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The Development of Science through Educational Strategies

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We live in a world that reflects a multitude of features that result from scientific discoveries. The fruits of these discoveries are simply taken for granted by the great majority of the population, who have little or no understanding of science, and a poor appreciation of the value of science. How many people think of science when they drive a car, fly in an aeroplane, watch television, play tennis, go to work, to school, to the doctor or to hospital, or even go to the department store to buy clothing, or to the restaurant to buy food? I think particularly of chemistry, as the central science, and wonder about the level of chemical understanding in the general community. Education is the key to most things, and it is certainly the key to an understanding of science. The level of general understanding and appreciation of science, and chemistry, is reflected by the nature of our education. I cannot speak with any authority about the education systems in most Asian countries, nor about the manner in which they develop the areas of science, and chemistry. I shall give some opinions based on the experience in Australia, and this seems to be quite similar to the situation in other Western countries, where there is perhaps a longer and more highly developed tradition of systematic education than in the Asian region. The problems that I see in our education system are so strongly entrenched that they will be extremely difficult to overcome. By sharing my views with readers of *ScienceAsia*, I hope that at least some of these problems might be more easily avoided if they do not already exist, or overcome if they do exist, in Asian education systems.

So let us consider what makes science of any interest at all to the general community. Children grow up with a knowledge of arithmetic, and while not all will be captivated by the magic of numbers, the value of arithmetic - and later on of algebra, geometry, calculus and so on - becomes very clear to them. Our whole array of life tasks requires the manipulation of numbers, and there is a strong appreciation of the value of mathematics even among people who are not particularly numerate. Children also grow up wondering about the things they see around them, and of course the most spectacular are the sun, moon and stars. Consequently, the magic of astronomy really captures the public imagination. An appreciation of physics, to some extent, then follows, and there is an expectation that it is physics that will be the key to unlock the doors to outer space, other galaxies and consequently new and exciting experiences. Once again, there is no great requirement for a strong knowledge of physics, but the general public is glad to have physicists who can do their brilliant work for them. Biology has long ago captured the public imagination, and time and again, this has been enhanced by the stunningly beautiful and technically superb television and film productions. Also the subject matter of reproduction of species by a myriad amazing methods never ceases to entrance because of its sheer fundamental importance.

So what about chemistry? It seems to me that chemistry is largely ignored by the general public. In the cases where it does reach the public mind, it is most frequently in the context of toxic chemicals that cause deleterious effects in many ways. It is not uncommon to hear people say that they refuse to eat any food that contains chemicals. There are also frequent misleading advertisements, such as one some years ago urging people to buy woollen rather than synthetic fabrics, because wool is not made from chemicals. The movement to "organic" food also reveals a poor understanding of chemistry, because it seems to mean that because pesticides have not been used in the production of the products, these products must be superior. In the situation where animal products, such as chickens, are described as "organic", presumably this means that they have been raised without the assistance of added chemical agents that might promote growth or inhibit disease. However, clearly such chickens have been raised on some kind of food, and that does not automatically guarantee their superior quality. During the drug debate prior to the Sydney Olympic Games in 2000, there was a rare burst of clarity when the respected (at least by me for this comment) reporter, Malcolm Knox wrote in the *Sydney Morning Herald* as follows. "What is a drug? A chemical? The *Macquarie Dictionary* defines a drug as "a chemical substance given with the intention of preventing or curing disease or otherwise enhancing the physical or mental welfare". But everything is chemical. Bread is chemicals. Milk is chemicals. Bread and milk enhance performance. Does that make them performance-enhancing drugs?"

Food is just one part of the human experience. We human beings are entirely made up of chemical molecules, as are all animals, and indeed the entire world. Everything is molecular and it is impossible to find or contemplate a "molecule-free" or "chemical-free" environment. The material world is simply a combination of natural and synthetic chemical substances. None of us would be here without the chemistry involved in sexual attraction, conception, and reproduction. The whole operation of our biological systems is controlled by chemistry. All mental and physical processes are defined by precise and highly selective chemical reactions. Not only do we live in a totally chemical environment, but we are fascinating vessels of reacting chemicals, which allow us to breathe, walk, talk, see and indeed stay alive.

There is, I think, a rather better understanding of the role of materials such as plastics in our daily life, but attention often focuses on some of the problems associated with disposal and degradation. Polymer chemistry developed from the petrochemical industry in the 1920s and soon led to the discovery of many important plastics materials, including polyvinyl chloride, polystyrene and polyethylene. The development of "ready to use" gloss paints, nitrocellulose lacquers, alkyd resins, and water-based latex paints followed. Nylon, the first wholly synthetic fibre, made its debut at an international exposition in San Francisco in 1939. On May 15, 1940, nylon stockings went on sale throughout the USA, and in New York city alone 4 million pairs were sold in a matter of hours. Other synthetic fibres, including acrylic and polyester, were soon to follow. These synthetic fibres, used either alone or in blends with natural fibres, provide attractive and durable carpets, drapes and other soft furnishings. Most of the clothes in our wardrobes are made from 100% synthetic fibres or synthetic and natural fibre blends. Even natural fibres (which of course are themselves chemicals) are chemically cleaned and processed, and then coloured with natural or synthetic dyes. But the plastics revolution is by no means over yet. The synthesis of new polymers and composite materials is making a tremendous contribution to medicine, with the use of synthetic fibre implants, and to transport, with carbon fibre composites for strength and lightness in cars and aeroplanes, and to the progressive miniaturisation sought in the micro-electronics industry. The continuing computer revolution is quite dependent on plastics, not to mention the chemistry of liquid crystal display. Another example where chemistry has made a massive public impact is in digital photography. The development of photography from the outset, through the advances in panchromatic film colour photography, has been a wonderful demonstration of chemical brilliance, as the technology is based on quite sophisticated chemical reactions being carried out in quantitative yield and with complete reliability. The latest advance is even more breath-taking.

There is also a growing awareness of the fragility of the environment and the damage that can be caused by land clearing, generation of greenhouse gases and global warming. These environmental issues have largely been seen as residing in the realm of biology, but it is increasingly being appreciated that the serious application of the most sophisticated chemistry, physics and mathematics is required. Although the problems will be solved by fundamental science applied by large teams of professional scientists, it is important that the general public understands the issues. There is also the crisis of water shortage in many areas, and politicians debate the relative merits of recycling and desalination, often with a very poor understanding of the science. There is a desperate need for education of the public in this regard.

So I return to education at the more formal, and younger age level. How can we generate in children an understanding of the molecular nature of the world (and indeed universe)? Most chemical education starts quite late, usually in secondary schools. It also is provided via a curriculum designed by chemists, who know that it is an important subject, but usually fail to justify this importance. Because students should know about chemistry, the syllabus usually starts off with the fundamentals of the subject (and this is true of science in general). Students frequently fail to see the relevance and have the impression that the subject is being taught because it is good for them. Fortunately, some are still captivated by the fascination of the subject and continue on with enthusiasm. But the overwhelming impression is that chemistry is for professional chemists, not for everybody.

This is the crucial flaw in chemistry education. In order to overcome this, we need to take chemistry into the primary school, and (to be deliberately provocative), into the kindergarten or pre-school. And the teaching of chemistry must start with organic chemistry (which it never does in current higher level curricula). The importance of chemistry is that we and the world are just collections of molecules, most of which are organic. It is not difficult to describe to young children the many examples of common simple chemicals that they would encounter every day, and there are some excellent sources of such compilations available. But rather than expand on this, I consider that the crucial issue is to teach every child the description of molecular structures. Every child at school learns to read, write, and do arithmetic. These three skills are central to all education systems and it is taken for granted that they are absolutely essential. Imagine if every child at school also learnt the language of chemical structure description. I suggest that this could be done by restricting the molecules to the elements carbon, nitrogen, oxygen and hydrogen. Nature shows us that these atoms are joined together such that carbon is attached to four atoms, nitrogen to three, oxygen to two, and hydrogen to one. The children (and here I include kindergarten and pre-school) could then be given some balls of plasticine and some sticks, and set the task of making some molecules, according to those simple rules (of what we call valency) described above. They could then progress to learn that a simple hexagon describes a chemical molecule in which each vertex is a carbon atom, so six carbon atoms are joined together in a ring. They could also learn that, since carbon has four atoms attached to it, they could fill in the missing hydrogens to describe one molecule, but they could also attach other atoms to describe different molecules. You could then show children a structure of, for example, pinene (a good one for Australian children), camphor, or even cholesterol, so that they could understand the representation of atoms connected together in different ways. The aim of this approach is not actually to teach chemistry, but by teaching the descriptive representation of chemicals all around us, to build up an appreciation and understanding of a world of molecules. A newspaper article could use such a chemical structure for the future general public, who would simply be content to understand that what they saw was just another molecule.

Later in the education process, the reason for teaching chemistry would be very clear. Because the world is made up of molecules, it is very important that we understand more deeply the principles governing their nature and behaviour. That is the reason for studying general and physical chemistry, rather than doing it because we chemists blandly assert that these areas are important.

In conclusion, I make the point that the aim of my suggested early education plan is not to attract more students to chemistry, but to raise dramatically the level of understanding and appreciation of chemistry in the community. If the latter can be achieved, then it is hard to imagine that the former will not follow.