Secondary School Chemistry

An Aquarium as a Means for the Interdisciplinary Teaching of Chemistry

F. Calascibetta,* L. Campanella, and G. Favero
Department of Chemistry, University of Rome "La Sapienza", P. le Aldo Moro, 5 - 00185 Roma, Italy;
*Franco.calascibetta@uniroma1.it

L. Nicoletti
Department of Animal and Human Biology, University of Rome "La Sapienza", Roma, Italy

This article presents a program developed over the past few years by a group of researchers working in collaboration from the Faculty of Mathematical, Physical and Natural Sciences of "La Sapienza" University of Rome and from MUSIS (Multipolar Museum of Science and Scientific Information in Rome).[1] The program, known as "Chemistry in an Aquarium", is aimed at showing how the study and analysis of physical and chemical parameters related to life in and the development of an aquarium can be used to teach chemistry at different school levels. The final goal is to introduce the fundamental concepts and principles of chemistry in their interaction in the life and equilibrium of an ecosystem. This topic was developed during several refresher courses for science teachers held between 1994 and 1997. At the conclusion of the article we show how, in the course of our research, it was also possible to successfully test the use of this original approach to construct new ways of presenting chemistry in a museum environment and in informal education.

Background

One of the problems most frequently encountered in the teaching of chemistry is without doubt the learners' poor knowledge of chemistry's fundamental concepts and cognitive procedures. This in turn is often one of the causes of the widespread attitude of suspicion, if not actual hostility, displayed toward chemistry by students and the general public alike. It is also responsible for the free circulation, also in the media, of a number of completely erroneous but extremely frequent commonplaces, such as the alleged contradiction between what is "natural" and what is "chemical" (*1–5*).

In our opinion, part of the responsibility for this negative image must be attributed to the way chemistry is taught. The history of this branch of learning shows us that, starting from a study of the transformation of matter, chemists succeeded in constructing an extremely powerful microscopic model. Facts and phenomena from the macroscopic world can thus be accounted for in terms of the geometry of molecules, bond energies, and so on, and chemical processes translated into formulas and equations (*6*). However, a number of textbooks at all school levels have possibly focused too strongly on this aspect, neglecting to provide sufficient stimulus to equate the formalism with real-world processes.

The reduction of chemistry to a mere sequence of chemical formulas, molecular models, etc. makes it appear to be completely detached from the subjects studied by other branches of science such as biology or geology. This is all the more alarming in our country if we consider that, according to the Italian legislation regulating high school teaching, it is essentially only the graduates in the above disciplines who will end up teaching chemistry and consequently perpetuate a barren, incomplete, and negative image of this subject.

In view of the foregoing, we deemed it important to come up with an approach to chemistry in which the emphasis was laid on its close relationship with what goes on in the surrounding environment and in living organisms. This shows how some knowledge of chemistry is needed to understand the many complex systems, phenomena, and processes of the real world.

Our "Chemistry in an Aquarium" project uses a simplified ecosystem model (an aquarium) as the basis for introducing a number of fundamental chemical concepts and principles, in an approach involving the illustration of the unit of science.

Of course, the subdivision into disciplines is still necessary in teaching, to emphasize the peculiarities of the various approaches to the study of nature and to make them easier to learn. However, the problems of the real world are almost always multidisciplinary. The use of an aquarium in teaching entails simultaneous application of the concepts of physics, chemistry, biology etc., thereby showing up the close interrelations among the topics of each discipline and overcoming the often artificial barriers raised between them in teaching, with the paradoxical result of causing unnecessary overlapping and redundancy in the presentation of principles and topics common to the various subjects (*7, 8*).

Structure and Organization

The Aquarium

The aquarium around which the courses were organized was a Mediterranean marine aquarium with a capacity of about 300 liters. The Mediterranean marine environment was chosen because Italian students would be more familiar with this type of aquarium and also because it represents a more colorful and varied world than an equivalent freshwater environment. However, much of the content presented in the courses can certainly be applied, after appropriate modification, in any kind of aquarium. In all cases, in choosing the type and above all the number of organisms present, consideration must be given to the need to reconstruct as balanced as possible a model of a real ecosystem. Any overloading of the system, with the consequent continual fluctuations in the value of the physicochemical parameters, would jeopardize the health of the aquarium (*9, 10*).

Structure of the Courses

The courses organized in the last few years were attended by several hundred teachers from different grades and types of schools in Rome and its surrounding provinces. Their educational background, too, varied widely: there were graduates in Chemistry, but also in Natural and Biological Sciences and in Physics. Some of the participants were elementary school teachers and had no specific scientific training at the university level. Although this wide range of participant backgrounds made presentation of the content more difficult, it had the advantage of stimulating thought concerning the classroom transfer of the experience and allowed an exchange of skills and approaches not only between course members and teachers but also among the course participants themselves. This also ensured that the multidisciplinary nature of our research was never lost sight of.

Contents

The following topics were developed for presentation.

1. *The Mediterranean marine aquarium:* components, functioning, setup.
2. *Temperature:* how it is measured and its relationship with the marine organisms in nature and in the aquarium.
3. *Light:* relationships with the marine organisms in nature and in the aquarium.
4. *Salinity:* composition of the salts dissolved in sea water in nature and in the aquarium; determination of salinity by means of density measurements; saline composition of sea water and qualitative chemical analysis; chemical tests for chlorides and carbonates; flame tests for alkaline and alkaline-earth metals; flame tests and emission spectra; from qualitative analysis to volumetric quantitative analysis; volumetric titration; determination of salinity by means of chloride titration (Mohr's method).
5. *Osmotic pressure:* general and physiological considerations; modality of regulating osmotic concentration in aquatic organisms.
6. *Quantity of dissolved gases:* oxygen and its determination by chemical assay (Winkler's method) or amperometric titration; oxygen and water motion in nature and in the aquarium; oxygen and carbon dioxide; photosynthesis and respiration; carbon dioxide, limestone rocks, and pH; mechanism underlying buffer systems.
7. *Nitrogen cycle in the aquarium:* ammonia and the ammonium ion, nitrites, nitrates; colorimetric and spectrophotometric methods for determining the species involved in the cycle; historical origin of optical methods of analysis.
8. *Marine organisms present in the aquarium:* outline of systematic classification; use of dichotomous keys in determination.
9. Techniques for the collection and conservation of marine organisms, rearing in the aquarium and observation methods.
10. Identification of the more common marine organisms, which are easily found in Italian seas, with the aid of microscopes and textbooks.
11. Natural processes as indicators of the state of the environment.

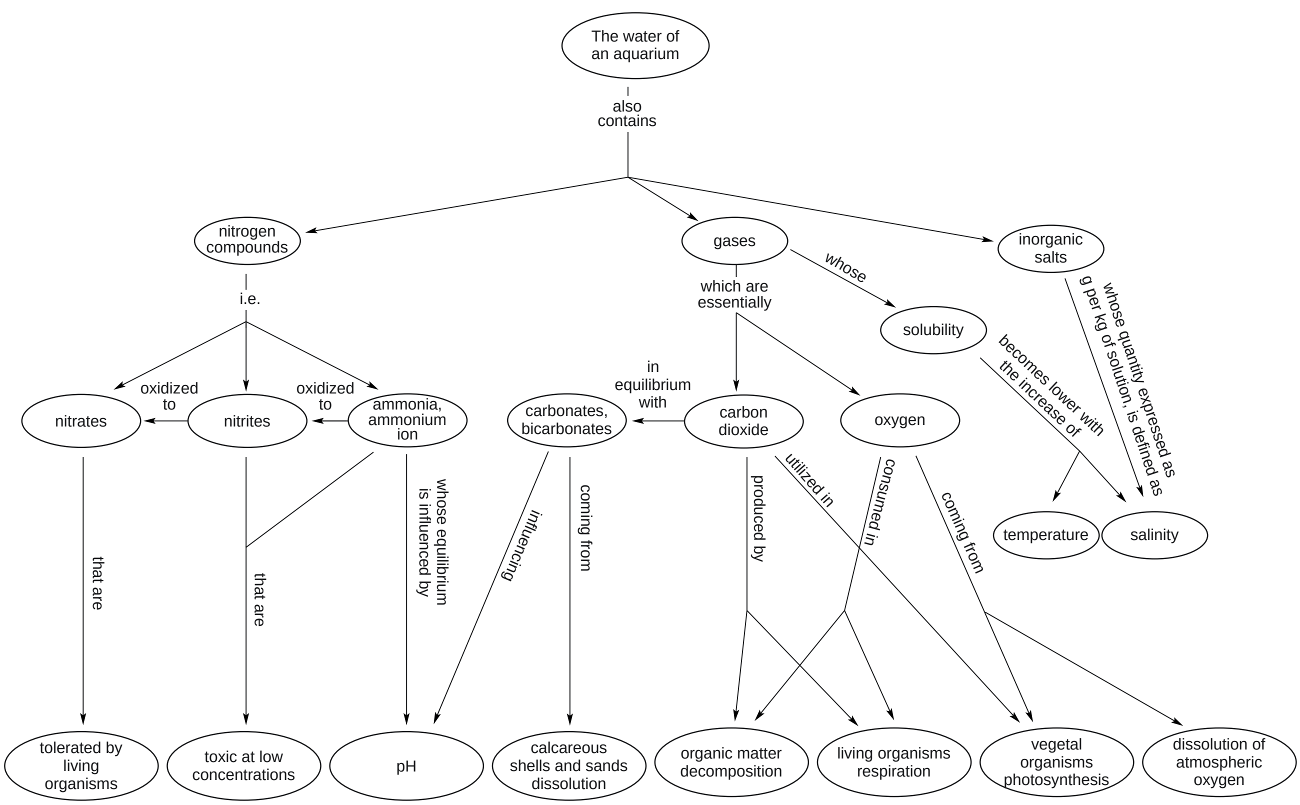

Figure 1. Concept map showing the relationship among the topics.

We fully realize that a sequential presentation of contents like that given above fails to illustrate the close links that can be set up among the various topics (e.g., temperature, salinity, and dissolved oxygen; solubility of oxygen and photosynthesis; photosynthesis, dissolved carbon dioxide, pH, and buffer effect; etc.). A partial account of these relationships may be obtained from a concept map (Fig. 1). This map is by no means complete and its value is no greater than that of other maps that could be based on the same concepts. It is included merely for the sake of example.

Thus, the course went beyond the mere theoretical examination of the chemical concepts related to the study of an aquarium, but, as far as possible, incorporated relevant experimental activities. These, carried out in groups of two or three, gave nonchemists experience with procedures typical of chemical analysis and the more common and widely used instruments. Wherever necessary, course notes containing further explanations and information on the topics treated were prepared and distributed.

Project Outcomes and Developments

Above all, our idea was enthusiastically received by those attending the refresher and specialist courses. Teaching units based on the aquarium and addressing different school levels were developed as part of the courses themselves. These units were later tried out by many of the teachers in their own schools.

One important result of our project was its inclusion in a European initiative aimed at reviving and enhancing the image of chemistry. Such an improvement is certainly crucial for our discipline worldwide and has also recently been recognized more fully in the chemical industry (*11–13*). A thorough reappraisal has therefore been made of the fundamental role that museums and science centers can play, particularly for the benefit of young people. Cooperation with educational institutions is necessary to guarantee the circulation of correct information concerning science and technology and their effects.

Over the past few years, this has led to the development of a combined initiative by ECSITE (European Collaborative for Science, Industry & Technology Exhibitions) and CEFIC (European Chemical Industry Council). This project, named "CHEMistry for Life",[2] selects, develops, and shares new museological proposals in the field of chemistry (*14*).

Transferring our initiative into this new context obviously entails making a few changes to cater to different types of museum visitor. For the occasional adult user, the aquarium and its associations with chemistry could be regarded as something attractive. In such a context, we have prepared an interactive CD-ROM that will illustrate the topics treated simply, with the help of images, texts, graphs, etc. The CD could also be used as a tool to support teachers utilizing an aquarium as a starting point in a chemistry curriculum.[3]

For users prepared to devote more time to aquarium activities (for example, classes accompanied by their science teachers), a miniature laboratory could be set up beside the aquarium, to allow hands-on activities of the type developed in the courses.

Conclusions

The results obtained during these years of experimentation and application of our project have confirmed and emphasized the project's potential for chemistry teaching in technical schools with a chemical orientation. In this type of school, the analysis of physicochemical parameters required in monitoring an aquarium is a more stimulating way of introducing the principles and procedures related to classical and instrumental analytical techniques.

This type of use is already treated in the literature (*15–17*). However, an aquarium offers another particularly interesting opportunity to all kinds of schools at both beginner and higher levels: it encourages integrated multidisciplinary science teaching. The use of an aquarium for teaching has proved extremely helpful in arousing the learners' interest, in giving them a unified and more concrete image of science, and in promoting a more correct and insightful involvement in environmental questions.

In the teaching of chemistry, in particular, the use of an aquarium can be a way to offset the incorrect yet widespread image of an abstract, specialized discipline, remote from nature or even hostile to it, and to vigorously reaffirm the essential role of chemistry in the study, analysis, and safeguarding of the world around us.

Notes

1. The underlying intention of the MUSIS project is to set up a science museum in Rome, where none exist. Numerous MUSIS initiatives are specifically addressed to the world of the school and training, thus giving rise in some cases to actual "teaching laboratory" experiences, aimed at assisting science teachers in their work.

2. CHEMistry for Life was officially launched on 27 November 1997 in Brussels, on the occasion of the ECSITE Annual Conference. More information about CHEMistry for Life can be found at the Web site *http://www.deutsches-museum.de/akt/koop/e_chemli.htm*.

3. Information on how to obtain the CD-ROM *Chemistry in an Aquarium* may be requested from MUSIS President, Luigi Campanella, by writing to the address indicated above. The main contents of the CD-ROM can be found at the Web site *http://window.to/chemistry.*

Literature Cited

1. Quadbeck-Seeger, H. J. *Angew. Chem., Int. Ed. Engl.* **1990**, *29,* 1177–1188.
2. Ames, B. N.; Gold, L. S. *Angew. Chem., Int. Ed. Engl.* **1990**, *29,* 1197–1208.
3. Rainer-Canham, G. *ChemTech* **1992**, June, 329–332.
4. Lee, M. *Chem. Br.* **1995**, *31,* 181.
5. Hanson, J. R. *Educ. Chem.* **1998**, *35* (1), 28.
6. Ben-Zvi, N.; Gai, R. *J. Chem. Educ.* **1994**, *71,* 730–732 (and references contained therein).
7. Schultz, E. *J. Chem. Educ* **1996**, *73,* 447–449.
8. Randall, J. *J. Chem. Educ.* **1997**, *74,* 1409–1411.
9. Adey, W. H.; Loveland, K. *Building Living Ecosystems*; Academic: San Diego, CA, 1991.
10. Stumm, W.; Morgan, J. T. *Aquatic Chemistry*; Wiley: New York, 1981.
11. Grossmann, I. E.; Ottino, J. M. *ChemTech* **1998**, Aug, 7–11.
12. Letcher, S. V.; Euler, W. B. *ChemTech* **1998**, Dec, 10–13.
13. Roberts, K. *Chem. Br.* **1998**, *34* (6), 34–37.
14. Johnson C. *Chem. Ind.* **1998**, 486–489.
15. Hughes, K. D. *Anal. Chem.* **1993**, *65,* A883–A889.
16. Harris, T. M. *J. Chem. Educ.* **1993**, *70,* 340–341.
17. Gilles de Pelichy, L. D.; Adams, C.; Smith, E. T. *J. Chem. Educ.* **1997**, *74*, 1192–1194.