with the process gives him an intuitive knowledge which is a natural integration of data only obtained by the trained chemist after much labour and observation. I have watched the gradual working up of a mass of molten steel in an open hearth furnace, the chemist comes along and takes his sample and as rapidly as possible does a carbon colour test, but the workman in charge looks through the blue glass at the boiling mass and says to his mate "I think she's about right now Bill" and pours the charge successfully without reference to the chemist.

My own personal experience has given me the greatest respect for the intuitive knowledge of the skilled workman in a primitive industry. By a process of natural selection he has often found out just the conditions for success, some of which may escape the observation of responsible or even of scientific supervisors.

In the technical research necessary to improve the primitive process, expensive mistakes may be made through lack of knowledge, or failure to realise the importance of these details.

The value of the chemist's work and thought of course lies in giving numerical expression to the workmen's intuitive knowledge so that the process may be intelligently directed and improved. "Science is measurement" it has been said and only by measurement and control can an art become a scientific industry, and be altered and developed in new directions to suit new needs. If the right relation between the scientific leader and the workmen is established there will be mutual respect and a willingness to learn on both sides.

And not only must there be this human understanding between the chemist and the workmen in charge but every subordinate down to the humblest wheeler out of ashes from the boiler must feel that he has his proper part to play in the right working of the whole organisation, of which the chemist should be the directing brain.

Coming now to the conclusion, how is this type of man to be produced? In the first place the general type will depend not on any detailed educational programme but on the spirit which informs that programme. Thus it is essential that an absolutely sound foundation of chemistry, physics and if possible mathematics, be laid, but if the tone of University life be to separate the graduate from his humbler brethren so that when he meets them in the works he does not feel the fellowship of common service it is to that extent unfitting him for his career in applied chemistry.

The wider idea of service must then be present always in the student's mind and it will be helped without premature specialisation if advantage is taken in the courses of purely scientific chemistry whether inorganic, organic or physical to choose typical examples from technical chemistry to illustrate general principles. Thus the law of mass action may be illustrated by the reactions taking place in a blast furnace, the phase rule from the cooling of alloys and the crystallisation of mixed salts, no better example of which of course can be found than Vant Hoff's study of the Stassfurt deposits. The subject of colloid chemistry can be illustrated by reference to the problems of the rubber industry, sewage and soil chemistry and the ceramic and pottery industries.

Examples of catalysis of course abound in modern industrial developments notably the hardening of oils, the synthesis of ammonia, the contact process of sulphuric acid and the whole realm of enzyme chemistry.

A student whose theoretical training has been given this practical bent and whose social education has been in the direction of a wide and generous humanity will, especially if he has devoted some of his vacation time to workshop practice, be in a position to take advantage of the more specialised post graduate training which is to fit him to enter a works with some confidence.

In this post graduate training he should come in contact with experimental plant typical of all general operations such

as disintegration, dessication, distillation, filtration, &c. Such plant may be the smallest unit, capable of turning out a technical, as distinct from a laboratory yield of any given product, but it should be an exact model if possible of a full scale plant.

My personal view is that it is a good thing for a student to "worry through" an operation on a semi-technical scale with sufficient guidance only to prevent injury to the plant, and that he should have more systematic teaching later. Speaking as one who has no natural bent towards or special interest in mechanical devices, I know *e.g.* that after a certain amount of tribulation with a motor car one is in a much more receptive state of mind for an explanation either from book or friendly helper.

I believe therefore that students who have been judiciously watched and guided without too much detailed instruction at first in the operation of various typical pieces of experimental plant are much better able to appreciate systematic instruction. After some six months then of this exploring work in any specific direction which each student may for various reasons choose, all students should be given a short course of lectures on mechanical engineering, fuel, steam and power problems, with special reference to chemical plant. They should also then devote some time to mechanical drawing and to working out problems in plant and machine design. In this way they will acquire confidence in the preliminary consideration of actual manufacturing propositions which they will have to discuss with the mechanical engineer later.

Along with this they should be guided in the right way of handling some specific industrial possibility and asked to work out a business proposition from the data of their laboratory or experimental semi-technical experiments. These reports may be criticised by the professor and form a very useful method for developing that 'technical sense' to which reference has been made. Further criticism of such reports may be obtained by making them the subject of a colloquium where they are open to discussion by the whole staff and the general body of students.

In this way each may learn from the other and there is or should be a cross fertilisation of ideas.

Of course wherever possible visits to actual works should be encouraged.

At present at the Indian Institute of Science these methods are being tried out in a modest way and it is not possible

for more than a limited number of paths of industrial research to be followed. But one foresees the time when there will be a model plant for each staple industry, as *e. g.* war conditions have caused the installation of a complete model of an acetone fermentation plant which enables the greater number of essential problems of this highly modern industrial development to be tried out.

The same was the case with the sandal oil industry which is now such a source of profit to Mysore.

The production of soap will shortly be transferred from the Department of Applied Chemistry to a new factory in Bangalore.

The students who have worked through these experimental plants will not feel strange when they go into large scale works and they also will have learnt to appreciate the help of labour and how they can direct it to the best advantage by wise and humane encouragement and sympathy without sacrifice of strict discipline.

But throughout all such developments the main idea must never be lost sight of not to create a narrow specialist but a leader of industry. It is most true in applied science as in wider issues that he who is over anxious to save his life will lose it. A student *e. g.* who only wants to learn to make soap and has no interest in other lines of work will not succeed even in making good soap because of the limited sphere of his mental activity.

But if he determines to widen the avenues of his thinking and to study to be able to apply his scientific knowledge, realising the mechanical, financial and not least the human factors involved, then he will be able to take his rightful place in the actual factory which he may afterwards enter and in due course be called upon to control. Then all questions of status will settle themselves, and engineer and chemist will work in friendly co-operation. The chemist whose science deals with molecular engineering will be able to translate his requirements to his colleague who deals with mass engineering, and together with intelligent labour responsive to their joint requirements. they will build up a live and sane industrialism, founded upon active and trained intelligence and containing within itself the potentiality of indefinite expansion.