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Challenges for Chemical Education: Implementing the `Chemistry for All´ Vision

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Abstract: Over the last two decades, concern has been mounting within the chemistry profession over the general populace having negative views and opinions of chemistry, chemicals and a 'chemophobia' of chemical processes and the chemical industry. This phenomenon has been consistently blamed on the 'media' for exposing and emphasising the harmful consequences of chemical accidents and under-emphasizing or ignoring chemical triumphs. In 2004, the International Union of Pure & Applied Chemistry (IUPAC) commissioned a review of public perceptions of chemistry and sought strategies for enhancing the public image of chemistry, chemicals and the chemical industry. The subsequent report indicated the need for strategic chemical education programs dedicated to communities and embracing a 'Chemistry for All' vision to empower communities to understand the complex world in which they live. Such a program should also emphasize that the advantages and opportunities that chemistry offers to humanity in terms of enhancing global standards of living far outweigh its disadvantages and disincentives. This paper discusses the extent to which chemical education has advanced so as to develop a 'Chemistry for All' vision that can feasibly be implemented.

Key Words: Chemistry for all, chemical education, chemistry education, chemophobia.

INTRODUCTION

The perennial paradox is that, although 'chemicals' provide major recognisable benefits to humanity by raising standards of living and well-being, such benefits are largely taken for granted by the majority of the populace resulting in a prevailing negative public image of chemistry and chemicals. This is believed to be due to the global media sensationalizing environmental chemical 'incidents' whilst marginalizing erudite progress reports of major developments in science and technology and the tangible benefits of these two commodities at large [1]. This so-called 'chemophobia syndrome', which appears to be widespread in communities, is directly related to the inability of individuals to associate chemistry with materials and processes which enhance the quality of life and the quality of the natural environment which supports life. Communities need to understand that chemistry has consistently fulfilled its commitment to the needs of people, but in doing so there have been some negative spin-offs. It is unfortunate that, in general, people have consistently focussed on the latter and largely ignored the former. For example, fossil fuels currently generate the bulk of global energy requirements, but public focus tends to be concentrated on the environmental impact of the greenhouse gases that fossil fuel power generators produce.

In 2004, IUPAC commissioned an enquiry into the general public perception of chemistry and its benefits to society [1]. The subsequent report found that the prevailing widespread negative perception of chemistry correlates with limited understanding of chemistry, chemists and chemicals and an even more shallow understanding of the function and operations of the chemical industry. The report concedes that such a negative community image of chemistry can only change by concerted educational programs, promoted by organisations, such as the American Chemical Society (ACS) and the Royal Society of Chemistry (RSC), national science foundations, science policy makers, science teachers, science students and 'public forums', thereby constituting a 'Chemistry for All' educational strategy.

Most importantly, the outreach of this strategy can be enhanced by frequent blogs, YouTube videos and social media outputs from professional chemists exalting the virtues of chemistry and its active role in advancing the standard and quality of living.

This paper discusses how chemical education philosophy and pedagogy have progressively developed over the last decade to embrace the 'Chemistry for All' concept and identifies the key chemical concepts which constitute chemical literacy, leading to some understanding of how chemistry enhances standards of living whilst simultaneously enabling environmental sustainability.

THE PRESENT STATUS OF CHEMISTRY LITERACY

Since communities in general continue to have negative views and opinions about chemistry and the chemical enterprise, the present very limited level of community wide chemical literacy needs to be significantly enhanced. Initially, it is necessary to assist communities to understand and appreciate the benefits of chemistry and chemicals and its potential to enhance standards of living and sustain life. Professional chemists and chemistry educators must understand how people form their opinions about chemistry. There is abundant evidence [2, 3] to confirm that chemistry has, over many decades, created valuable materials and products which have benefited every aspect of daily living. A wide variety of consumer goods are chemically-based – cosmetics, soaps, detergents, paints and cleansing agents. Construction of modern homes employs a variety of 'chemical materials' – notably polymeric materials. Availability of high quality drinking water and processed and preserved foods involve chemical processes and agricultural development and has traditionally been dependent on chemical fertilizers and pesticides. Life expectancy has increased as a result of the development of targeted pharmaceuticals and the continued growth of the chemical industry has sustained global economies.

In view of such chemistry attributes, it is pertinent to rationalize why the general populace does not recognise the pivotal role of chemistry in not only supporting a healthy and rewarding lifestyle, but also in sustaining the environment. Unfortunately, communities only focus on the negative aspects of chemistry. Quite simply, these tend to be accentuated by adverse media coverage [4]. It cannot be denied that while chemical products have very substantially enhanced standards of living, their manufacture, use and ultimate disposal can pose varying levels of concern to people in the context of 'toxic wastes', 'water and soil contamination' and 'air pollution'. For example, the quintessential materials of the 20th century were 'polymers', which heralded the arrival of the 'plastic age' whilst simultaneously causing a most serious threat to global environmental sustainability. This phenomenon was recently brought into public focus by the voyage of 'Plastiki' across 8000 miles of the Pacific Ocean from San Francisco to Sydney [5]. 'Plastiki' was a catamaran constructed from some 12,500 discarded plastic soft-drink bottles glued together using a sugar/cashew nut (bio-degradable) mixture. The aim of the mission was to emphasise the extreme levels of 'plastic pollution' in the oceans, which cause serious reductions of marine life and degradation of marine ecosystems.

Likewise, communities are well aware of the harm caused by 'drugs of dependence', such as heroin, which destroy human lives; however, they are at the same time unaware that morphine, which is widely used to relieve pain, is closely related chemically to heroin. It is this lack of association of 'drugs' with beneficial chemical activity which in part sustains the negative opinion of 'chemistry syndrome'. Also, communities are well aware of chemicals that are used in warfare, such as Agent Orange, and especially since recent wars have been associated with 'weapons of mass-destruction'. Also, communities are concerned and sceptical about the progressive genetic modification of plant and animal species, aligning this frontier science with 'chemical-infested foodstuffs'. Hence the general populace has difficulty coping with the ethical directions in which modern chemistry is advancing, and these concerns overwhelm any positive perceptions of chemistry which are self-evident to those who are chemically literate.

Unfortunately, evidence is rapidly accumulating to suggest that the global environment is in a state of decline and public awareness campaigns are omnipresent. However, amid all the hype, the fundamental cause of this decline is often overlooked – namely that the rapidly increasing global population cannot be sustained by diminishing global resources, disproportionately consumed, and hence communities are not aware that they are largely responsible for their own ultimate demise through malnutrition. In this context, communities are not aware that chemistry can and is making major contributions to sustaining human life in areas such as food security, clean water supplies, energy security and mitigating global warming [6].

Compounding the negative image problem is that communities are unaware of what professional chemists 'do' and the difference between a 'chemist' and a 'pharmacist'. Furthermore, their image of the chemical industry is largely based on its production of the 'odours', 'colours', 'tastes' and 'textures' of everyday experience with the prefix of 'nasty' attached, and their 'chemophobia' develops from and is sustained by chemical industrial accidents which are vigorously reported in the media.

Communities blame the chemical industry for producing toxic chemicals, such as pesticides, and toxic wastes, such as 'trace metals', but they are unaware that over the last decade, the chemical industry has undergone a major restructure embracing the principles and practices of 'green chemistry', thereby forming the foundation of a sustainable chemical industry. This revolution in 'chemical practice' is further evidence of chemistry and the chemical industry making a continuing commitment to recognise and address its responsibilities to society at large.

The general populace has a fear of chemistry because it does not understand its language or the models that are used to visualise it. It can only relate to the real world and so has inordinate difficulty in relating to the microscopic world of atoms and molecules which make up the real world. Since chemistry is the science of atoms and molecules and how these interact to form the real world, the 'Chemistry for All' vision must provide educational pathways for communities to understand the microscopic world and thereby empower them to understand the macroscopic world in which they live. Furthermore, inclusion of both positive and negative attributes of chemistry in chemistry curricula in schools can also assist in resolving the image identity problem (particularly if the negative attributes of chemistry are portrayed as careless application of chemical principles and practices), and that more socially responsible (green) application of these principles can ultimately resolve these problems.

It therefore follows that community chemistry literacy is primarily empowered by strategically-structured chemical education programs which are focussed on basic chemical principles, chemical processes with emphasis on the chemical products that enhance standards of living, and chemical processes that sustain the environment.

THE PRESENT STATUS OF CHEMISTRY EDUCATION

The 'Science for All' vision is not a new phenomenon. In 1938, Hogben [7] published his classic treatise 'Science for the Citizen' with the Foreword:

> *'Science for the Citizen is partly written for the large and growing number of intelligent adults who realize that the impact of science on society is now the focus of genuinely constructive social effort. It is also written for the growing number of adolescents who realise that they will be the first victims of the new destructive powers of science misapplied.'*

This message largely remained dormant until the mid - 1980's when Fensham [8] proposed that everybody should, through progressive education, be aware of the scientific principles that affect their everyday lives. Scientific literacy is, in Fensham's view, of equal importance to reading, writing and math skills and that these four interrelated skills should be afforded equivalent prominence in the educational process of society at large. Hence, scientific literacy should be a major goal of the educational system at all levels in addition to the basic '3R's' goals. However, this creates a dilemma for educationalists since science teaching methodologies have to be developed that not only include basic science principles, but also show how these principles enhance quality of life and sustain the environment. In this context, Cross [9] argues that there is an intuitive link between a sustainable future for humanity and the impact of science on the populace; and hence the need for a 'social construction of science'. He believes that it is possible for 'ordinary people' to have a basic understanding of science so that they can interact constructively with the current debates on issues such as 'global warming', 'renewable energy resources', 'nuclear energy' and 'genetic modification of foodstuffs'. The challenge is to restructure science education so that it leads to unilateral scientific literacy and includes the evaluation of current social issues that have scientific content and focus. Such a framework better prepares people to evaluate evidence and make judgements that empower them to face the many challenges that threaten human life and the sustainability of the environment.

Embedding the 'human element' into chemistry education has been a slow process and has only recently gathered momentum following the 2006 IUPAC report [1] on the desperate need to inform and engage communities with basic chemical knowledge to allow them to make informed judgements on how chemistry (and chemicals) benefit communities. In this context Mahaffy [10] has shown that there is an integral connection between 'chemical reactivity' and 'human activity' and has proposed that the traditional three levels of learning chemistry – 'macroscopic', 'symbolic' and 'molecular' – be extended to a fourth dimension, the 'human element', leading to the so-called 'tetrahedral chemical education model'. It is this fourth dimension which has been largely overlooked in chemical education teaching and research, and a lack of relating chemistry and chemicals to the human element may have been a major factor in contributing to the negative public image of chemistry. However, inclusion of the human element leads to a new vision for chemical education which is, in principle, wider in implementation than in traditional school and tertiary education forums.

This new vision for chemical education should be closely aligned with the roadmap for the future development of chemistry, as incorporated in the United Nations charter on the International Year of Chemistry (IYC) announced in 2011 [11]. This charter identified current global crises: water quality, food security, energy security, disease control, climate change and environmental sustainability. All of these issues relate to human sustainability and chemistry enables solutions to be found [6]. However, it has been proposed by Hill and Mustafa [12] that environmental sustainability is the primary global challenge which fundamentally encapsulates all of the other IYC issues, since all are related to it. Thus, we propose that the 'new chemical education' has three dimensions, as shown in Figure 1.

Over the last two decades, there have been some notable developments of these dimensions. For example, Atkins [13] has proposed that 'chemistry is based on just a few simple ideas', which has led to re-evaluation of the content and context of secondary college and tertiary courses in 'basic chemistry', together with more effective learning processes and outcomes. Hill [14] has suggested that the Atkins philosophy correlates directly with the core chemistry knowledge of new chemical education. Also, Hill [15] has designed a curriculum framework for the tertiary 'basic chemistry' course which embraces the Atkins 'simple ideas' philosophy [13], the Fensham, and Kumar and Chubin 'Science for All' philosophy [8, 24, 25] and the Mahaffy 'human element' proposal [10]. Furthermore, Hill and Warren [16] have shown that this curriculum framework can be extended and adapted to include the 'environmental sustainability' dimension of new chemical education, thereby becoming consistent with the IYC challenges. This restructured basic chemistry course with emphasis on 'people engagement' may play a major role in reversing the lingering negative views and opinions of chemistry, chemicals and the chemical industry held by communities.

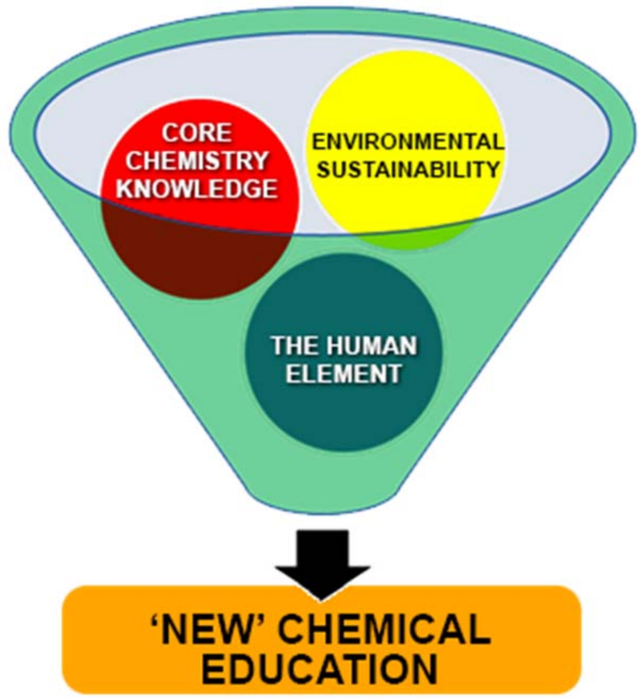

Figure 1. Dimensions of 'New Chemical Education'

TESTING THE EFFECTIVENESS OF THE NEW CHEMICAL EDUCATION PARADIGM

Climate change is probably one of the most contested contemporary issues. The pro-lobbyists argue that the scientific evidence for climate change is irrefutable [17]. The opponents and sceptics argue that such evidence is inconclusive and ambiguous and that even the term 'climate change' is ambiguous because in reality, 'climate' is 'perpetually changing' and that periods of global warming and global cooling are cyclical and have occurred before the advent of anthropogenic carbon dioxide emissions [18]. It is clear that understanding the climate change (global warming) phenomenon requires knowledge of the basic principles of several sciences and how to mitigate it needs recognition of the associated 'social', 'political' and 'economic' aspects. Thus, science education at all levels must be intensified if the wider community, politicians and economists are to effectively address the causes and (already apparent) consequences of global warming and thereby promote a sustainable future for humanity [19]. Chemical education has a major role in the challenging process of informing the general populace of the causes of global warming using simple, basic chemical terminology and discussing options presently available for addressing it. We suggest a framework for such a community chemical education initiative on global warming, as shown in Figure 2.

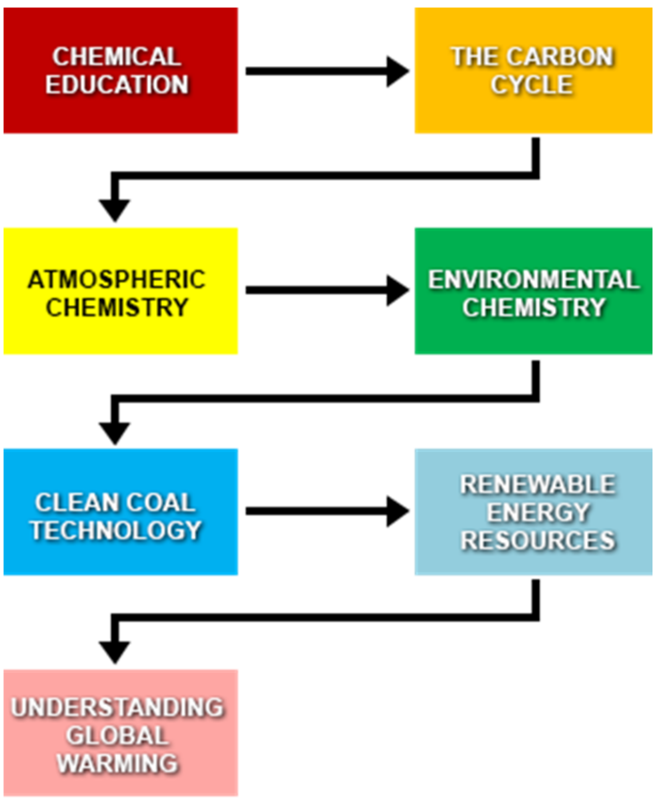

Figure 2. Understanding 'Global Warming' via Chemical Education.

Such an initiative is probably the ultimate challenge for new chemical education since topics such as 'what constitutes climate', 'what is a greenhouse gas', 'what is global warming', 'what is a renewable energy resource' and 'what is clean coal technology' have to be explained in terms that non-scientifically orientated communities can understand [20 – 23, 26]. Even more challenging is to change the 'quick fix' syndrome of the 'save the earth' organisations who argue that the only way to address global warming is to shut down the worst industrial offenders of greenhouse gas emissions, namely coal-fired power generators. In the State of Victoria (Australia), about 85% of electricity demand is provided by (brown) coal-fired power generators located in the La Trobe Valley. Peak demand is met by supplementary power provided from the Snowy hydroelectric scheme located in New South Wales. This scenario is a global phenomenon, namely that base-load electricity is predominantly provided by coal-fired power generators. The fundamental dilemma is that at present demand rates, the energy outputs of all existing energy resources (hydro, solar and wind) combined cannot provide base-load power requirements and hence closure of coal-fired power generators will cause catastrophic and unmanageable reductions in global power generation. The logical (compromise) solution is to 'clean' existing coal-fired power generators by application of clean coal technology (CCT). However, a further dilemma is apparent in that CCT in its various manifestations is at an 'experimental stage' and is not expected to become commercially available for at least a decade. Thus, a carefully constructed chemical education program is able to provide the general populace with a balanced interpretation of the global warming phenomenon, its causes, consequences and its credible mitigation strategies.

Finally, a public chemical education program can include an introduction to the intangible concept of environmental sustainability by giving meaning to the jargon of global warming, such as 'carbon tax', 'carbon economy', 'carbon footprint', 'energy crisis', 'green energy' and 'carbon emission trading scheme', all of which are currently widely used in the media, but usually with inadequate explanation. Such programs are likely to have widespread public appeal, particularly if delivered via the unsurpassed outreach capacity of the internet by way of Facebook, YouTube, blogs and perhaps Skype. These online chemical education initiatives should involve professional chemists and chemical educators interactively discussing contemporary chemical phenomena in terms which the general public can relate to and understand. Commercial sponsorship can probably be obtained to fund such initiatives, particularly from industries which are publicly perceived to produce toxic chemicals and from organisations which promote environmental sustainability.

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