THE SYSTEMIC APPROACH TO TEACHING AND LEARNING CHEMISTRY AND THE BIG IDEAS OF SCIENCE EDUCATION

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ABSTRACT

The systemic approach to teaching and learning chemistry has been implemented and researched for a number of years. There is substantial evidence of learning benefits from its application in the context of specific chemistry topics. In the wider context of science curricula however, the ambition of Fahmy and Lagowski to change curricula from linearity to systemic seems yet to be realized. We suggest that such a change could be initiated by introducing the Big Ideas of Science Education into existing curricula in a systemic manner. We exemplify our proposal with the case of the Grade 7-9 Natural Sciences curriculum in South Africa. *[African Journal of Chemical Education—AJCE 7(3), Special Issue, October 2017]*

FROM LINEARITY TO SYSTEMIC

'Normal science' was characterized by Kuhn [1] as puzzle-solving within a framework of established paradigms. For this reason he advocated that future scientists should follow a normal science education that built basic subject knowledge and skills. This logic has been widely adopted in school science curricula, but in more recent times criticism has grown. This can be illustrated by van Berkel's commentary [2] that school chemistry curricula:

> *"tend to be isolated from common sense, everyday life and society, the history of science, the philosophy of science, technology, school physics and from chemical research"*

The evidence is that such curricula are not attractive to the majority of learners. Their content, according to Aikenhead [3], is "socially sterile, impersonal, frustrating, intellectually boring, and/or dismissive of students' life-worlds".

Curriculum designers, noting the lack of enthusiasm of many school learners, have responded in various ways. Chemistry in the Community [4], Salters Chemistry [5] and, more recently, Chemie im Kontext [6], for example, are some of the variants of curricula that try to reach out to learners and their interests, whilst delivering basic chemistry knowledge and skills.

Attending to the need to capture the interest of school learners is clearly a sound objective. However, the need to deliver useful scientific knowledge that can inform and empower school leavers in their later life, regardless of the career they choose, is also important (as the above-mentioned curricula recognise). So what is offered to interest the learner needs to be coherently planned. A systemic approach to teaching and learning chemistry (and science in general) can be a way to do this. In the last two years of the 20th century, Fahmy and Lagowski made a case for "the use of a systemic approach in teaching and learning chemistry for the 21st century" [7]. Their meaning was a "study of chemistry concepts through interacted systems in which all relationships between concepts are clear". They sought "to change our educational systems from linearity to systemic". Linearity is one of the features of normal science education as traditionally implemented, so their proposal also represents a challenge to that tradition.

Since then several papers have reported on research in the classroom focused on the achievement of students when taught by traditional and by systemic approaches. Considerable evidence has been accumulated, demonstrating superior achievement by learners taught systemically about a number of chemistry topics [8].

Following a suggestion by Bradley [9], the approach has evolved to incorporate the 'chemist's triangle', leading to the Systemic Chemistry Triangle [SCT] as a teaching and learning strategy [10].

The Systemic Approach to Teaching and Learning Chemistry (SATLC) has demonstrated its worth in the context of the school chemistry classroom. However, it remains a teaching and learning approach applied to selected topics and working within the framework of an existing curriculum. It is therefore an open question as to whether national school curricula themselves have yet been touched by the approach. It is also not clear whether the criticisms of curricula that provide 'normal science education' have been addressed through this approach. It seemed appropriate therefore to investigate how in a school curriculum the ideals of the systemic approach to teaching and learning might be achieved more comprehensively. As we shall argue in the next section, the Big Ideas of Science Education [11], seem to offer a solution.

A SYSTEMIC APPROACH IN SCIENCE CURRICULUM DESIGN

We became interested in this possibility after undertaking the design of study guides for qualified Grade 7-9 teachers studying towards an Advanced Diploma in Education by distance learning. For that purpose we engaged with the 'Principles and Big Ideas of Science Education', a report published by the Association for Science Education (ASE) in 2010 [11]. In this publication many of the same sentiments about student science learning for the future are cited as motivation for the concept of Big Ideas. On the one hand is the almost irresistible tide of new information arising from continuing scientific research and development; on another hand is swelling numbers (globally) of children of school age, and on yet another hand there is growing awareness of global stresses due to expanding populations and economic activity. All these were alluded to in the original SATLC article of Fahmy and Lagowski, [7] of more than a decade previously. Designing school science curricula that have a different aim from those providing 'normal science education', remains a challenge.

The ASE report [11] declared:

"Current school science leaves many students untouched in developing broad ideas of science that could help understanding of things around them and enable them to take part in decisions as informed citizens."

"The goal of science education is not knowledge of a body of facts and theories but a progression towards key ideas which enable understanding of events and phenomena of relevance to students' lives."

The Big Ideas of Science Education report, simply put, argues that these problems and ambitions demand, that we should teach science by first identifying the Big Ideas of Science and then planning our teaching accordingly. Hence in every grade you teach the prescribed content, but with awareness that, as you do so, you also are developing one or two Big Ideas of Science. This awareness is not just an abstract idea but something you include in your teaching and learning program, and even your lesson plans. By focusing upon a limited number of Big Ideas of Science, the feeling (and the reality!) of a mass of disconnected facts can be avoided and learners can acquire a more coherent knowledge of the subject.

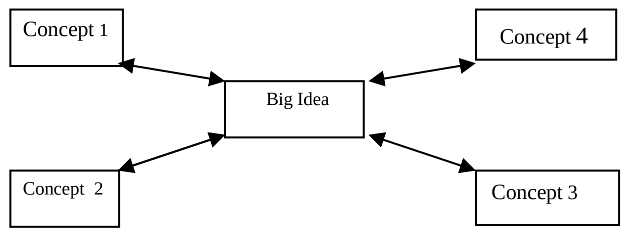
In the ASE report, 10 Big Ideas of Science and 4 Big Ideas about Science are identified (and re-confirmed with slight wording changes in a recent up-date, Working with Big ideas of Science Education [12]). No explicit distinction is made amongst the different sciences, although it is fairly easy to relate a Big Idea of Science with a traditional school science subject. Four of the Big Ideas of Science seem attributable to the Physical Sciences, with others being attributable to Biology and Geology. Chemistry educators would probably claim that the Big Idea:

All matter in the Universe is made of very small particles

is of particular relevance to them, although it certainly cannot be an exclusive claim. This being accepted we describe in the following section how this Big Idea of Science can lend further weight to the case for a curriculum that is more systemic.

BIG IDEAS IN A SYSTEMIC SCIENCE CURRICULUM

The diagram below shows how a Big Idea of Science can function to link concepts and topics that may themselves show little or no linkage – a situation that often arises within the context of national school curricula!



To help clarify the idea, we shall take a concrete example from the South African Natural Sciences curriculum for Grades 7-9 [13]. The curriculum content of this is organized into 'strands' called Life & Living, Matter & Materials, Energy & Change, and Planet Earth & Beyond. Very roughly, these 'strands' can be identified with science content typical of biology, chemistry, physics and geology, respectively. Consequently for present purposes we select the Matter & Materials 'strand' as our example, to explore how the Particle Big Idea can make links.

In Grade 7 we find the following topics, listed in the prescribed sequence for teaching during the second term:

1. Physical properties of materials
2. Separating mixtures
3. Acids, bases and neutrals
4. Introduction to the Periodic Table

It is relevant to our understanding that we also take account of the preceding grade (6) content of the Matter & Materials 'strand':

Solids, liquids and gases (arrangement of particles)

Mixtures

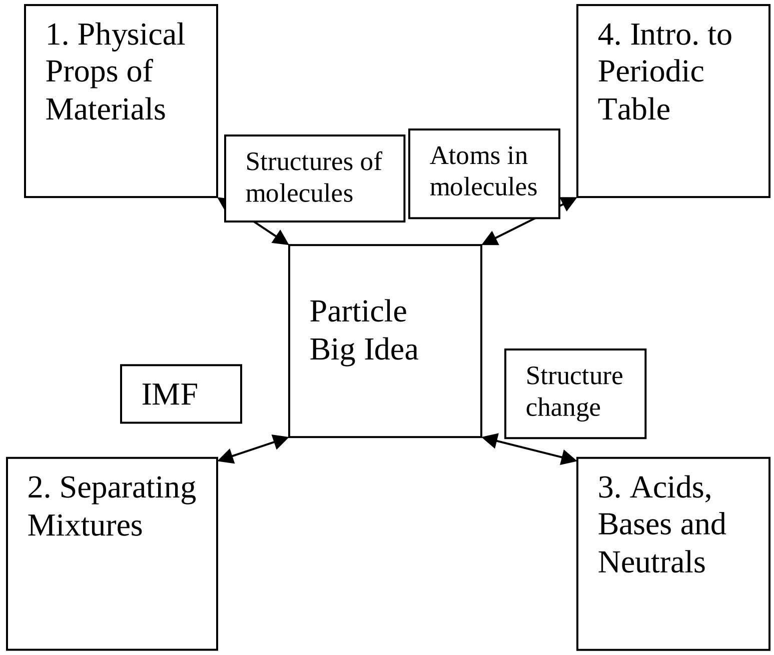
Solutions as special mixtures

Dissolving

It is then, in Grade 6 that a simple particle model of matter is introduced. The three states of matter are compared in terms of what is described as ‘the arrangement of particles’. The particles are undefined in any way, except that they are said to be all the same and that they move. Concepts such as energy, forces and particle structure are not referred to.

This then is the immediate background to the Grade 7 content and concepts of the Matter & Materials ‘strand’. It might seem that the first step had been taken towards the development of the Particle Big Idea in Grade 6, and that in Grade 7 a further step or steps would be seen. This is however not the case: there is no reference to the particle concept anywhere in Grade 7. Some continuity between Grade 6 and 7 topics may be seen of course, in the attention to mixtures, and in the physical properties topic (which includes reference to melting and boiling points of materials). The other Grade 7 topics have no links with any previous topics.

The diagram below shows the Grade 7 Matter & Materials topics linked with the Particle Big Idea. We consider the four topics as systems, previously not interacting with each other, as brought into interaction through the Particle Big Idea. The relationships involved are indicated by the linking concepts.



The new particle concept that can be introduced through these topics is shown above the linking lines. Following the given topic sequence, it shows that the new aspects of the particle model that can be introduced are:

1. Particles have a structure and the structures can be classified as discrete, macromolecular, or infinitely extended.
2. There are forces between the particles/molecules, sensibly termed intermolecular forces (IMF).
3. The structures of particles/molecules can be changed; the process is termed chemical reaction.
4. Atoms joined by chemical bonds, constitute the particles/molecules and give rise to their varied structures.

How then can the links be established? The following paragraphs briefly indicate this.

1. <u>Physical Properties of Materials</u>, in the South African science curriculum document, deals with a variety of physical properties: strength, flexibility, boiling and melting points, electrical conductivity and heat conductivity. The materials suggested for study include everyday ones, mostly solid: paper, cardboard, copper wire, rubber, plastic, stone/clay, brick, glass, aluminum

foil, wax paper, rope/string, water.

In our view, experiencing observations with such materials, should create a crisis of confidence in the simple particle model of matter described in Grade 6. The model of 'arrangements of particles' to account for the three states of matter is not capable of dealing with the realities presented by this topic. The simple (or simplistic) model needs diversification in ways that relate to the realities. The term molecule needs to be introduced and the structure types identified by Jensen [14] (discrete, macro, and infinitely extended), offered as a working hypothesis.

2. Separating mixtures is a topic that follows on from the Grade 6 topic of mixtures and highlights the observation of both homogeneous and heterogeneous mixtures.

   The particle model can explain the phenomena in terms of intermolecular forces (IMF) between discrete molecules, which result in attraction between like molecules being either stronger or weaker than between unlike molecules. Substances with infinitely extended molecules will not form solutions without molecular break-up, which may be translated as requiring chemical reaction.

3. Acids, bases and neutrals deals with the use of an indicator (litmus) to identify such materials, for example in the home. This study uncovers a new type of phenomenon, that is chemical reaction. The color change of the indicator is due to a color change of the indicator molecules. This happens because the molecules undergo a structure change. This is seen to be reversible. The molecules of the test material must also experience a structure change.

4. Introduction to the Periodic Table arises in the curriculum, before the concepts of element and atom have been defined! Definition and explanation follows only in the Matter & Materials strand in Grade 8. From our point of view however, introducing the concept of atom closes the circle in developing the Particle Big Idea in Grade 7. Atoms are the building blocks of molecules, wherein they are chemically-bonded together. Different atoms bond together in different ways to constitute the diversity of molecular structures, which in turn explain the diversity of materials in our environment.

It must be emphasized that the linking new particle concepts described above, which appear on the link-lines of the diagram, are proposed to be introduced in a simple manner. For example, the possible different types of molecular structure require no more than rational thought. There is no intention of a thorough discussion of how and why these structures form, for example. It is a question of thinking like a scientist, who brings to the study of the physical properties of materials, the simple particle model (as introduced in Grade 6). Because it is inadequate in explaining these new observations, the scientist asks how the simple model can be improved to do so. Discrete molecules (as with water) exist, but we have to allow for other types if we are to understand much of our environment.

Arising from this we see a systemic approach to the teaching and learning of the Grade 7 topics, which of themselves seem unconnected. The systemic approach is made possible by identifying a Big Idea of Science, which can be seen to have links with each topic. In the process of teaching these topics it should also become obvious that some of the Big Ideas about Science, set out in the ASE document, are also exposed, such as:

> *Science is about finding the cause or causes of phenomena in the natural world. Scientific explanations, theories and models are those that best fit the facts known at a particular time.*

Observing physical properties of materials, testing for acids and bases, etc, may have some interest for Grade 7 learners, especially if they can engage in simple practical activities. But there can be a deeper purpose to these if the particle idea is to be developed from them. We have designed and adapted several microscale experiments for teachers to explore this purpose in their self-study. Thus teachers on the course can recognise that, they are experiencing how science and scientific models develop. They may also consider that some of their learners may show heightened interest through the same or similar practical activities. This possibility of opening doors to new interest in science is of course part of the motivation for inquiry-based science education.

We have made similar analyses of the content of the Matter & Materials 'strand' in Grades 8 and 9, and constructed systemic diagrams based upon the Particle Big Idea. Thus we may say that we have designed a systemic curriculum for the Matter & Materials 'strand' Grades 7-9. This is at least a step towards one of the goals envisaged by Fahmy and Lagowski for the teaching and learning of chemistry for the 21st century [7].

CONCLUSIONS

The systemic approach to teaching and learning chemistry, first proposed in 1999, has been under development for several years. It represents an approach to teaching and learning that can be introduced by individual teachers on a topic by topic basis, within the framework of a national curriculum they are obligated to deliver. This possibility has enabled the testing of the approach, and student achievement has been enhanced.

A comprehensive transformation of the curriculum itself from linearity to systemic seems not to have been attempted yet. It is our feeling that such attempts should begin.

The concept of the Big Ideas of Science Education may offer a way forward for this ambition. A Big Idea of Science can help the construction of systemic diagrams for sections of the curriculum, even when the curriculum content itself suggests there is no possibility. In addition, by adopting a Big Idea of Science as the central concept in a systemic diagram, important Big Ideas about Science can be highlighted. From such a beginning, if successful, more far-reaching systemic diagrams may be conceived that actually bring about an overall reconsideration of the curriculum.

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