Chemistry in the Singapore school curriculum

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Abstract

Singapore adopts a spiral curriculum to help students gain better understanding of the concepts in matter as they progress from primary to upper secondary education. The syllabuses for each year of primary (ages 9 to 12) and lower secondary science (ages 13-14) are spelt out in detail and are closely followed by teachers. Upper secondary teachers are given the liberty to sequence the learning outcomes but they need to complete the syllabus within two years to prepare students for the national examination at the end of upper secondary education (age 16). This paper argues that the sequencing of learning objectives in a 'logical' order by teachers, especially in upper secondary, poses problems for students as they may have difficulty understanding the abstract concepts taught as well as the representational systems used to explain the characteristics and interaction of matter.

Introduction

Singapore was a British colony and, prior to 1960, the school curriculum offered was that of a typical English grammar school of the time (Mackie, 1971). Even till today, the University of Cambridge Local Examination Syndicate (UCLES), first introduced in 1891, still has close links with the Ministry of Education, Singapore. The syndicate collaborates with the Ministry of Education to develop the school curricula and national examinations at the end of secondary and pre-university education. The educational system in Singapore is constantly evolving to meet the changing demands of society, and is becoming more diverse and flexible, with greater choices and pathways for students. Broad-based education is now emphasized to facilitate the development of life skills, independent learning, critical and creative thinking.

The syllabuses for each year of primary and lower secondary science are spelt out in detail in documents produced by the Curriculum Planning and Development Division (CPDD), Ministry of Education, and are closely followed by teachers. The learning objectives were developed in consultation with experts and practitioners, and took into account any educational initiatives from the Ministry of Education, such as the implementation of school-based practical assessments to replace the one-off end of year practical examinations from 2006 which expanded the scope of practical work that was done in schools. In general, teachers in the upper secondary and pre-university levels have two years to complete the respective syllabuses which are co-developed by the CPDD, the School Examination and Assessment Board (SEAB), which is a statutory board in charge of national examinations, and the UCLES, but have the flexibility to structure the instructional sequence over the two years. The SEAB and the UCLES also collaborate in administering two national examinations in Singapore, the General Certificate of Education Ordinary Level examinations at the end of Secondary Four (age 16) and the General Certificate of Education Advanced Level examinations at the end of Pre-University Two (age 18). In addition, the SEAB is responsible for administering the national examinations for primary education, the Primary School Leaving Examinations, at the end of Primary Six (age 12).

The primary science (ages 9-12) and lower secondary science (ages 13-14) curricula (Curriculum Planning & Development Division, 2004a,b) are based on a 'science as inquiry' framework, and comprise five themes in primary science (Diversity, Cycles, Systems, Energy, and Interactions) and six themes in lower secondary science (Diversity, Cycles, Energy, Interactions, Models and Systems, and Measurement). The syllabuses encompass a core body of concepts in both the life and physical sciences to provide a broad understanding of the environment, and the interaction between science, technology and the environment. The 'science as inquiry' framework in primary and lower secondary science continues in the upper secondary (ages 15-16) curriculum (CPDD, 2000) and the pre-university (ages 17-18) curriculum (CPDD, 2003a,b,c). However, students learn science as separate subjects, physics, chemistry and biology, in upper secondary and pre-university. This is different from the general science focus in primary and lower secondary science. The end goal of the upper secondary and pre-university science curricula is to produce confident citizens in a technological world, able to take or develop an informed interest in matters of scientific import, and to recognise the usefulness, and limitations, of the scientific method and to appreciate its applicability in other disciplines and in everyday life. Pupils sit for high stakes national examinations at the end of primary, secondary and pre-university schooling.

Sequencing of the Learning Outcomes Related to Matter

The sequencing of the learning outcomes related to matter is based on a spiral approach to match pupils' cognitive development, build upon their existing understanding and facilitate the gradual mastery of concepts and process skills (CPDD 2004b). This paper will focus on the learning of matter (non-living things) at the primary and secondary levels. The learning outcomes for matter at different levels in primary and secondary education can be found at the CPDD website[1] and the SEAB website[2].

Primary Science

The percentages of learning outcomes in the primary science syllabus (CPDD, 2004a) associated with matter, living things, and energy and forces are given in Table 1. The percentages are calculated based on the ratio of the number of learning outcomes associated with matter, living things and energy and forces to the total number of learning outcomes. This gives a rough overview of the balance of the learning outcomes assuming the learning outcome statements are of equal 'content value'. Students do not learn science in the first two years of primary education; they concentrate mainly on the English language, a second language and mathematics. The students start their formal science education at Primary Three (age 9). In their first lesson on matter, they learn about different materials (solids only) with different physical properties, and relate the uses of these materials with their properties. Students would have encountered the materials in their everyday life, so they should be able to link their experiences of materials with what is taught in class. In Primary Four (age 10), students learn about the properties and states of matter under the theme of Cycles, and that air is a mixture of gases under the theme of Systems. These concepts on matter are more difficult and abstract than those encountered in Primary Three. There is no learning outcome related to matter in Primary Five (age 11) but in Primary Six (age 12), students revisit the topic of materials and their uses under the theme of Diversity.

Table 1: Learning outcomes in the primary science syllabus

Learning outcomes associated with	Number of learning outcomes (n=106)	Percentage
Matter	19	18
Living things	42	40
Energy and forces	40	38
Others	5	5

It can be seen from Table 1 that the percentage of learning outcomes associated with matter (19%) is lower than those of living things (40%), and energy and forces (38%). The concepts in the learning of matter, especially the particulate nature of matter, are generally more abstract and less readily related to the everyday experiences of the primary school students as compared to those in living things, and energy and forces. Hence, only the simpler concepts of matter are taught in primary science, leading to the lower percentage. Indeed, Nakhleh and Samarapungavan (1999), and Stavy (1994) found that students had difficulties learning concepts related to matter, for example, the macroscopic physical attributes of solids and liquids, and the particulate nature of matter. As for gases, Snir, Smith and Raz (2003) state that students may have difficulties thinking of them as matter because they "think that matter is something that they can see, touch, and feel" (p. 799).

Lower Secondary Science

The percentages of learning outcomes in the lower secondary science syllabus (CPDD, 2004b) associated with science as an inquiry, measurement, matter, living things, and energy and forces are given in Table 2. The percentage of learning outcomes associated with matter (25%) is still lower than those of living things (34%), and energy and forces (31%) but more comparable than in primary science.

Table 2:
Learning outcomes in the lower secondary science syllabus

Learning outcomes associated with	Number of learning outcomes (n=106)	Percentage
Science as an inquiry	9	6
Measurement	8	5
Matter	40	25
Living things	54	34
Energy and forces	49	31

In the lower secondary science syllabus, the sequence of learning objectives starts with the classification and uses of materials in Secondary One (age 13), something which is very similar to what students learn in primary science. This is followed by the topics of 'elements, compounds and mixtures', separation techniques, 'solutions and suspensions', and 'acids and bases'. In Secondary Two (age 14), students will learn the particulate model of matter, simple concepts of atoms and molecules, and chemical changes and reactions.

Learning about elements, compounds and mixtures at Secondary One without knowing the particulate model of matter (which is taught in Secondary Two) may be problematic because it can be difficult for students to differentiate elements, compounds and homogeneous mixtures at the macroscopic level. For example, a shiny, metallic substance can be an element or an alloy, and a colourless liquid can be a compound or a solution, so students need to know the representations of elements, compounds and mixtures at the microscopic level to make sense of the differences. In addition, the lower secondary science syllabus has no explicit learning outcome on the microscopic level representations of elements, compounds and mixtures; the students are only required to know the simple model of solids, liquids and gases in terms of the arrangement and movement of particles, and the distinction between an atom and a molecule. Nonetheless, students need to be taught the particulate representations of elements, compounds and mixtures to have a better understanding of these substances. However, this is not an easy task as "students have to take their existence on faith and build up knowledge structures of molecules and molecular behaviour without having direct experience with molecules" (Fellows, 1994, p. 988). Even college students had difficulty differentiating microscopic level representation of pure compounds, homogeneous and heterogeneous mixtures (Sanger, 2000); many classified microscopic representations of pure compounds as homogeneous mixtures, and several of them classified all mixtures as heterogeneous. Snir et al. (2003) also maintain that the particulate model of matter is difficult for students to understand because "it requires that students develop an understanding of two profoundly important, but counterintuitive, ideas" (p. 795) - the discontinuity of matter and the use of "an explanatory model as a metaconcept in science." (p. 795). In the lower secondary science syllabus, models are described as simplified representations of phenomena constructed to facilitate understanding of phenomena. However, the use of models in science is seldom discussed in class, so students may not have clear ideas of a scientific model, its usefulness and limitations.

Upper Secondary Chemistry

Matter is mainly taught in chemistry in upper secondary science. Upper secondary students (ages 15 to 16) study chemistry as a subject by itself, or as part as a combined science subject, for example, Biology/Chemistry or Chemistry/Physics. The sequencing of the topics of the Chemistry 5068 syllabus (available at the SEAB website[2]), which is chemistry as a single subject, by ten schools (S1 to S10) and two textbooks (T1 and T2) will be the focus of discussion in this section.

In November 2005, the author approached teachers attending a chemistry education workshop in his institution, and teachers with whom he had worked in previous research studies to request if he could study their Chemistry 5068 schemes of work and interview teachers on the schemes of work. Ten secondary schools (S1 to S10) consented to make available their schemes of work for analysis, and six senior chemistry teachers (ST1 to ST6) from three schools agreed to be interviewed on the rationale behind their schemes of work. The rank-orders of the topics and sub-topics in the ten schemes of work are presented in Table 3, together with that from two textbooks (T1 and T2) which are approved by the Ministry of Education for use in secondary schools. It can be seen from Table 3 that the order given in the Chemistry 5068 syllabus is generally not closely followed except by textbook T2. It has to be noted that the syllabuses for upper secondary science are not curricular documents but examination documents in that the content to be assessed in the national examination is given in detail in the documents. There is no official curricular guidance given in upper secondary science, so the schools are at liberty to sequence the learning outcomes and select the instructional material and strategies as they deem appropriate; they only need to teach all the topics stated in the syllabus within two years to prepare students for the national examination at the end of Secondary Four (age 16). This is fortunate as there does not seem to be any discernible rationale for the order of the topics in the syllabus. For example, the identification of ions and gases is the third sub-topic of the first topic in the syllabus; however, the theory involved is discussed only in 'Redox', the sixth topic, and in the seventh topic, 'The Chemistry and Uses of Acids, Bases and Salts'. If the above order is followed, students could be taught to carry out tests for cations, anions, gases, oxidising and reducing agents without knowing the reactions involved, that is, why the test works (Tan, Goh, Chia, & Treagust, 2001, 2002). Data from Table 3 show that three schools (S5, S6 and S10) and the two textbooks presented the characteristic properties of acids and bases, the preparation of salts, and redox reactions before the identification of ions and gases, which was the recommended order. However, schools S5 and S6 taught the identification of ions and gases as the last sub-topic, which could be several months after the other sub-topics; students might forget what they had learnt earlier, so teachers in schools S5 and S6 need to make explicit links with the earlier material. Six schools (S1, 2, 3, 4, 7 and 9) taught the characteristic properties of acids and bases, and the preparation of salts before the identification of ions and gases, but redox reactions after it so students might have difficulty understanding the tests for sulfur dioxide and the nitrate (V) ion which involve redox reactions. School S8 was unusual in that its sequence was redox reactions, the identification of ions and gases, and then characteristic properties of acids and bases, and the preparation of salts.

Textbook T2, which followed the sequence of topics in the Chemistry 5068 syllabus closely, might create difficulty for students using it especially if they follow the order of topics in the textbook. For example, the sequencing of 'Electrolysis', before 'Redox', might create difficulty as electrolysis essentially involves reduction and oxidation reactions. Students from school S3 might also face the same difficulty as they were taught electrochemistry before redox reactions. Another example is chemical calculations in the topic, 'Formulae, Stoichiometry and the Mole Concept'. A student must be able to write chemical equations to do stoichiometric calculations, but they learn the chemistry of the various elements and compounds only at a later stage (schools S1, S2, S3, S7, S8, S9, T1 and T2); if they do not know the reaction that occurs in a given situation, it is nearly impossible to write down an equation describing the reaction, and hence, to do any calculation. The students should have learnt some reactions (e.g. acid-base reactions) in lower secondary science but these are insufficient for upper secondary chemistry. Thus, to overcome this, teachers will generally give the equations involved. This can result in chemical calculations becoming algorithmic with little reference to the chemistry involved. Three teachers from school S6 which sequenced 'acids, bases and salts' before chemical calculations realized the consequence of the reverse order as indicated in the following transcript:

ST3:...I think to do the mole concept so early in Secondary 3...they are not ready...it is too overwhelming for them...it is too overwhelming...I think reactions are easier for them to grasp than to do the calculations...so I think they are not ready...so I switch the order...one reason is that they can write the equation themselves... the other thing is their readiness for mole concept.

ST2:You don't have enough exposure to chemicals if you start so early...whereas if you have like a lot of reactions, a lot of chemicals, they are familiar with acids, they are familiar with solutions...they are familiar with salts, then at least they... their understanding will be...

ST1:It will be more meaningful.

ST2: They need concept of chemical reactions so they have something that they can link to in the calculations.

Note 1. The above transcript has been lightly edited to improve its readability.

Table 3. Sequencing of topics in ten schemes of work and two textbooks

Sequence in the Chemistry 5068 syllabus	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	T1	T2
1. Experimental chemistry												
1.2 Methods of purification and analysis	2	1	2	2	2	1	2	1	1	7	2	2
1.3 Identification of ions and gases	12	15	12	9	33	33	12	12	12	27	13	16
2. The Particulate Nature of Matter												
2.1 Kinetic particle theory	1	2	1	32	1	2	1	2	2	1	1	1
2.2 Atomic structure	4	3	3	3	3	4	4	3	4	3	4	3
2.3 Elements, compounds and mixtures	3	7	4	1	4	3	3	4	3	2	3	4
2.4 Ionic bonding and structures	5	4	5	4	5	6	5	5	5	4	5	5
2.5 Covalent bonding and structures	6	5	6	5	6	5	6	6	6	5	6	6
2.6 Metallic bonding structures	7	6	7	6	7	7	7	7	7	6	7	7
3. Formulae, Stoichiometry and the Mole Concept												
3.1 Chemical formulae and equations	8	11	8	*	8	10	8	13	8	8	8	8
3.2 Stoichiometry and mole concept	9	12	9	13	15	11	9	14	9	18	9	9
4. Electrolysis	23	28	20	19	23	26	19	26	22	21	25	10
5. Energy from Chemicals	27	27	26	14	26	23	26	27	28	28	27	11
6. Chemical Reactions												
6.1 Speed of reaction	28	25	22	15	27	27	25	28	23	19	28	12
6.2 Redox	22	26	23	16	22	14	18	11	13	20	10	13
7. The Chemistry and Uses of Acids, Bases and Salts												
7.1 The characteristic properties of acids and bases	10	13	10	7	10	8	10	15	10	12	11	14
7.2 Preparation of salts	11	14	11	8	11	9	11	16	11	13	12	15
7.3 Properties and uses of ammonia	25	16	24	20	24	25	28	17	26	14	14	17
7.4 Sulfuric acid	26	17	25	21	25	24	27	18	27	15	15	18
8. The Periodic Table												
8.1 Periodic trends	13	8	17	10	12	15	31	8	14	9	18	19
8.2 Group properties	14	9	18	11	13	16	32	9	15	10	19	20
8.3 Transition elements	15	10	19	12	14	17	33	10	16	11	20	21
9. Metals												
9.1 Properties of metals	16	18	13	22	17	18	20	21	17	22	21	22
9.2 Reactivity series	17	19	14	23	18	19	21	22	18	23	22	23
9.3 Extraction of metals	18	20	15	24	19	20	22	23	19	24	23	24
9.4 Iron	19	21	16	25	20	21	23	24	20	25	24	25
9.5 Aluminium	24	22	21	26	21	22	24	25	21	26	26	26
10. Atmosphere and Environment												
10.1 Air	20	23	27	17	16	12	29	19	24	17	16	27
10.2 Water	21	24	28	18	9	13	30	20	25	16	17	28
11. Organic Chemistry												
11.1 Alkanes	29	29	29	27	28	28	13	29	29	29	29	29
11.2 Alkenes	30	30	30	28	29	29	14	30	30	30	30	30
11.3 Alcohols	31	31	31	29	30	30	15	31	31	31	31	31
11.4 Carboxylic acids	32	32	32	30	31	31	16	32	32	32	32	32
11.5 Macromolecules	33	33	33	31	32	32	17	33	33	33	33	33

Note
* denotes that the school did not cover the sub-topic of Chemical Formulae and Equations as these were deemed to have been covered in adequate detail in its lower secondary science programme

Note 2. ST1, ST2 and ST3 represent Teacher 1, 2 and 3 from the school S6 who were interviewed together as a group.

Some of the difficulties that the curriculum writers in the CPDD have at each syllabus revision are what to retain, add or remove as changes can create problems for the teaching and learning of particular topics in the revised syllabus. For example, in the sub-topic, 'Identification of ions and gases', students are required to test for the gas, sulfur dioxide. However, the reactions which liberate sulfur dioxide are not included in the syllabus. If their teachers do not discuss the reactions, the situation will arise where students have to test for sulfur dioxide but do not know when to test for it, that is, they do not know when the gas will be liberated. Another point of contention is the removal of chemical equilibrium from the present syllabus because the topic was considered difficult at this stage, and that students taking chemistry at the next (pre-university) level will study the topic in greater detail. Research (e.g. Tyson, Treagust, & Bucat, 1999; Van Driel, de Vos, & Verloop, 1999) does show that chemical equilibrium is difficult for students to understand, and this might be the reason for its removal from the present syllabus. However, this makes it difficult for teachers to discuss the manufacture of ammonia by the Haber process and sulfuric acid by the Contact process, both of which are still included in the syllabus, as the processes involve concepts in chemical equilibrium. Thus, students may not be able to make sense of the conditions involved in the Haber and Contact processes and would merely memorize the conditions required unless teachers devote some time to the discussion of chemical equilibrium.

Logical versus psychological order

It can be seen from Table 3 that the schools and textbooks focus on methods of purification and analysis, the particulate nature of matter, chemical formula and equations at the start of the Chemistry 5068 course. Learning chemistry involves "operating on and interrelating three levels of thought: the macro and tangible, the sub micro atomic and molecular, and the representational use of symbols and mathematics" (Johnstone, 2000, p. 9). This is because when changes occur in chemical substances (which may or may not be visible), the underlying mechanisms that account for these changes are developed based on the theories and representations developed by scientists, so the microscopic and symbolic representations "afford certain ways of thinking and talking about underlying entities and processes" (Schank & Kozma, 2002, p. 256). Thus, it is logical to teach particulate nature of matter, bonding, and chemical formula and equation early in the course because chemical phenomena and reactions which are encountered later can then be discussed and interpreted at the microscopic and symbolic levels. For example, teachers ST1, ST2 and ST3 believed that the concept of ions, which was taught in atomic structure, was essential for the understanding of 'acids, bases and salts' as the following excerpt shows:

ST3:Acids, bases and salt, whether they have done in the lower secondary...so it is at least not so overwhelming

ST2:Acids, bases and salts form ions

ST3:You will need this concept also

ST2:They will need the structure of the ion...maybe not so much the bonding concept

ST3:But at least the ions they must know

ST1:They will understand what hydrogen ions are because you already teach it in the atomic structure

ST2:So it's like if you...do the atomic structure already... then of course you go into it...they form ions, some of them...you just tie up with the bonding quite naturally rather than split up the bonding and do later on

ST3:Then when we talk about degree of ionization, we talk about...strength of acids, they are able to appreciate the ions...at that point already they don't question so much...what is ion, because they already done that...they are quite accepting... for us to illustrate the strength of acids with the ions, the dissociation... actually they are quite ok

However, as previously mentioned, microscopic entities such as atoms, ions and molecules cannot be seen, so students have to accept that such things exists. In addition, the learning of these concepts requires "formal operational reasoning in the Piagetian sense, and at the same time pose a heavy burden on students' working memory" (Zarotiadou & Tsaparlis, 2000, p. 38). Though the students have encountered the particulate model of matter and basic concepts of atoms and molecules in the lower secondary science programme, it is uncertain if they have understood these concepts sufficiently to make sense of the more advanced concepts discussed in upper secondary chemistry. There is also a possibility that the difficult and abstract topics may turn students off chemistry early in the course (within the first six months!) and it may be difficult to motivate students to persevere in their learning of chemistry, especially those who do not intend to pursue further chemical education (Harrison & Treagust, 2002). To help students understand the microscopic and symbolic representations of chemical phenomena, schools tend to use physical models and technology such as multi-media resources and dataloggers as reflected in their schemes of work. Multimedia CD-ROMs and internet websites are commonly used to show animations, for example, of the structure of atoms, bonding and electrolytic processes, and research has indicated that these resources have a positive impact on students' understanding (e.g. Schank & Kozma, 2002; Wu, Krajcik, & Soloway, 2001). Teachers also use dataloggers in demonstrations and experiments to help students 'visualize' certain processes in topics such as energetics and kinetics. For example, research on the use of dataloggers in Singapore (Tan, Hedberg, Koh, & Seah, 2006) shows that dataloggers are commonly used to generate heating, cooling and titration curves, illustrate changes in temperature in exothermic and endothermic reactions, monitor rates of reactions and determine the potential of galvanic cells. The real-time graphical display allows students a glimpse of underlying processes especially where there are no visible changes at the macroscopic level, for example, in neutralization reactions.

The sequence of instruction generally continues with 'acids, bases and salts', chemical calculations, periodic table, qualitative analysis, redox, metals, environmental and industrial chemistry, electrochemistry, kinetics, energetics and organic chemistry. 'Acids, bases and salts' is the first 'descriptive' chemistry topic where students encounter many chemical reactions which they can see in demonstrations or do in experiments; this topic gives students first hand knowledge of the materials and "a feel for the phenomena" (Woolnough & Allsop, 1985, p. 34). Apart from chemical calculations, the other topics also provide macroscopic experience, albeit to varying degrees. Johnstone (2000) and Nelson (2002) argue that the teaching of chemistry should start with the macroscopic level, to make concepts "as concrete and visualisable as possible" (Johnstone, 2000, p. 13). Explanations at the microscopic and symbolic levels could make more sense to students if they are able draw upon and to link these explanations with their experience of chemical phenomena. With appropriate instruction, students can be helped to "develop the link between the macroscopic observations in the laboratory and the microscopic models that chemist used to explain them" (Haidar & Abraham, 1991, p. 932).

Except for School S7, all schools and textbooks discuss organic chemistry towards the end of the chemistry programme, and a possible reason is that organic chemistry is generally considered difficult for beginning students. However, Johnstone (2000) argues the syllabus should begin with organic chemistry as students are familiar with "petrol, camping gas, plastics and foods" (p. 12) and the organic chemistry at secondary level involves only simple bonding concepts, structures and formulae.

Research on the sequencing of chemistry topics

The author has been engaging teachers since August 2006 to explore different ways of sequencing the topics in the Chemistry 5068 syllabus. A few teachers are exploring teaching descriptive chemistry topics first before proceeding to the more abstract topics. This is to enable students to be familiar with reagents and reactions so that they can link abstract concepts which they learn later to these reagents and reactions. However, the teachers are concerned with students' ability to cope with all the abstract and difficult topics or sub-topics if they are 'bunched up' together in the latter part of the course.

Other teachers are trying not to teach abstract topics such as chemical bonding as a topic but to 'drip-feed' the relevant abstract concepts where applicable when they teach the more descriptive chemistry topics. Instead of teaching atomic and molecular structures as a topic, molecules, ions and dissociation may make more sense to students if they investigate the properties of hydrogen chloride when dissolved in water and when dissolved in toluene in the topic of acids, bases and salts; hydrogen chloride remains as a molecule in toluene but dissociates to form hydrogen and chloride ions in water, and it is the hydrogen ions that give acids their characteristic reactions. Research is ongoing to determine if alternative ways of sequencing the topics help students to understanding chemistry better; teachers will be reluctant to change established sequences of instruction without any evidence that alternative sequences can lead to better understanding of concepts.

Conclusion

Formal learning of matter begins in primary school when students are nine years old when they learn that different materials have different properties and link the use of the materials with their properties. In lower secondary science, the students also start with the classification and use of materials followed by topics such as elements, compounds and mixtures, separation techniques and the particulate nature of matter. The spiral curriculum continues in upper secondary when students revisit concepts on separation techniques, element, compounds and mixtures, particulate nature of matter, but in greater detail, before moving on to more complex concepts such as atomic structure, bonding, stoichiometry and periodic trends. This structured curriculum is planned to help students gain better understanding of the concepts in matter that they encounter at various levels. However, the sequencing of learning objectives in a 'logical' order by teachers, especially in upper secondary, may pose problems for students as they may not be able to cope with abstract concepts encountered early in the programme, as well as the representational systems that chemists use.

Notes

1 URL of the CPDD website:
http://www.moe.gov.sg/cpdd/syllabuses.htmhttp://www.moe.gov.sg/cpdd/syllabuses.htm

2 URL of the SEAB website: http://www.seab.gov.sg/

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includes ion pairs. This form is known as Onsager's "triangle reaction" network (8). The relationships between equilibrium constants then are: $K_{sp}=[Na^+][Cl^-]=K_3$ $\quad K_1 \cdot K_2 \cdot K_3=1$

K_1 and K_2 involve $(Na^+Cl^-)(aq)$ contact ion pairs which are not the most abundant species present; hence K_1 and K_2 values would be <1 which in turn will make the K_{sp} value >1. However, the important point to note is that the product of $[Na^+][Cl^-]$ is still constant and our original definition of solubility product remains valid. However, since the $[Na^+]$ and $[Cl^-]$ concentrations are smaller than in V1 due to the presence of ion pairs the solubility product should be smaller than V1 prediction.

The best value for K_{sp} is then obtained from V2 because the activity coefficients account for non-ideality of solutions caused by various secondary processes.

There are several messages and pedagogically important issues arising from this work. First, how can the concept of chemical equilibrium learnt in Year I and applied to ideal solutions be applied outside this narrow textbook context (i.e. sparsely soluble salts). Second, the work highlights the effects of extreme conditions (e.g. high ion concentrations of saturated solutions) on the behavior of species involved in the equilibrium, i.e. the difference between ideal and non-ideal solutions. Third, it demonstrates to students how a seemingly simple question whose answer can be obtained by plugging numbers into the known equation subsumes a wealth of important chemical concepts. The subject of this article also involves lateral thinking by encouraging students to link and relate concepts like equilibrium, activity coefficient, molar concentration, ion hydration and ion-pair formation. This lateral thinking is brought about by the expansion of understanding of a known concept as new material is being learnt.

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