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Training the Next Generation of Biochemists

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Biochemistry and its related disciplines (the "biosciences") seek to provide an explanation of how living organisms work and how they interact with each other and with their environment. All are practical subjects: bioscientists observe structures and organisms and carry out experiments. On the basis of their findings they propose hypotheses to try to provide explanations for life phenomena at the molecular level. In other words they seek to provide chemical and physical explanations for biological function. This process of observation and experimentation and coming up with explanations, is what they understand by 'research'.

The next generation of bioscientists need to be trained and this is not simply a matter of getting them to remember a lot of information. The future bioscientists have to understand what research is and how to do it, and although they do indeed need a large amount of background knowledge in their chosen subject area, research is not really about knowledge as such. As Tim Hunt wrote in his Foreword to a recent collection of articles from *Trends in Biochemical Sciences* [1]:

I was brought up to believe that finding out how to find things out was rather more important than what you actually found . . . in trying to educate young scientists, simply telling them how things were, that was the lazy way. In other words, knowing how we know is at least as important, for a real scientist, as what is known.

So how are we doing in our present-day undergraduate and post-graduate courses with respect to training these future researchers?

Explosion of Knowledge in the Biosciences – The Overloaded Curriculum

Undergraduate courses especially, tend to be overloaded with information and undergraduates therefore perceive information as the most important thing. Over the last 50 years there has been an explosion in the amount of knowledge in the biological sciences. The growth of information has been exponential and shows no sign of slowing down. It is driven to some extent by medical and commercial pressures but this is in addition to the fundamental research objective of satisfying curiosity, which is fuelled by the development of many new techniques and by the growth in computing power, making more and more experimental approaches possible. A consequence of this is that undergraduates have much more information to cope with, and they tend to concentrate more on remembering content, at the expense of learning about how data are obtained and interpreted. The content – the background – is important, and it is also much easier to assess whether students can remember facts than it is to test the development of the skills of obtaining and interpreting information. Teaching departments have, perhaps inadvertently, encouraged this trend. Rote learning of content for the examination succeeds in the traditional system – but it is only one part of the equation – and we should remember that exams drive student behaviour. However, factual information is only one part of what is required.

Many departments have incorporated a strategy for dealing with the intellectual development of their students, to get them to move away from simply remembering information to developing the skills of experimentation, observation, interpretation and finding information. We need to get students to understand that knowledge "is constructed in a context based on judgement of evidence": critical appraisal is vital. The material presented in the textbook, for example, represents a distillation based on the critical interpretation of observation and experimentation by numerous scientists. In our teaching we should explain not only research findings but also how the research was carried out and evaluated. We should link research with teaching, because students need to be made to understand how experimental evidence is obtained and how it is interpreted. This will include a consideration of how experiments are planned (controls, sample size, etc) as well as how they are carried out.

Research Projects

In the final year of a three- or four-year BS course in Biochemistry and related subjects in the UK, most students carry out some form of research project. (In certain other countries this may take place within a MSc course before embarking on a PhD.) Typically this is a fairly circumscribed piece of research carried out in the laboratory of a faculty staff member where there are postgraduate students, technicians and post-doctoral fellows at various stages of their careers. It is clearly a brilliant opportunity to see how science is done: how experiments are planned, how up to date equipment and analytical methods are applied, thinking about how many replicates are needed before one is sure that the result is valid, what controls must be done, how data are interpreted, and how data are presented in the form of reports and posters. This is a true experience of science as it is done in a modern laboratory.

Many departments, simultaneously with the final-year (or the MSc) project expect that students will become acquainted with the primary literature. Obviously if they are actually doing a lab project they will work as scientists and this will be part of what they have to do. Even so, there is an element of training required in how to find information and use the literature, and this is often explicitly given in the form of seminars and set work. The scientific literature has its own style and conventions and part of the stock in trade of the working bioscientist is to know how to use it and ultimately to write for it. This is not easy to organise in large classes – it is best done by individual discussion in the lab for example – but departments need a clear strategy of how this training is to be done.

Training our postgraduates

At the postgraduate level, the new graduates have to keep up with the literature although perhaps now in a more restricted field, and they also have to keep up with and become expert in the use of new techniques and instrumentation.

The reasons for needing to understand how research is done is that our graduates and postgraduates will go into research in academic institutions or in industry or hospitals, etc. In their future careers they will be required to apply knowledge. Application can only come from understanding what that knowledge is in the first place, including an understanding that the knowledge may be imperfect or even incorrect. In addition, students need to realize that the knowledge required may not be something they have been taught or that they have read about. Indeed it may not even have existed at the time of their graduation, so they need to know how to find new or developing knowledge.

Content, techniques and process

Any scientist working in the biosciences understands that research progress depends on observation and experiment which are subjected to analysis and interpretation and which in turn lead to hypotheses that may be supported or refuted by further observation or experiment. They understand this almost implicitly because as practitioners they become imbued with the culture of the science and how it is done. At some stage in their careers such individuals must have either been taught explicitly about this or must have picked these ideas up informally – we sometime say by 'osmosis'. Possibly the time of the PhD is when this comes across most strongly as a very important feature of how they work, but in fact, whether they know it or not, they are picking up this culture often unconsciously in the lab and as they read the scientific literature.

Thus, an important part of the job for any bioscience graduate or postgraduate going into the pharmaceutical industry, into public health microbiology, or into agribusiness, for example, is not to know just what was in textbooks or other secondary literature at the time of their graduation. This will not do in competitive industries. It is not even satisfactory to know what is in the up to date textbooks or the review papers in the literature. Workers in these industries must look at published data in the current bioscience literature and carefully consider interpretations of the data derived by authors of these reports. This critical interpretation will depend on an understanding of the experimental and observational techniques that have been employed in the published work. Thus, learning how to do this is a vital part of a bioscientist's training. Most guidelines for PhD examinations exhort the examiners to assess whether the candidate "is capable of being critical of experimental data and their interpretation, both in respect of their own data and those of others"[2]. But this process should commence before the PhD programme is embarked upon, and preferably should be started in the undergraduate curriculum. It should be noted that since the majority of published scientific work at the present time is written in the English language, proficiency in English is therefore also required. Unfortunately, for many around the world this is not optional!

It is important that students wishing to take a PhD or indeed those wishing to do post-doctoral research, think carefully about who they work with and where they work. Mary Osborn, current president of IUBMB, says, for post-doc work "go to the best labs and work with the best people"[3]! In a speech in 1967, Nobel Prizewinner Sir Hans Krebs, speaking of his own training in science research at the hands of his illustrious forbears and teachers, said of postgraduate work [4]:

Besides the art of experimenting and observing, the pupils learned the ways of thinking required by science. They learned how to select the object to be explored, how to interpret and evaluate the results obtained, and how to integrate them into the whole body of knowledge. In this way students were not only made familiar with methods and facts, but were imbued with the general scientific spirit which shapes the pattern of the true scholar and investigator.

Again the emphasis is not on remembering a huge body of knowledge but on learning the ways of thinking required by science. We should ask ourselves at what points(s) in training our students does this occur. One way of expressing the idea of linking research with our teaching is "teaching in an atmosphere of research": this should start even at the undergraduate level. Krebs went on to add:

So, above all, attitudes rather than knowledge are conveyed by the distinguished teacher.

These days we translate this into 'research students becoming imbued with the "culture" of the science laboratory'. This is not something that can be taught in the formal sense but is something picked up by being a sort of apprentice in a successful research laboratory or group. We should think about this when we are selecting our new potential PhD students – and they in turn should also think about this when selecting the laboratory in which they wish to work!

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