THE CHEMIST'S TRIANGLE AND A GENERAL SYSTEMIC APPROACH TO TEACHING, LEARNING AND RESEARCH IN CHEMISTRY EDUCATION

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ABSTRACT

The three levels of science thought (macro, micro, symbolic), identified by Johnstone and represented by a triangle, may be viewed as a core closed-cluster concept map of the type advocated in the systemic approach to teaching and learning of chemistry. Some of the implications of this view for teaching, learning and research are explored. *[AJCE 4(2), Special Issue, May 2014]*

CHEMICAL EDUCATION FOR HUMAN DEVELOPMENT IN AFRICA

There are as many approaches to teaching and learning chemistry as there are chemistry teachers. All school teachers nevertheless are required to follow a defined curriculum, which may be nationally defined. This is certainly the case in Africa, where the national curricula show variation from country to country, but have much in common. Especially at the secondary level of schooling, these curricula emphasize preparation for tertiary-level education, even though it may be a small minority of learners who will follow this path in future.

This divergence between minority expectations and majority needs is quite common around the World and it is not just an African issue. Still, with a conference theme "Chemical Education for Human Development in Africa", we may pause to reflect on this divergence and question whether we support or do not support the aim implicit in this theme.

A recent paper by Reid [1] illuminates the issue and claims school chemistry as part of and integral with General Education. Reid proposes the following aims of school chemistry curricula:

1. understanding something of the way the world works;
2. appreciating the huge contribution of chemistry in human welfare;
3. appreciating how chemistry gains its insights.

The proposals have no overt national affiliation and indeed they are open to Africa as to any continent. Furthermore on the surface they seem more likely to serve majority needs than most national curricula in Africa currently do. Curricula that just assume that learners see purpose in learning how to do stoichiometric calculations or giving the electron configuration of a ground state copper atom usually do not have such aims. Instead, the implicit aim is to prepare for the matriculation examination at the end of secondary school so that, if successful, one may access tertiary level study [2].

SYSTEMIC APPROACHES TO CHEMICAL EDUCATION

Fahmy and Lagowski [3] have argued for and researched systemic approaches to teaching and learning of chemistry. An emphasis of these approaches is the inter-relatedness of things, especially the cross-links between vertical developments of concepts as are most often presented in concept maps [4]. Indeed, Fahmy and Lagowski have emphasized the importance of "closed-cluster concept maps" in their recent articles. These too are not associated with any particular school curriculum, but seem well suited to chemical education for human development in Africa.

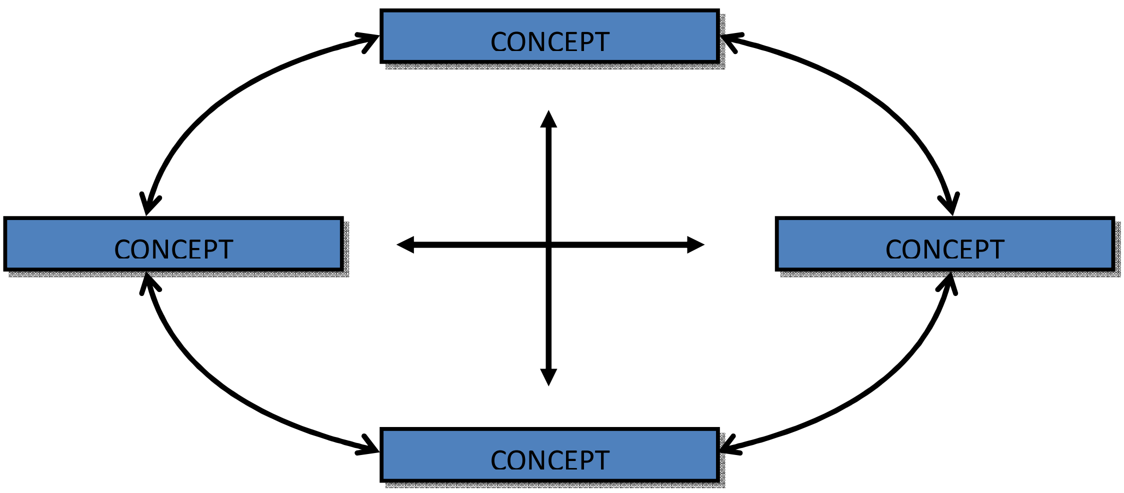


Fig 1 SATLC: Closed-cluster concept maps

THE CHEMIST'S TRIANGLE (5)

Johnstone [6] drew attention many years ago (1999) to the existence of what he called the three forms (or levels) of chemistry: macroscopic, sub-microscopic and symbolic (representational). These three forms or levels are not independent, but in fact closely related. This can be represented by a triangle with the three forms at the corners of the triangle.

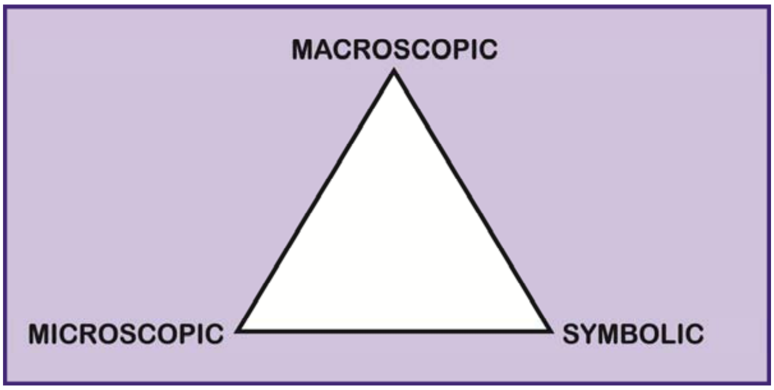


Fig 2 The Chemist's Triangle

This may be recognized as one of the centrally-important closed-cluster concept maps of chemistry, which can assist teachers, learners and researchers. Being devoid of other indicators it can serve chemistry education at all levels and in all curricular contexts.

But alone it is but an aide-memoire that can be understood after experiencing its use. There is no better way of doing this than by exploring the points of the triangle and their inter-relationships, with CHEMISTRY itself as the focus.

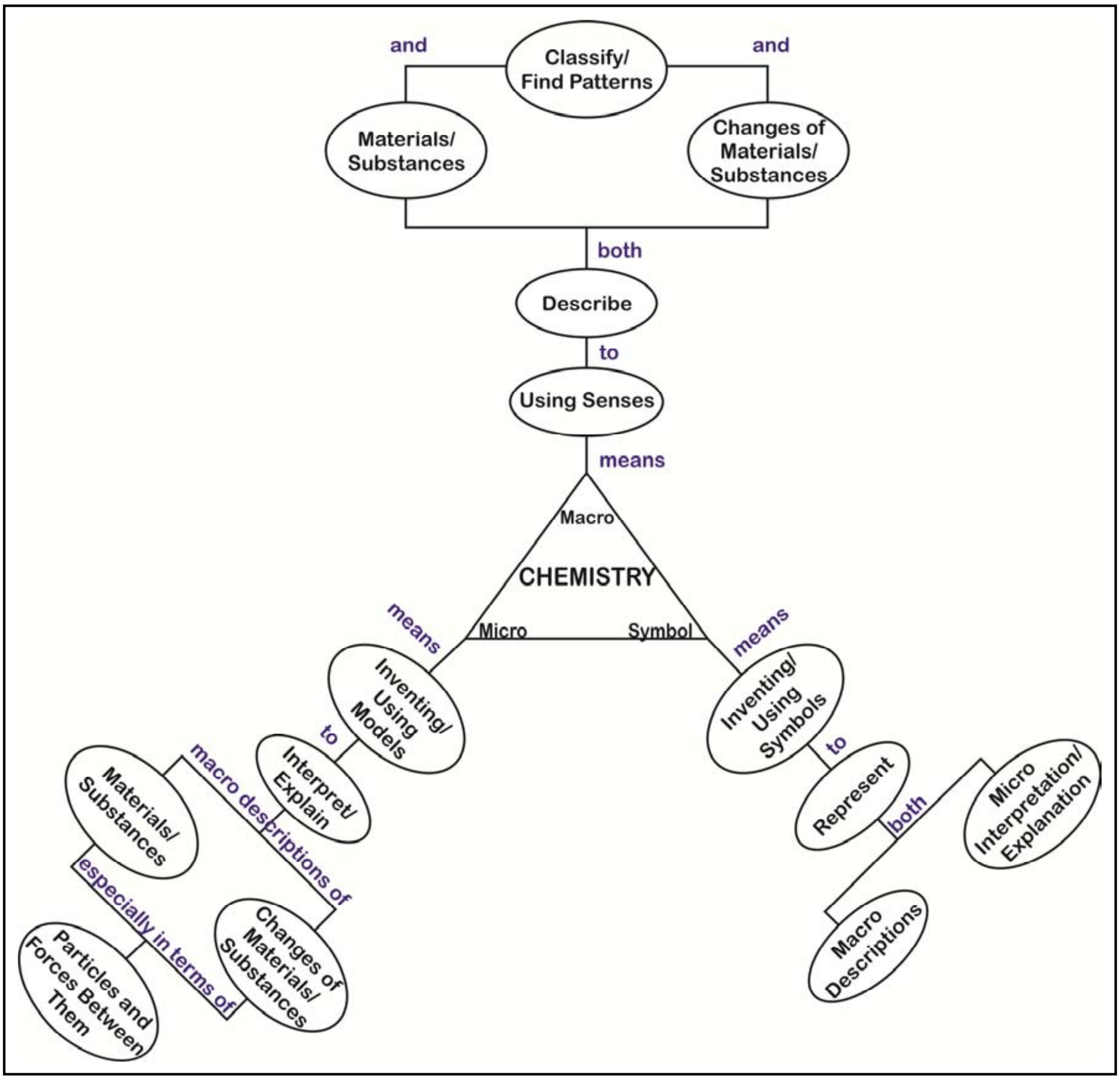


Fig 3 The Chemist's Triangle – Chemistry

Contemplating this figure, an experienced chemist would be able to exemplify these generalities for hundreds, or even thousands, of different cases. And thus a teacher, in words suited to the level of education, can explain how it all starts with macroscopic observations and descriptions, leading scientists to identify patterns, etc. Symbols may be invented in support of these. And, as scientists must, they look for explanations of the observations and the patterns of these. In the last few centuries these explanations have been consistently in terms of microscopic (or sub-microscopic) particles and their interaction. This also often leads to additional symbols.

Important periods in the history of chemistry are well-represented within this framework, as is exemplified in the Fig 4 following, simply by adding the names of three critically important chemists from the period 1780-1820:

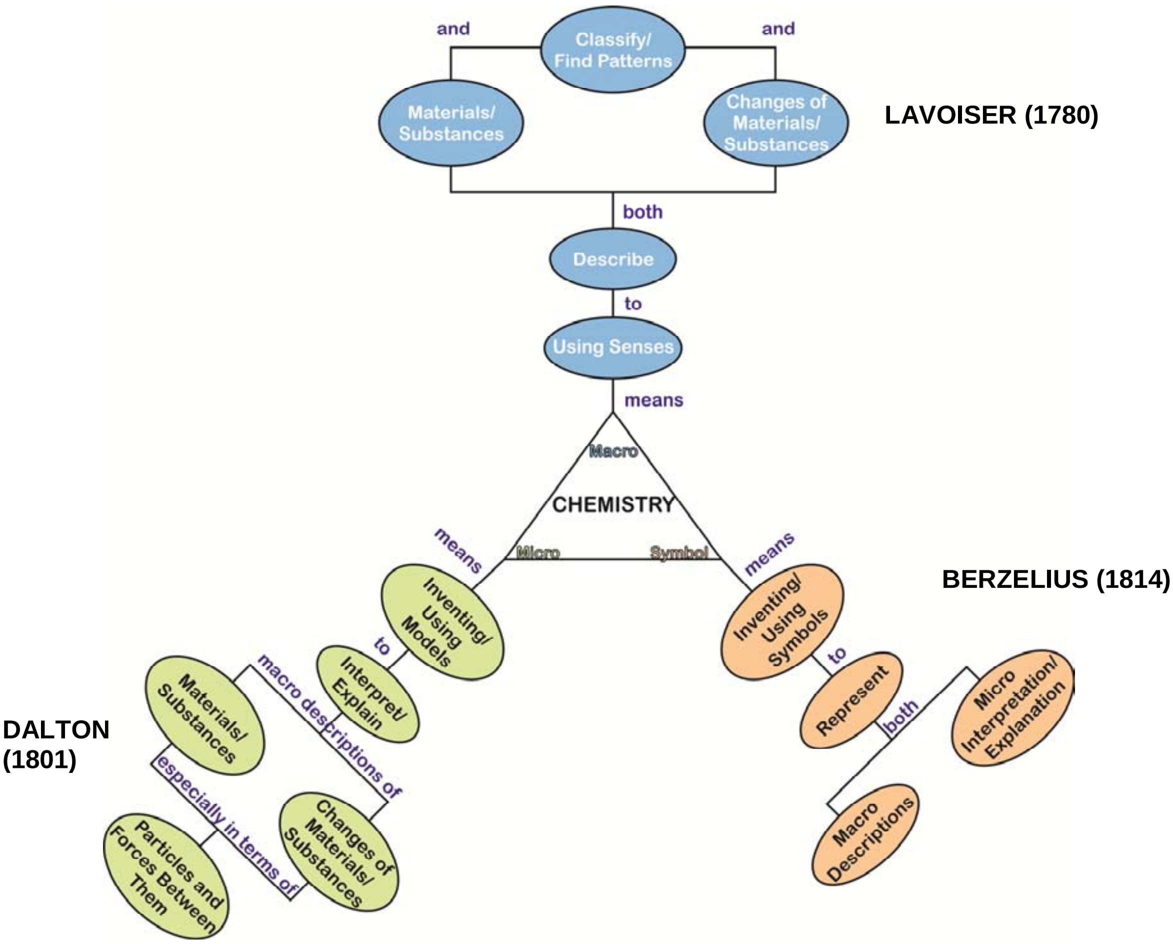


Fig 4 Chemistry Development 1780-1820

We may remember that it was Lavoisier who made the observations that led Dalton to re-launch the atomic theory, and he developed symbols for his atoms. Berzelius however introduced the kind of symbols and formulae for pure substances which are closely related to those generally adopted thereafter.

Discussion around this Figure will illustrate very well the typical character of chemical progress, and how the different corners of the triangle interact and evolve with time. It is the same for teaching and learning: the eternal dynamic interplay as teaching and learning happen and conceptual development occurs, model the historic development of the discipline itself, which continues in present-day research.

THE CHEMIST'S TRIANGLE IN THE CURRICULUM

We can use the triangle to get our thoughts in order on any chemistry topic or theme. For example, Figure 5 shows how the triangle can be used to generate a rich picture of concepts associated with chlorine:

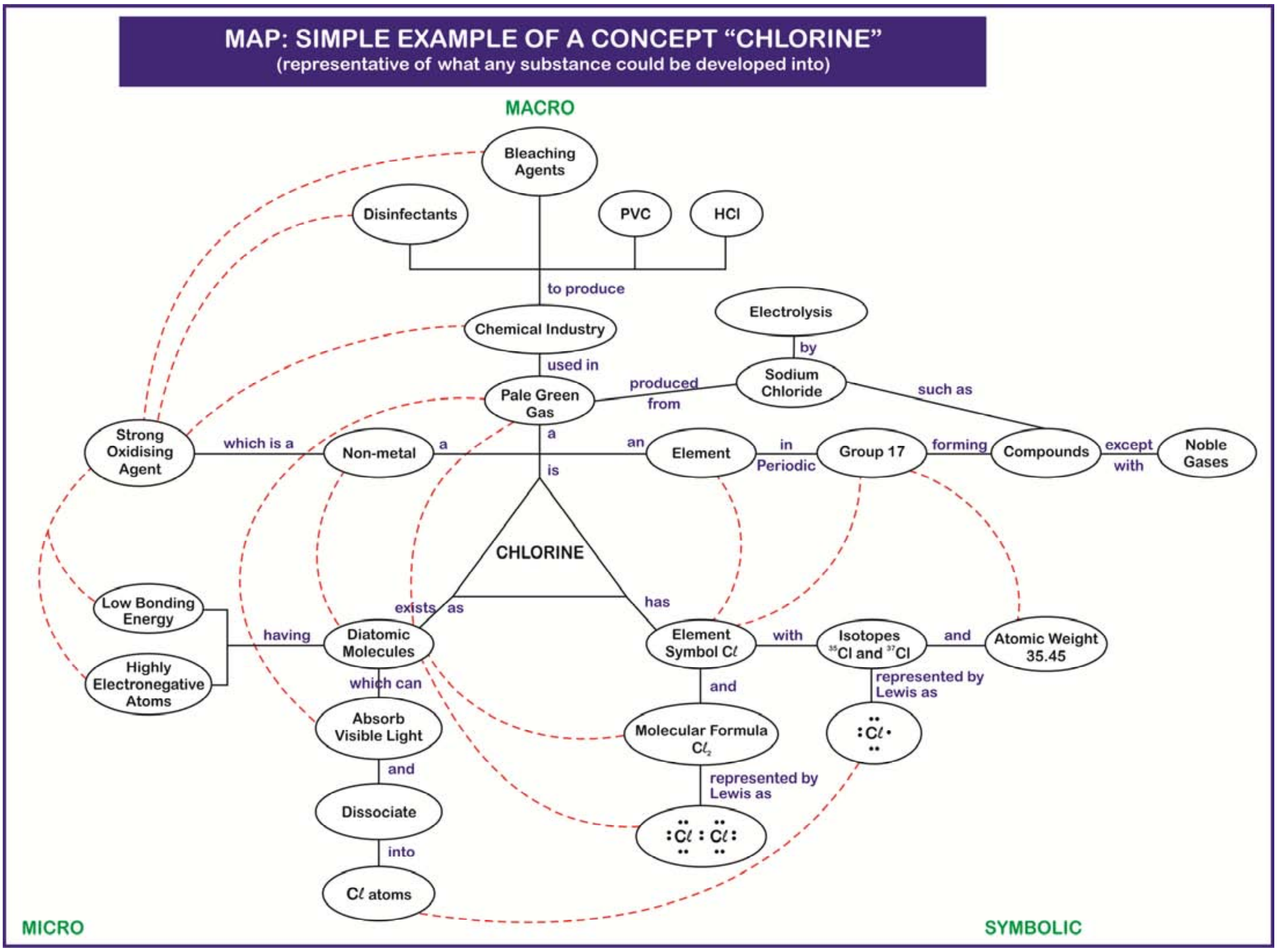


Fig 5 Chlorine

This example allows us to show too how macro/micro and symbolic concepts can be cross-linked to highlight particular relationships. Teachers might wish to do this for specific reasons within their curriculum, or might call upon learners to find cross-links as a summarizing/revision exercise.

Another example is of a typical chemistry topic, rates of reaction:

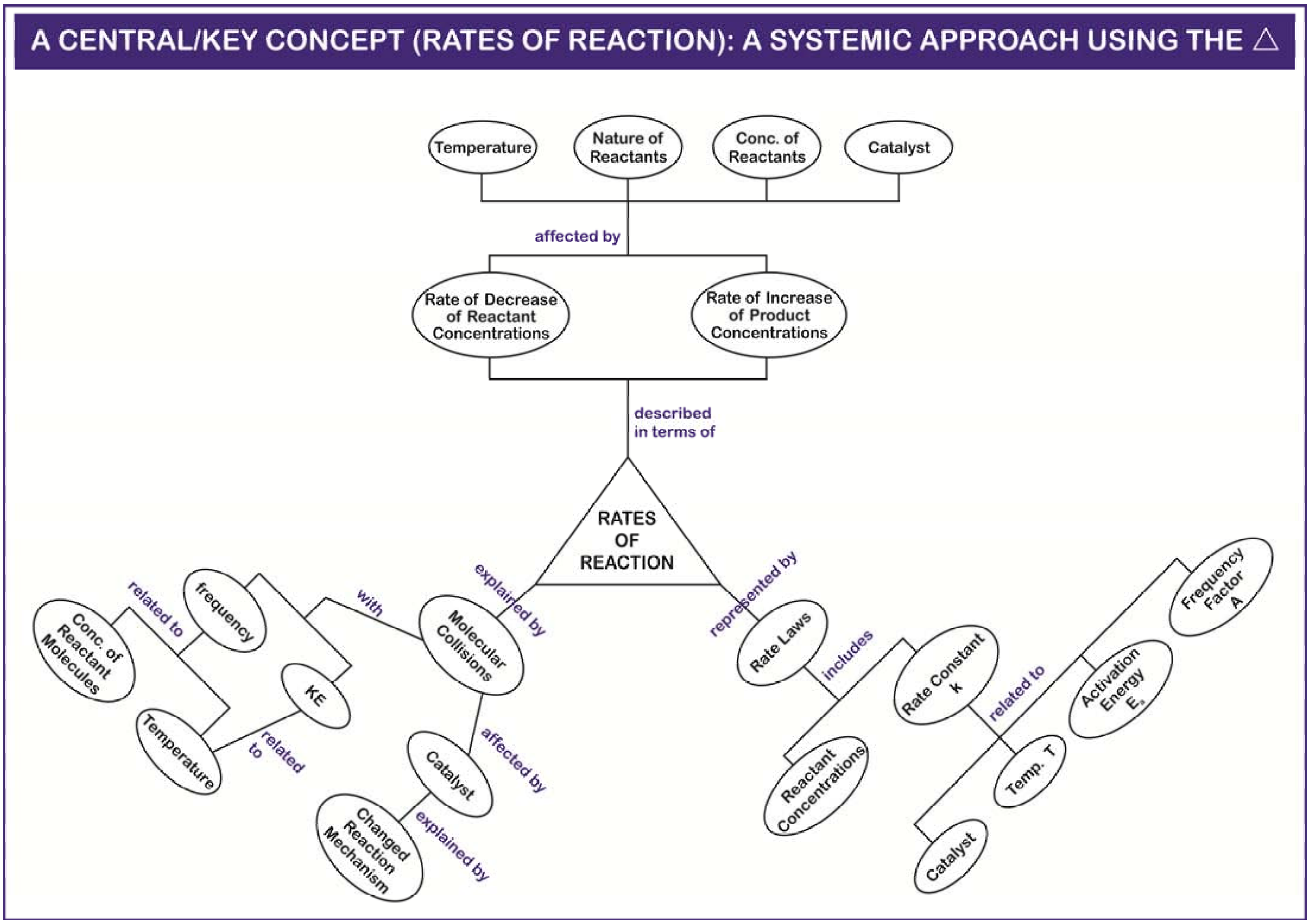


Fig 6 Rates of Reaction

POTENTIAL BENEFITS OF USING THE CHEMIST'S TRIANGLE IN TEACHING AND LEARNING

These have yet to be fully explored, but here we mention two to stimulate further thought.

1. Reducing working memory overload

Johnstone and his group have demonstrated the crippling effect of working memory overload on learning achievement [7]. These researchers showed how restructuring the same course or lesson content with this objective in mind led to consistently better achievement by learners. They note that novice learners have great difficulty in working at all three levels at the same time, almost certainly because of information overload. Deliberate use of the chemist's triangle has clear potential in this regard (chunking of information for a start!), as do closed-cluster concept maps in general. It can serve as an advance organizer and/or as a meaningful summarizing framework.

2. Language and symbols that confuse

Listening to typical chemistry lessons and reading typical textbooks must often be puzzling for learners even when their teachers think the language and symbols are crystal clear. Apart from specific technical word problems [8], there is the confusion of descriptive language for macroscopic and sub-microscopic thought [9]. The triangle is a stimulus to clarify our language in the classroom as well as in the curriculum documents.

An example would be the topic of acids, where in one and the same chapter or lesson, acids may be described as substances that neutralize bases and change the color of indicators and as proton donors. Clearly the first two statements refer to macroscopic observations, whilst the third is about microscopic interpretation. It is the molecules of acids which we should say are proton donors, and based upon this model we interpret the observations about neutralizing bases and changing the color of indicators. Symbolically we might use formulae such as HA(aq) for our macroscopic references, whilst the microscopic references might use H^+ or H_3O^+ and A^-. (Parenthetically we may note that the term proton in this connection is unsuitable and the term hydron should be used instead!)

Another example of this macro/micro confusion is provided by this multiple choice question, where there is only one correct statement completion:

Nitrogen

A. is a colorless, odorless gas

B. is diatomic

C. is trivalent

D. has a triple bond.

Presenting this question invariably causes alarm amongst experienced chemistry teachers because they see all the options as correct. However, careful consideration shows that B and D are attributes of the nitrogen molecule, whilst C is an attribute of the nitrogen atom. These are microscopic attributes. The stem of the question refers only to nitrogen and therefore only A correctly completes the statement. To the teacher it is obvious when the micro is meant even though the macro is stated, but to the novice learner this distinction is not clear. Yet it is a crucial one, as the chemist's triangle forcefully reminds us.

Symbols and formulae also deserve much more careful attention. For example does it matter or make a difference when we write HA, HA(g) and HA(aq)? Are all these representing acids? And what about NaCl, NaCl(s) and $(NaCl)_n$? What do these refer to and how should we use them for clarity?

HOW DO TEACHERS IN AN IN-SERVICE COURSE RESPOND TO THE CHEMIST'S TRIANGLE?

The RADMASTE Centre undertakes a lot of in-service teacher training which caters for teachers who do not have adequate knowledge and skills. Some may be relatively successful teachers, as measured by the pass rates achieved by their classes. However, these pass rates are often achieved by rote learning, and the teachers may be quite confused about many basic concepts. Therefore we discuss topics in the school curriculum that they are required to teach, deliberately avoiding the typical textbook approaches which they are familiar with and have learned.

One aspect of our approach embodies use of the chemist's triangle and a frequent emphasis on the three different levels it reflects. The triangle is introduced early and explained with an example and then is also used at the end to summarize. Teachers have some awareness of hierarchical concept maps, but have usually never really thought about the three levels.

Teachers are generally intrigued by this novel vision of the subject and at the end of the course can produce quite acceptable chemists' triangles with little collections of concepts attached to the correct points. Two example diagrams are attached resulting from an assignment they completed at the end of the course. One of these shows the individual concerned chose sides of the triangle rather than corners, but never mind!

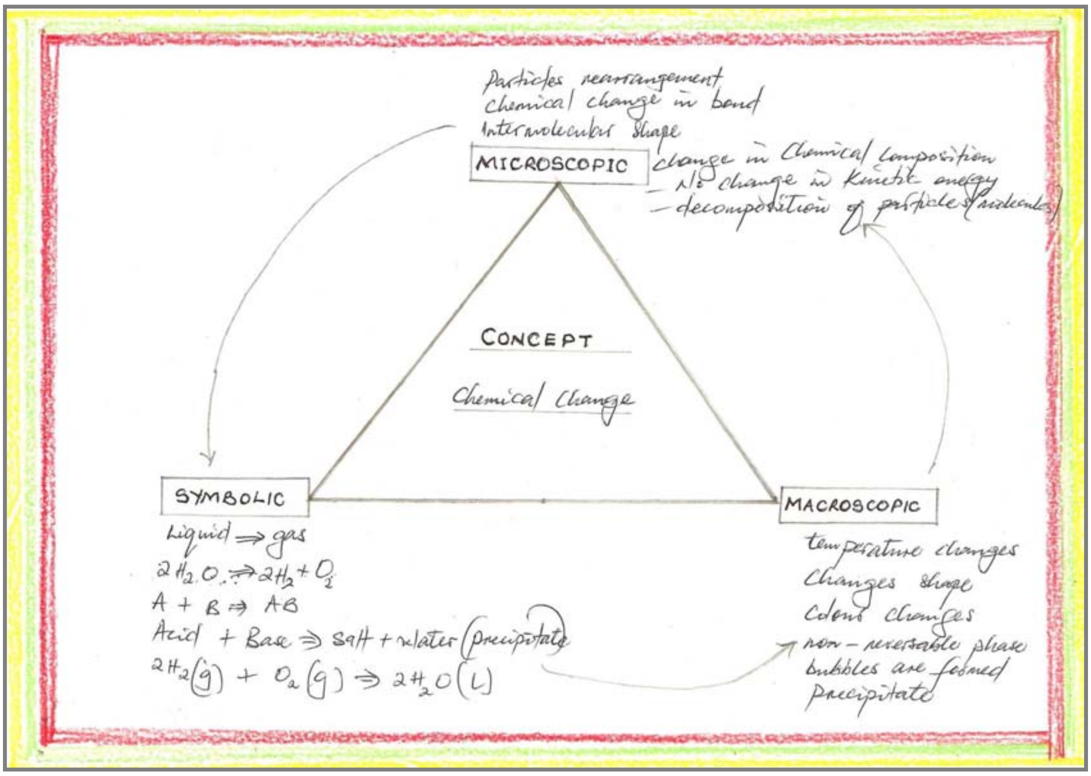


Figure 7 Example of in-service teacher's triangle –chemical change

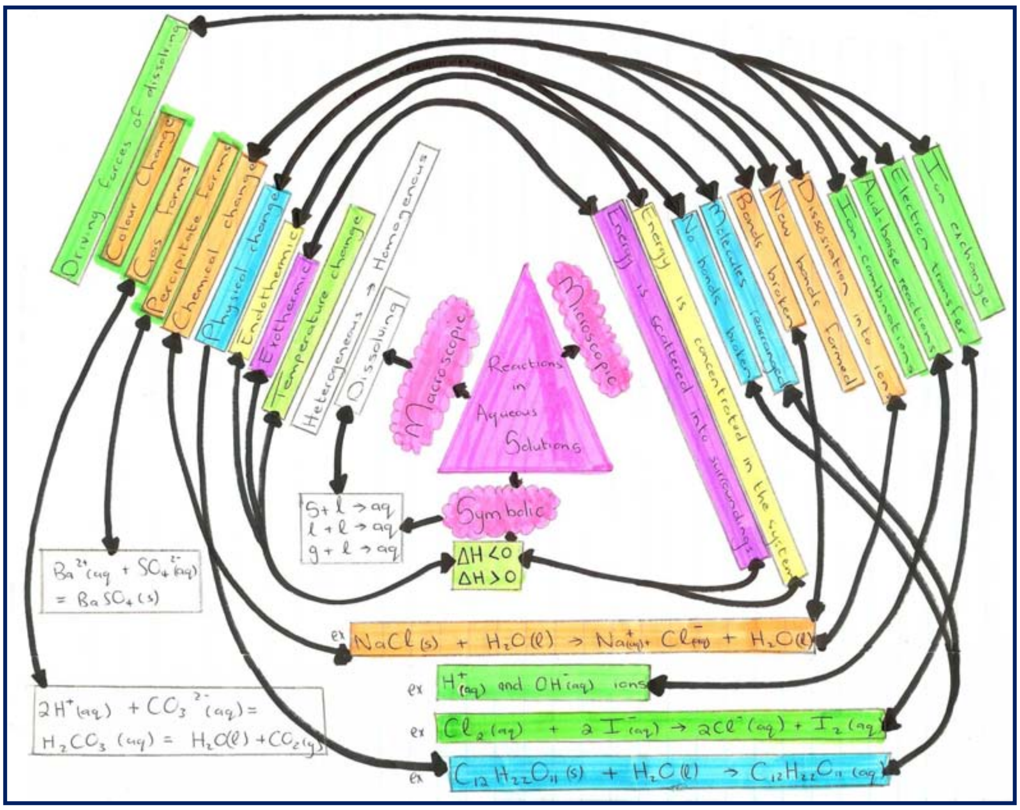


Figure 8 Example of in-service teacher's triangle – reactions in aqueous solution

BRINGING THE CHEMIST'S TRIANGLE TO LIFE

Reference has been made to teachers' surprise at the three levels of thought represented by the chemist's triangle. This has prompted us to provide experiences for them (and perhaps for their learners) that can enrich their comprehension of its origins. We can exemplify such experiences with the case of the electrolysis of water. As the following Figures indicate we start (of course) with observations, by doing the electrolysis of water on microscale. On completing this, learners write balanced chemical equations as part of their symbolic description on the macroscopic level. Then comes the interpretation of their observations in sub-microscopic terms, and this can be aided by the use of models – both 2-D (drawn with a molecular stencil) and 3-D (models made with beads and prestik (adhesive putty)). A tremendous amount of thought is involved in getting all these parts of the complete (3-level) picture, and a real eye-opener to those who have never before seen it all together. Despite all the mental effort, the hands-on activities (microscale electrolysis, drawing and model building) are quick, so there is time for the effort. Truly a hands-on, minds-on experience.

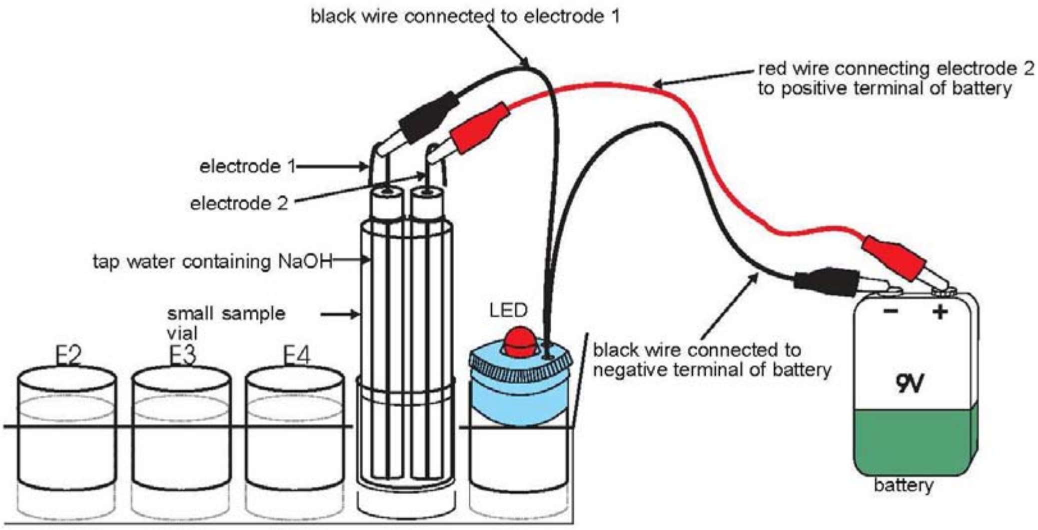
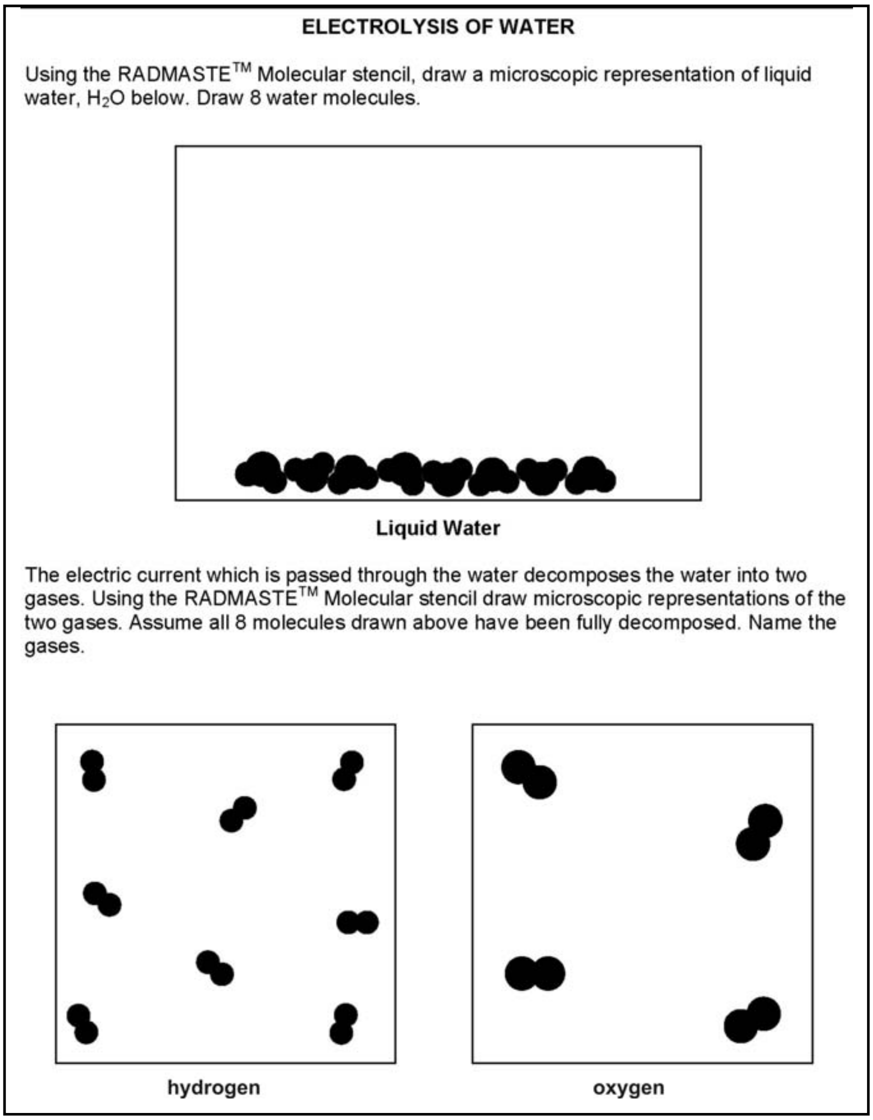


Figure 9 Electrolysis of water – microscale set-up



ELECTROLYSIS OF WATER

Using the RADMASTE™ Molecular stencil, draw a microscopic representation of liquid water, H_2O below. Draw 8 water molecules.

Liquid Water

The electric current which is passed through the water decomposes the water into two gases. Using the RADMASTE™ Molecular stencil draw microscopic representations of the two gases. Assume all 8 molecules drawn above have been fully decomposed. Name the gases.

hydrogen **oxygen**

Figure 10 Electrolysis of water - 2-D modeling

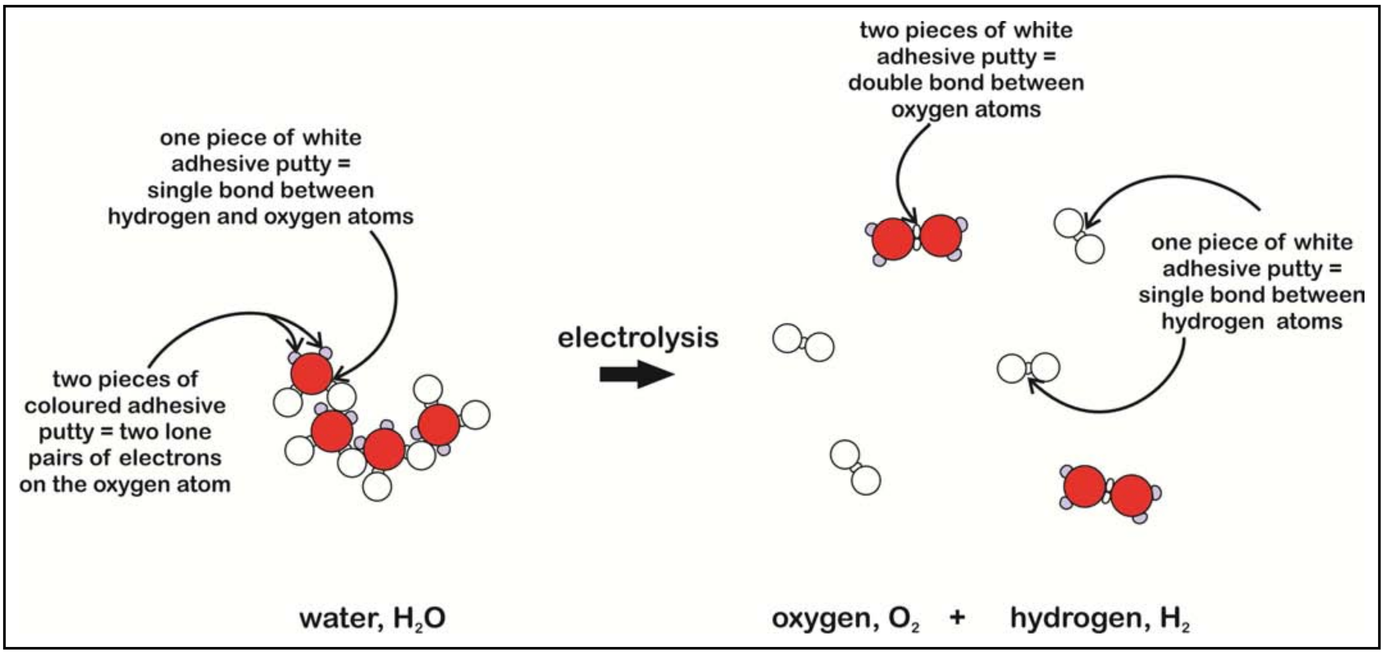


Figure 11 Electrolysis of water – 3-D modeling

THE CHEMIST'S TRIANGLE FOR NOVICE LEARNERS

We have not had the chance to try out the kind of approach described here with novice learners. We hypothesize that there will be learning benefits from doing so, but research is needed to find out.

Some authors have made cases for the triangle to be expanded to a tetrahedron to take account of the interaction of chemistry with the environment, or indeed other dimensions. This seems to me to confuse rather than improve. The three levels are the core characteristics of the discipline. The environment, industry, ethics, and so on are without a doubt important. But they do not lie at the core of the discipline and would be better taken into account by a circle around the triangle to signify their relevance to the curriculum at hand.

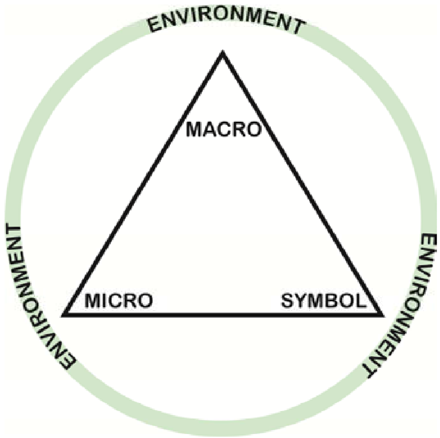


Figure 12 The Chemist's Triangle in the Context of Environmental Issues

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ACKNOWLEDGEMENTS

I thank Erica Steenberg and Andrew Chikochi for results from their in-service courses and Beverly Bell for assistance in preparing several Figures.