International Organization
for
Chemical Sciences in Development

Education in Chemistry: Scoping the Future

CHEMRAWN-IOCD Meeting
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Meeting Summary

Participants

John Bradley	Johannesburg (South Africa)
Stefano Cerri	Montpellier (France)
Mei-Hung Chiu	Taipei (Taiwan)
Henning Hopf	Brunswick (Germany)
Christa Jansen	Darmstadt (Germany)
Alain Krief	Namur (Belgium)
Stephen Matlin	London (UK)
Goverdhan Mehta	Hyderabad (India)
Gary Molander	Philadelphia (USA)
Niceas Schamp	Gent (Belgium)
Chris Stevens	Gent (Belgium)
Leiv Sydnes	Bergen (Norway)

Welcome and opening remarks

Opening the meeting on behalf of IOCD its Executive Director, **Alain Krief** (Emeritus Professor in Organic Chemistry, University of Namur), welcomed the participants who had come from around the world to contribute to the discussions. He noted that chemistry education was undergoing major changes, with computers and the internet having an increasing impact on where and how courses in chemistry could be provided. Nevertheless, he stressed that it remained important to recognise that educators should be in close contact with learners and that learning is context dependent. While many leading politicians around the world had acknowledged the value and importance of education, there was little evidence that chemistry was gaining an appropriate level of attention and it was being neglected, for example, as a subject in web sciences. It was also important to see the role of chemistry education beyond the school, encouraging greater public understanding and more informed and balanced treatment of chemistry-related topics in the media. Beyond traditional classroom teaching, chemistry learning needed to be supported through informal approaches and learning by doing, with the creative and practical aspects of the subject being stressed.

Responding on behalf of CHEMRAWN, **Leiv Sydnes** (Professor of Organic Chemistry, University of Bergen; Past President of IUPAC and current chair of CHEMRAWN), also welcomed the participants and the opportunity that the meeting provided to consider the future of chemistry education and the identification of potential roles for IOCD. Following discussions at the IUPAC 47TH General Assembly and 44th World Chemistry Congress in Istanbul in August 2013, CHEMRAWN and IOCD had agreed to collaborate in convening this special consultation and looked forward to identifying opportunities for further activities of mutual benefit in the future.

Introduction

Stephen Matlin (Adjunct Professor, Institute of Global Health Innovation, Imperial College London; Head of strategic Development, IOCD) gave an opening presentation on ‘Chemistry Education for the 21st Century’, in which he provided a brief introduction to IOCD; a perspective on the global changes taking place to set the scene for the discussions to be held; and IOCD’s ambition for the goals and key outcomes of the meeting.

Having been created at UNESCO in 1981, IOCD had become registered in 1983 in Belgium as a non-governmental organization, basing its Secretariat in Mexico City with the support of the Mexican government in 1985. IOCD quickly established a series of working groups in aspects of medicinal chemistry and the utilization of natural products and created some analytical service centres, initially in Europe, Mexico and the USA and later in Africa at the University of Botswana (Network for Analytical and Bioassays Services in Africa), to support chemists in low- and middle-income countries by provided spectra free of charge. Initially, IOCD also established a panel for chemical education that was linked to the International Centre for Chemical Studies in Ljubljana and this had operated for several years before being wound down. Gradually, IOCD had shifted from supporting collaborative research projects to organizing and sponsoring conferences and training workshops to assist capacity building, and to achieve systemic improvements in chemistry capacity by, for example, training laboratory managers and contributing to national policy development. IOCD had marked its 30th anniversary in 2011 with a celebration of achievements but also with a major overhaul of its focus and approaches to ensure its continuing relevance in the 21st century. Its work was now focussed in three areas: chemistry for better health; chemistry for a better environment; and capacity building in chemistry education.

Reflecting on the value of education in chemistry, Matlin observed that the chemical sciences had been good for human beings in terms of wealth and health– but only up to a point, and only for some, since the world’s accumulated wealth was very unevenly distributed and average life expectancies varied greatly between richer and poorer countries. Fundamental breakthroughs in the chemical sciences since around 1800 had laid the foundations for some of the world’s biggest industries, including the electrochemical industry, synthetic chemistry, biotechnology, materials industries related to rubbers, fibres, polymers and plastics, the pharmaceutical industry, analytical sciences with applications that include food, medicine and the environment, agrochemicals including fertilizers, pest control agents and growth regulators, and solid state chemistry products such as semiconductors and transistors that have provided the basis for modern information and communications technology industries whose applications are transforming our lives. Economists have concluded that the steep decline in mortality during the 20th century had its origin not directly in wealth but in technical progress – where ‘technical progress’ refers to a combination of technological advances and their diffusion and uptake in different countries and the capacities of the countries themselves to conduct and apply research. Ismail Serageldin, Founding Director the new Library of Alexandria in Egypt, has commented that “developing countries cannot do without home-grown capacity for scientific research and technological know-how. Increasingly, a nation’s wealth will depend on the knowledge it accrues and how it applies it, rather than the resources it controls. The ‘haves’ and the ‘have-nots’ will be synonymous with the ‘knows’ and the ’know-nots’.” For the poorer countries, not acquiring and using new knowledge is not only a matter of economics – it is also a question of life and death. To put it simply – “ignorance is fatal”.

It was not surprising, therefore, that among the targets of the MDGs for 2015 are the achievement of universal primary education and a global increase in the rates of adult literacy. But there are still more than three quarters of a billion adults in the world who are illiterate, and three quarters of these are concentrated in just 10 of the largest countries. Globally, the average literacy rate is around 85%, but there is a large gender imbalance with two thirds of the adult illiterates being female. The gender parity index for adult literacy is at its worst in the Arab states, Sub-Saharan Africa and South-West Asia, and it is these same countries that are furthest from meeting the 2015 targets. In the field of science, the lowest densities of research workers are found in countries in Africa and parts of Asia and Latin America and, not surprisingly, low densities of skilled human resources for research correlate with low levels of scientific output. Over 50 years ago, Paul DeHart Hurd wrote about ‘Scientific literacy as a goal of science education’. Forty years later, Hurd observed that ‘Although 350 years have now elapsed since it was first proposed that a purpose of science education ought to be the contributions that science makes to public life and the common good, the appropriate curricula have yet to emerge. He urged that ‘Science curricula need to be reinvented to harmonize with changes in the practice of science/technology, an information age, and the quality of life.’

Chemistry literacy has sometimes been taken in a very narrow sense, to mean, for example, the capacity to balance a chemical equation. But John Gilbert has emphasised a much wider approach, taking chemistry literacy to encompass a number of procedural competences: understanding the nature of chemistry, its norms and methods and the key theories, concepts and models of chemistry and how chemistry and chemistry-based technologies relate to each other; and appreciating the impact of chemistry and chemistry-based technologies on society. Gilbert has also identified a number of degrees of chemical literacy, including practical or functional chemical literacy, civic chemical literacy, and cultural chemical literacy.

In the digital age, there is increasing concern by countries to improve their 'e-literacy' – for example, the state of Kerala in India has just launched an e-Literacy Programme which aims to achieve 100% e-literacy within 33 months. Educational modes, which since antiquity relied on direct interactions in real time between teachers and learners, has in recent years seen an increasingly rapid evolution of alternatives, with open and distance learning (ODL) approaches moving from correspondence courses to the use of broadcast media (in particular TV broadcasts) and then to the age of computer-based learning with web-based supporting materials. The new technologies have enabled the establishment of massive open online courses (MOOCs), variously making claims to be "education for everyone" and "education at scale", with large programmes like Udacity, Corsera and edX being accessed by millions of students

A number of challenges were highlighted, including how to make good quality, relevant chemistry education available, accessible and affordable to all? How must chemistry education change, with regard to modes of teaching and learning; and with regard to its relevance not only to the latest scientific knowledge and theories, but also to the wider world of work in general and to the need to support and enable social responsibility by all people? Cutting across all of these challenges is the often neglected question of how to address a range of gender issues in teaching and learning.

In responding to the forces now re-shaping education, new dimensions to learning chemistry must be emphasized. Mahaffy has proposed that Johnstone's widely adopted 'triangular' metaphor of learning in chemistry which focuses on macroscopic, sub-microscopic (or molecular) and symbolic aspects of the subject, should be replaced by a 'tetrahedral' metaphor that emphasizes also the human element of learning. Mei-Hung Chiu has added a further corner to form a pyramid and suggests the term meso rather than molecular to represent the linkage between the macroscopic and microscopic worlds; and the addition of language as another factor influencing students' understanding of complex science concepts.

Another challenge in the changing world of chemistry education includes the problem of how to provide an education in experimentation, which many would argue is vital as a way of learning - seeing chemistry as an experimental science which uses observations to create and test theories and to help train the learner in deductive reasoning; and as a way of developing the practical skills of the future 'chemist' or 'chemical technologist'. In the case of distance learners, the Open University developed an approach home experimental kits and opportunities for laboratory work in residential summer schools. Another approach has been the development of kits for microscale science.

Chemistry education in the 21st century needs the engagement of five critical groups of stakeholders, with the learners of chemistry being supported by inputs from teachers, researchers, industry and policy makers – a pyramidal model of stakeholders in chemistry education.

One common thread running through all the modes of education, whether it is the textbook in the classroom or texts that can be mailed in the post or downloaded from the internet, is the need for materials to support teachers and learners, to provide them with reliable, up-to-date knowledge, explanations, examples and illustrations. The traditional support material to provide a knowledge source for teachers and learners has literally taken the form of a ledge – a library shelf holding text books. The modern equivalent for the digital age must take the form of a knowledge base – a set of digital files and resources that can be accessed through computers and mobile devices using the internet and mobile networks. The meeting would have the opportunity to discuss IOCD's plans to develop a chemistry knowledge base - ChemKnowBase.

The objectives of the meeting were to: (1) reflect on recent, current and prospective changes in chemistry education; (2) advise on the establishment of an *IOCD Working Group on Chemistry Education*; and (3) consider how to promote greater global engagement in the debate about the future of chemistry education, such as through a paper or conference.

Presentations

Leiv Sydnes presented a talk on CHEMRAWN's Strategy and the work of IUPAC, emphasising IUPAC's philosophy that 'we have to act globally if we want to move forward collectively'. He highlighted the challenge of sustaining momentum and achieving impact in the long term and stressed the need for IOCD to keep a strong focus in its programme, with ChemKnowBase having the potential to provide support of practical value to chemistry educators at various levels.

Mei-Hung Chiu (Professor of Science Education, Graduate Institute of Science Education, National Taiwan Normal University; Chair, IUPAC Committee on Chemistry Education – CCE) gave an overview of the work of the IUPAC and the CCE, including the major programme to promote chemistry during the 2011 International Year of Chemistry. Chiu then described the work of her own Institute in the field of 'augmented reality' (AR). This was supporting the teaching of chemistry in Taiwan high schools by providing new ways of visualizing complex chemical entities such as DNA and linking chemistry into the wider world through the use of mobile phone technology, with applications in field trips and experiments as well as in the classroom. The AR applications supplement traditional approaches and can be used to complement the use of textbooks. They are still undergoing development and extension, but there is already evidence that the subject is being made more interesting and attracting increased numbers of students to chemistry courses in the participating schools.

Stefano Cerri (Professor of Informatics; Deputy Vice-President for International Relations, University of Montpellier), spoke on the theme of 'Distance Learning & WebScience: Empowering human *connected* communities'. He outlined projects undertaken by his group in Montpellier, including successive 'AGORA' programmes (a 'shared desktop' approach) that had overcome spatial isolation and enabled scientists and educators to communicate and collaborate effectively over great distances. He stressed the important roles played by teachers as champions, helpers and guides; the progress of scientific processes from 'stamp-collecting' to 'physics' ; the contribution of collaborative innovation and serendipity ; and the challenges in constructing a 'learning society' in which knowledge creation and learning are central elements. In a world where knowledge was becoming increasingly available on open access to those with computers and connectivity, the role of the teacher, potentially supported by facilities such as ChemKnowBase, was to ensure the transformation for the learners of data to information to knowledge to competence. Distance may even have advantages in this regard, with the technologies that are now being co-opted to overcoming distance barriers opening new opportunities to establish learning groups, find the right people to act as collaborators and enhance the interaction between participants.

Gary Molander (Professor of Chemistry, University of Pennsylvania) gave an overview of the rapidly developing field of Massive Open Online Courses (MOOCs) in Chemistry. MITOpenCourseware, initiated in 2002, had provided a means for distance learning by publishing all course materials online and making them widely available to everyone. To date there had been 2150 Courses and 125 million visitors from across the world (although only small proportions from South America, the Middle East and Africa), including 43% self-learners, 42% students and 9% educators. Subsequently a wide range of initiatives followed, including iTunbesU, Khan Academy Lectures, Udacity, edX and Coursera, which had many millions of users. The range and level of chemistry courses offered by the MOOCs varies greatly. As yet, it remains unclear what is the business model, since the courses have cost many millions of dollars to develop and mount; but on average only about 4% of those viewing courses actually complete them. Moreover, the majority of students enrolled hold college degrees and take a course to advance their career – it is not clear that the courses are providing greater access to underprivileged.

John Bradley (RADMASTE, School of Education, University of the Witwatersrand) spoke about Microscience and the role of the RADMASTE Centre, a self-funding unit within Wits University that aims to improve the quality, relevance and accessibility of education in mathematics, science and technology and which had developed microscale science kits. These are low-cost, versatile and especially suitable for use where budgets, supplies and facilities are limited, as the kits use very small quantities of reagents and problems of waste disposal are minimised. The microscale science kits are helping to meet the challenge of widening access for all to experimental chemistry and other sciences, by increasing motivation, developing experimental skills and the learning of the scientific approach and assisting students to gain a better understanding of theoretical aspects of the subject. It was noted, however, that the effectiveness with which teachers can exploit such kits is limited by their knowledge of chemistry: hence meeting their needs, for example through the proposed ChemKnowBase project, is an urgent matter.

Alain Krief explained the concepts underlying the ChemKnowBase and ChemKnowCore programme. That is now being developed by IOCD. For more than a decade, IOCD has maintained on-going projects in chemistry education, including Books for International Development (organized by University of Millersville, USA; collecting and shipping container-loads of donated textbooks to libraries in low- and middle-income countries); a distance education programme in medicinal chemistry (developed and presented by University of Kansas); on-line organic chemistry tutorials in Spanish (developed and presented by the UNAM); and promotion of the Global Microscience Project (developed by RADMASTE and supported by UNESCO). IOCD is now planning an on-line resource named ChemKnowCore which would contain a suite of inter-related resources to support teaching and learning in chemistry. ChemKnowCore will include ChemKnowBase, as well as a chemistry dictionary, experiments, courses, research accounts, games and links to other useful sites.

ChemKnowBase will provide a detailed, in-depth and comprehensive coverage of the field of chemistry, available as a freely accessible on-line resource that teachers can draw on in developing their lecture notes for specific courses and that students can use to further explain and exemplify the curriculum elements they need to learn. IOCD has proposed a strategy to build the ChemKnowCore/ChemKnowBase model to organize and produce the content. The first steps involve a series of face-to-face meetings between outstanding chemists and IOCD to create tables of contents in specific topics on which they are specialists; and selection of editors able to initiate some of the modules such as chemistry experiments (Prof. Buchkard Köning, Regensburg University) and chemistry accounts (Prof. Oliver Reiser, Regensburg U). IOCD has begun developmental work on the construction of ChemKnowBase with the ChemKnowCore shell, in collaboration with the Indian IT company Atomicka. ChemKnowBase is initially being developed as a university-level on-line resource, but it is planned that there will also be versions at the school-level and for the public understanding of science.

Christa Jansen (Head of School Sponsorship, Merck, Darmstadt) provided an overview of her unit's work in the Darmstadt region to provide support to schools at primary and secondary levels in teaching chemistry and stimulating interest in students to learn chemistry. Initiatives included provision of chemicals, laboratory equipment, lab coats and safety glasses from Merck' extensive catalogue, assistance with projects and visits to Merck industrial R&D laboratories as well as to 'Junior Lab' – multi-university/Merck cooperative centres attended by up to 3,500 pupils per year, where students can conduct experiments themselves. Merck also offers a number of awards, prizes and lectures, assists teachers in developing experimental learning both in the classroom and in out-of-school settings and organizes an annual conference for about 150 teachers. There was evidence that enthusiasm for teaching and learning chemistry was being enhanced in the area served by the programme, with rises seen in the number of students electing to study chemistry. It was notable that the Merck programme was being achieved with remarkably limited financial and human resources, demonstrating that considerable impact could results from focused and well-managed efforts.

Discussions and recommendations

Between and following the presentations, there were detailed discussions about the merits and potentials of the different learning and teaching strategies outlined; about the importance of informal as well as formal learning; about global gaps and challenges in chemistry education; and about the areas where IOCD could most fruitfully focus its limited resources in order to make a useful contribution and have a sustainable impact. As well as the presenters referred to above, other contributors to the discussions included **Henning Hopf** (University Professor, Institute of Organic Chemistry, Technical University Braunschweig), **Goverdhan Mehta** (National Research Professor, Hyderabad University, India), **Chris Stevens (**Professor, Faculty of Bioscience Engineering, Gent University) and **Niceas Schamp** (former Secretary-General of the Royal Flemish Chemical Society and first chairman of the Scientific Committee of the EU's INTAS programme).

It was noted that there is an already extensive and growing body of courses on aspects of chemistry available on the internet and IOCD should not try to compete in that field. Rather, it should concentrate on tools and materials that would underpin teaching and learning and be less dependent on changing curricula, fashions and rapidly changing technologies. Unlike 'wiki' approaches, IOCD should also ensure that it had full editorial control, ensuring consistency in content, range and quality. The materials and tools should emphasize connectivity within the branches of chemistry and with the sciences generally. 'Learning through connectivity' was an important transition for chemistry education to make in the 21st century and was a field where IOCD could make a distinctive contribution. Chemistry should always be placed in the context of its applications – which cover a vast range from the chemistry of life to energy, renewable materials, the environment, food and nutrition and much else – and chemistry education must be framed by an understanding of who are the learners and what is the purpose of their learning.

Key recommendations emerging from the discussions:

1. Under its Strategy 2011-20, IOCD should continue to concentrate within its three strategic priorities (chemistry for better health; chemistry for a better environment; and capacity building in chemistry education) and continue to develop a highly focused approach, concentrating selectively on initiatives that would be distinctive to IOCD, firmly embed chemistry within the broader field of science education, make best use of available resources, attract outside support and partners and have sustainable impact.

2. IOCD should form a Working Group that would integrate some of the existing programmes (such as Books for Development; microscale science; distance learning chemistry courses and tutorials; ChemDic) where these were of demonstrable value; and that would incorporate ChemKnowCore/ ChemKnowBase as a central new element. Atomicka was proving to be an enthusiastic and creative collaborator in developing the website for ChemKnowBase. However, it was recognised that the development of ChemKnowBase would require substantial additional resources and that IOCD would need to attract the interest of sponsors as well as writers if it is to succeed. It would be necessary to implement the project in stages to make it manageable.

3. IOCD and IUPAC have shared interests in strengthening the learning of chemistry and a wider understanding of the subject among the general public and should pursue opportunities to collaborate and to jointly promote the field. These include:
    - IOCD will make an approach to IUPAC to seek modest funds for a ChemKnowBase initiation project that can assist in defining the key attributes of ChemKnowBase and can provide exemplary content materials that will be of demonstrable value to teachers (globally, including those in resource-poor settings in low- and middle-income countries) and will assist in attracting the necessary resources for full implementation.
    - An IOCD representative (Stephen Matlin) can be invited to lecture at the next annual conference on chemistry education to be held in Toronto (13-18 July 2014) and to participate in the associated meetings of the Committee on Chemistry Education.
    - IOCD will provide an article on the CHEMRAWN-IOCD meeting in Namur, for publication in Chemistry International.

4. The ChemKnowBase must integrate experimentation into the resource materials developed, so that teachers and learners can understand and gain experience in the practical art of conducting experiments and in the use of experimental observations to test and validate theories and explore new knowledge, all of which are fundamental to an appreciation of the scientific method. The ChemKnowBase can recommend and provide examples of experiments that can be conducted both with conventional laboratory equipment and facilities and with microscale kits that may have advantages in different teaching and learning settings. It would be important to engage with industry in developing the ChemKnowBase, since they were interested to project the meaning and value of chemistry to the world; and moreover IOCD may also be able to explore a role in facilitating the provision by chemical supply companies of small aliquots of chemicals that are suitable for use in the microscale experiments.

5. A further area that the Working Group should consider is to greatly extend the existing information base on the IOCD website to provide linkages to high quality open access external resource materials that support teaching and learning in chemistry. While many chemistry resource

materials exist on web sites, these are highly scattered and it is not always easy for the user to locate them or to evaluate their quality. Similarly, there could be a collection of information about industry-school initiatives such as the Merck school sponsorship programme. Although it would be labour intensive to collect, establish and regularly update all the linkages, the information base would provide an invaluable resource for the chemistry education community globally and would attract widespread attention to and awareness of IOCD.

6. Work should continue on developing the draft of a paper entitled ‘Education and chemistry: meeting the challenge of access for all’, to which several of the meeting participants had already made preliminary contributions. The paper will aim to have a clear focus and impact on the directions that chemistry education is taking in the 21st century and to target not only educators but also researchers, industry and policy makers as the four critical groups that collectively contribute to the ability of students to learn chemistry.

7. IOCD needs to find additional sources of funds in order to make its work sustainable in the long term. It was noted that, under the new EU Horizon 2020 programme, substantial resources were being made available for ‘international cooperation’ involving collaborations with countries outside the EU. IOCD should explore the potential for gaining funding from this source, as well as through collaborations with a variety of public, private and not-for-profit organizations. The University of Namur, which hosted IOCD’s Secretariat, has taken a strong interest in the work on chemistry education and it was anticipated that funding would be provided by the University for an IOCD postdoctoral fellow to assist in developing this area. AS a member of ICSU, IUPAC might also be able assist IOCD with accessing funds from this source (LS undertook to explore this avenue).

2nd NARC-IOCD Symposium

IOCD and the Namur Research College (NARC) under the direction of Prof. Davide Bonifazi of the University of Namur collaborated in organizing their second joint Symposium in Namur on 15 January 2014, in which several of the participants in the CHEMRAWN-IOCD meeting on Chemistry Education participated. Lectures were given by Prof Gary Molander (University of Pensylvannia, USA) on “A Novel Mechanistic Paradigm for Cross-Coupling”; Prof. Henning Hoft, (Technische Universität Braunschweig, Germany) on “Linear Polyolefins - an old topic of organic chemistry in new light”; Prof. Mei-Hung Chiu (National Taiwan Normal University) on "Augmented Reality for Science Learning"; and Prof. Goverdhan Mehta (Hyderabad University, India) on “Enhancing Nature and chemical space – synergy between natural products and organic synthesis for human well-being”.