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Selection, sequencing and progression of content in biology in four diverse jurisdictions

Selection of content for a school syllabus is important in achieving progress towards inclusive generalisations which characterise powerful knowledge. Biology as a discipline progresses from knowledge of individual facts to inclusive generalisations such as homeostasis, energy transformations, heredity, and evolution. The present study evaluated the selection of content in the official biology syllabus for the seventh and eighth years of schooling in four diverse jurisdictions: Kenya, South Africa, British Columbia (Canada) and Singapore. The purpose was to determine whether and how content selection enabled progression to inclusive generalisations in biology and to compare selection, sequencing and progression among the four jurisdictions. General Topic Trace Mapping was used to compare each syllabus to a generic reference syllabus structured according to inclusive generalisations. Although there was some agreement in the scope of topics selected, jurisdictions varied in the way it was organised. Kenya included more everyday knowledge than other jurisdictions. British Columbia and Singapore selected content according to unifying themes, whereas South Africa and Kenya did not. South Africa selected content that enabled progression towards inclusive generalisations, but did not explicitly identify the generalisations. This study supports the contention that powerful knowledge in biology may be construed differently in diverse jurisdictions.

Significance:

Recent curriculum developments have favoured choice of content for school subjects that enables students to progress towards powerful knowledge. The current study provides evidence of variation in selection, sequencing and progression towards powerful knowledge in the biology syllabi of four jurisdictions: Kenya, South Africa, British Columbia (Canada) and Singapore. British Columbian and Singaporean syllabi explicitly identify unifying themes and organise content according to those themes, whereas South African and Kenyan syllabi lack explicit unifying themes.

Introduction

The construction of a school subject syllabus entails selecting disciplinary knowledge and skills that will best achieve the overall purposes of the curriculum and transforming it for the age and stage of development of school students.[1-3] Powerful knowledge is characterised as specialised knowledge that is related to its disciplinary roots, from which it can generate new ideas. Biology has the potential to provide access to powerful knowledge if its content is selected to relate individual facts to broader concepts, which themselves link into more inclusive generalisations representative of the discipline.[4,5] The present study compared content selection and progression in the biology component of the science syllabus for the 7th and 8th years of schooling in four diverse jurisdictions: South Africa, Kenya, British Columbia (Canada) and Singapore. It evaluated each syllabus in terms of whether it enables progression towards inclusive generalisations characterising powerful knowledge.[4] In this paper, inclusive generalisations are also referred to as 'unifying themes' or 'big ideas'.

Social realism[6] and modest realism[7] recognise that many scientific concepts and theories successfully explain reality and are increasingly true, within the constraints of existing technology for observing natural phenomena and human ability to comprehend such phenomena. Knowledge production is regulated by peer review, leading to reliable but revisable knowledge.[4] There is therefore an established body of powerful knowledge that has the potential to achieve scientific literacy. Recent curricula in countries such as the United Kingdom, South Africa, some Australian states, some Latin American and European countries and the Organisation for Economic Cooperation and Development (OECD) have reinstated knowledge as the prime organiser[1,8], replacing previous frameworks which foregrounded generic skills and competences[9]. Nevertheless, the OECD framework has been criticised for not focusing on powerful knowledge per se, but prioritising the economic utility of knowledge.[9]

The social realist position, termed 'knowledge for its own end' by Deng[1], aims to promote access to powerful knowledge which provides reliable explanations and transformative ways of thinking. Powerful knowledge in science equips students with conceptual thinking by linking particulars into inclusive generalisations which may be universally true. It enables students to relate new observations to existing concepts and to generate and evaluate alternative connections between observations and concepts.[4,6] Powerful knowledge is fundamentally democratic in that it is non-discriminatory.[6] Schools can promote social equality by providing access to powerful knowledge, providing disadvantaged children with possibly their only opportunity to move, intellectually at least, beyond their local circumstances.[2,6]

Not all subjects link particulars into broader generalisations as described by Young and Muller[6] for powerful knowledge in science. Deng[1] criticises a curriculum that prioritises knowledge for its own end because it is indifferent to the social and economic needs of a society. He favours a Bildung-related curriculum that selects and uses knowledge as a vehicle to develop human powers for the future.[5,10] Mathematics, geography[11-13] and history[14] can be structured to develop human potential through powerful knowledge. A Bildung-centred curriculum should cultivate self-determination, imagination, critically reflected action, and a sophisticated and informed understanding of the world.[5] Content selection should be guided by the potential of the content to develop human powers. Deng[5] does not elaborate on how a Bildung-centred curriculum should vary according to socio-economic contexts.

Although powerful knowledge has been claimed to promote social justice and equality of educational opportunity[6], studies supporting such claims are rare. Limited success has been reported in the USA and the UK in schools that have adopted a discipline-based subject curriculum and a strict disciplinary code.[15,16] Improved social equity is less easily demonstrated in other countries that have adopted a strong content-focused curriculum.[8] A knowledge-rich curriculum has yielded limited improvement in equality of academic performance in South Africa.[17] Clearly, the relationship between school curriculum, achievement of social justice and academic achievement is multifactorial and difficult to demonstrate.[8,18]

The choice and structure of curriculum is influenced by the context of a country/region.[19] The primary science syllabi of developing countries such as Kenya[19], Malawi[20] and Uganda[21] include more everyday topics such as health education, agriculture, parenting and/or domestic tasks than equivalent syllabi of wealthy countries such as British Columbia and Singapore.[19] Everyday knowledge has application in the lives of students but has limited application beyond the students' context.[4] Therefore, school science should include knowledge of basic facts and concepts in science, how investigations are conducted in science, the nature of science and its social and environmental relations and responsible uses of scientific knowledge in everyday life.[22] The weighting of these components depends on the age, stage of development and context in which the curriculum is enacted.

A biology syllabus that aims to develop powerful knowledge begins by identifying the most inclusive generalisations and matching subsidiary concepts according to the target student group.[1] Mayr[23] proposed that biology was constructed according to 'what', 'how' and 'why' questions. 'What' questions provide descriptions of the elements of the biological world, 'how' questions refer to processes causing effects in living systems, corresponding to the concept of proximate causation. 'Why' questions address 'the historical and evolutionary factors that account for all aspects of living organisms that exist now or have existed in the past', commonly known as ultimate causation[23(p.115)].

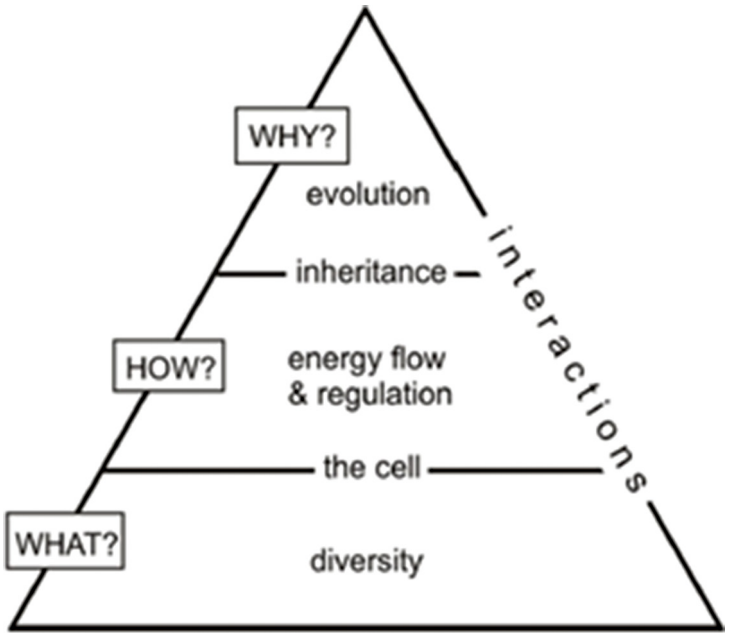
Johnson et al.[24] developed a model of the hierarchical knowledge structure of biology by mapping seven core concepts onto Mayr's[23] 'what', 'how' and 'why' questions. The model arranges the questions hierarchically and is reproduced as Figure 1.

The lowest level of the triangle in Figure 1 represents descriptive knowledge such as the diversity of life forms or the structures that constitute a living organism or the components of an ecosystem. The 'how' level represents functional biology, for example, how cells manage energy transformations and how organisms regulate their internal and external environment. The cell straddles what and how levels because its study is descriptive (what?) and functional (how?). 'Why' questions are generally answered in terms of unifying themes such as evolution and natural selection. Inheritance straddles the boundary between the 'how' and 'why' levels of the hierarchy because it controls an organism's functions and is ultimately responsible for evolution. Finally, interactions occur between the 'what', 'how', and 'why' levels and are therefore depicted straddling all three levels of the hierarchy; for example, structure is related to function, and both are linked through their evolutionary history.

Figure 1 presents a model of the academic discipline of biology, whereas a school subject should transform the main ideas but not exactly mirror its parent discipline. Junior secondary science, aimed at students aged approximately 12–15 years of age, is likely to be less specialised and more appealing to a general student body than science at upper secondary level. Scientifically literate citizens should be critical consumers of science, requiring scientific knowledge and understanding, knowledge of how science builds knowledge and knowledge of the social practices of the scientific community.[22]

In 2009, a group of 10 international experts in science education developed a set of principles to guide science education from age 5 to 17, which was revised in 2014.[22] The experts identified 15 'big ideas' in science, with associated content sequenced by broad age categories. Four of the 15 'big ideas' relate to disciplinary biology, while one relates to applications of science relevant to biology.[22] Harlen[25] added that science education should contribute to the Sustainable Development Goals (SDG) as expressed by the United Nations General Assembly[26], two of which are pertinent to biology education. The list of biologically relevant 'big ideas', their component topics and SDGs relevant to biology for ages 11–14 are:

1. **Living organisms are composed of cells and have a finite life span** (including structure and function of cells; cell specialisation; energy transfer in cells; tissues, organs and organ systems; structure and function of organ systems; homeostasis in cells).
2. **Living organisms depend on or compete with each other for a supply of energy and materials** (including ecosystem structure and functioning; nutrient cycling; transfer of energy and matter through an ecosystem; interspecific competition for resources; plant adaptations and effect of environmental change on populations).



Source: Johnson et al.[24] (under CC-BY-ND 4.0 licence)

Figure 1: Hierarchical model of knowledge in biology.

3. **Genetic information passes from one generation to another** (including chromosomes; DNA; genes; DNA replication during cell division; mutations; genetic mixing during sexual reproduction; genetic variation giving rise to phenotypic variation; natural selection acting on phenotypic variation).
4. **Evolution is responsible for the diversity of organisms, living and extinct** (including beneficial adaptations arising from genetic changes enhancing survival and reproductive success; increase in better adapted individuals in the population; speciation resulting from accumulated changes through natural selection; natural selection's role in the long history of life; biodiversity and classification).
5. **Applications of science often have ethical, social, economic and political implications** (including positive consequences, e.g. increased human life expectancy due to clean water, adequate food, improved medicine; negative consequences e.g. depleted natural resources due to increased demand for food, housing and waste disposal as human populations increase; habitat destruction causing extinction; benefits and disadvantages of improved transport networks, e.g. increased CO_2 levels, greenhouse effect; melting of polar ice, higher sea levels and disrupted weather patterns).

SDG3 Good health and well-being: Ensure healthy lives and promote well-being for all at all ages.

SDG13 Climate action: Take urgent action to combat climate change and its impacts (related to 'big idea' 5).

The list of 'big ideas' could be conceptualised quite differently by a different group of experts[25], but the curriculum should facilitate cognitive progression from concrete knowledge of facts towards deep conceptual understanding of abstract principles[22,27,28]. Only then can students engage with 21st century skills such as critical thinking and problem-solving.

The Trends in International Mathematics and Science Study (TIMSS) assessed syllabus represents content selected by a large proportion of participating countries, including developing and developed countries, up to and including the eighth year of schooling.[29] It is organised according to six knowledge categories, listed below with the closest matching big idea[24]:

1. Life processes of living things (Big idea 1)
2. Cells and their functions (Big idea 1)
3. Life cycles, reproduction and heredity (Big idea 3)
4. Ecosystems (Big ideas 2 and 5, SDG13)
5. Diversity, adaptation and natural selection (Big idea 4)
6. Human health (SDG3)

There is considerable agreement between Harlen's[22] 'big ideas' and the TIMSS assessed curriculum. Harlen's[22] outline provides some detail of how progression might be organised, but was developed from the perspective of developed countries, and may not be appropriate for developing countries. The present study compares the biology syllabus of two developing countries with that of two developed countries. Therefore, the TIMSS assessed syllabus represents the widest range of contexts available and was chosen as a starting point for constructing a reference syllabus for the present study.

The present study emerged from a project commissioned to benchmark the South African science syllabus for the Junior Secondary years (Grades 7–9 in South Africa) against the equivalent science syllabi of Kenya, Singapore and British Columbia (Canada). The original study was conducted in 2014, using syllabus documents in use at that time. The work presented here compares selection of content regarding progression towards powerful knowledge in the intended curriculum for the seventh and eighth years of schooling (Grades 7 and 8 of the Senior Phase of General Education and Training in South Africa). In all four jurisdictions, biology is incorporated into a combined science syllabus for years 7 and 8. Year 9 was excluded because biology is incorporated into combined science in South Africa and British Columbia, while it is a standalone subject in Singapore and Kenya.

The diverse contexts of the four jurisdictions included in the present study are illustrated by differences in the gross domestic product (GDP) per capita[30] and level of inequality measured by the Gini coefficient.[31] Singapore has a GDP of USD97 057 and Gini coefficient of 46, Canada has a GDP of USD48 720 and Gini coefficient of 33, South Africa has a GDP of USD12 032 and Gini coefficient of 63, and Kenya has a GDP of USD4926 and Gini coefficient of 41. South Africa and Kenya are poorer than Singapore and British Columbia, while South Africa has the highest level of inequality in the world, followed in the present study by Singapore, Kenya and Canada.

Inequality of educational opportunity in South Africa is evident in a marked difference between the academic performance of the relatively wealthy 20% of schools compared with the 80% of schools serving poorer communities.[17] Mathematics and science literacy as indicated by TIMSS has consistently been poor compared with other participating countries.[29] Singapore remains one of the best performers in TIMSS[29] and the Programme for International Student Assessment (PISA)[32]. British Columbia is a high performer in PISA[33], while Kenya does not participate in TIMSS or PISA. Although Kenya does not participate in international studies of science literacy, the relative health of its education system is indicated by its good performance in reading and mathematics in the Southern and Eastern Africa Consortium for Monitoring Educational Quality evaluation conducted in 2013.[34] Kenyan sixth-grade students outperformed their South African counterparts.

Students in the seventh to eighth years of schooling are approximately 12–15 years old, depending on the jurisdiction. In Singapore, the seventh and eighth years have a single syllabus called Lower Secondary, which cannot be divided into two separate years.[35] Other jurisdictions have a syllabus for each year of study. Science in all four jurisdictions includes a selection of content from biology, chemistry, physics, agricultural science, human health and/or earth and space science, depending on the jurisdiction. The present study focused on the biology-related components of each syllabus.

There is a limitation in that the intended curriculum, as expressed in policy documents, likely differs from the enacted curriculum in the classroom and the attained curriculum revealed through formal and informal assessment. Also, some content relevant to biology may be offered in other subjects. The research questions guiding the present study were:

- What biological knowledge has been selected in four science syllabi for the seventh–eighth years of schooling?
- How is knowledge organised so that it progresses to powerful knowledge in the four syllabi?

Methods

In South Africa and British Columbia, biology is a discrete component of the science syllabus called Life and Living[36] and Life Science, respectively.[37,38] In Kenya, biology is incorporated into six of ten units.[39] In Singapore, biology is integrated with physics and chemistry in four broad multidisciplinary themes, namely Diversity, Models, Systems, and Interactions.[35] For example, the theme Models includes Model of Cells – the Basic Units of Life, Model of Matter – The Particulate Nature of Matter, Model of Matter – Atoms and Molecules, and Ray Model of Light.

Statements describing the biology content were identified in each syllabus. In South Africa, content statements for Life and Living are listed as topics, for example: "Some inherited characteristics are height and tongue-rolling"[36(p.17-84)]. The content statements for Life and Living were analysed in the present study.

In British Columbia, each year of Life Science has an organising principle: Ecosystems in Year 7[37] and Cells and Systems in Year 8.[38] Content is listed as broad prescribed learning outcomes, for example, "It is expected that

students will analyse the roles of organisms as part of interconnected food webs, populations, communities and ecosystems", accompanied by more detailed suggested achievement indicators, for example, "Students….are able to identify populations of organisms in communities and ecosystems according to simplified food webs"[37(p.78)]. Prescribed learning outcomes and suggested achievement indicators were analysed in this study.

In Kenya, biological topics were located in science units entitled Human Body, Health Education, Environment, Plants, Animals, and Foods and Nutrition.[39(p.62–71)] Content is listed as specific objectives, for example, "By the end of this topic the learner should be able to explain fertilisation in human beings", and content, for example "fertilisation"[39(p.67)]. Specific objectives and content were used in the present analysis. Some content listed under the plant, animal and environment units was directly relevant to agriculture and was excluded, for example, signs of unhealthy crops, effects of livestock disease, soil conservation measures and ways of controlling air pollution. However, the boundary between biology and agriculture was blurred.

In Singapore, biology content and skills are described in three learning outcomes, which are Knowledge, Understanding and Application; Skills and Processes, and Ethics and Attitudes.[35] Content was extracted from the first and third learning outcomes.

The method of comparison identified elements present in one or more jurisdictions using a reference listing of content from the TIMSS Grade 8 assessed syllabus for 2011.[40] The 2011 TIMSS syllabus was selected because it was nearest in time to the present analysis. Biology constitutes 35% of the questions in the TIMSS tests. TIMSS recognises six knowledge categories, which are shown in Table 1. Topics give examples of content for each knowledge category.[40]

Table 1: Reference list of TIMSS 2011 knowledge categories and example topics[40(p.66–68)] matched with big ideas and Sustainable Development Goals (SDG).[22,25] Italics indicate added topics.

Knowledge categories	Example topics	Big idea
1. Life processes of living things	1.1 Locate major organs in the human body; identify the components of organ systems; explain the role of organs and organ systems in sustaining life.	1
	1.2 *Locate major organs in plants; identify components of plant organ systems; transport of water and other substances in a plant.*	1
2. Cells and their functions	2.1 *Identify and describe biologically important molecules.*	1
	2.2 Explain that living things are made of cells that carry out life functions and undergo cell division, and that tissues, organs and organ systems are formed from groups of cells with specialised structures and functions; identify cell structures and some functions of cell organelles; compare plant and animal cells; *transport of molecules by diffusion, osmosis and active transport.*	1
	2.3 Describe the process of photosynthesis and cellular respiration.	2
3. Life cycles, reproduction, and heredity	3.1 Compare and contrast how different organisms grow and develop; *describe human reproduction; describe plant reproduction.*	3
	3.2 Compare and contrast asexual and sexual reproduction.	3
	3.3 Relate the inheritance of traits to organisms passing on genetic material to their offspring; distinguish inherited characteristics from acquired or learned characteristics.	3
4. Ecosystems	4.1 *Describe the biosphere in terms of the hydrosphere, lithosphere and atmosphere.*	2
	4.2 Describe the flow of energy in an ecosystem; identify different organisms as producers, consumers, or decomposers; draw or interpret food pyramids or food web diagrams; *identify abiotic and biotic factors in an ecosystem.*	2
	4.3 Describe the role of living things in the cycling of elements and compounds through Earth's surface and the environment.	2
	4.4 Explain the interdependence of populations of organisms in an ecosystem in terms of the effects of competition and predation.	2
	4.5 Identify factors that can limit population size; predict effects of changes in an ecosystem on the available resources and the balance among populations.	2
	4.6 Recognise that the world's human population is growing and identify reasons why; discuss the effects of population growth on the environment.	5, SDG13
5. Diversity, adaptation and natural selection	5.1 State defining characteristics of major taxonomic groups and classify organisms according to these characteristics.	4
	5.2 Relate the survival or extinction of species to variation in physical/behavioural characteristics in a population and reproductive success in a changing environment.	4
6. Human health	6.1 Describe causes of common diseases, methods of infection or transmission, and the importance of the immune system.	SDG3
	6.2 Explain the importance of diet, exercise and lifestyle in maintaining health and preventing illness; identify the dietary sources and role of nutrients in a healthy diet; *understand and apply healthy sexual practice, dental hygiene, treatment of intestinal parasites, avoiding substance abuse.*	5, SDG3
	6.3 *Name and describe health issues related to human organ systems.*	SDG3

TIMSS knowledge categories and topics were adapted to accommodate content selection in all syllabi studied. The topic 'Characteristics and classification of organisms' was moved from 'Life processes of living things' to 'Diversity' and three TIMSS topics were omitted because they were absent in all four jurisdictions. Topics were added to accommodate content present in the syllabi but not in the TIMSS assessed syllabus.

Content topics present in each syllabus were mapped to the most closely related reference topic listed in Table 1. The process is similar to General Topic Trace Mapping used for cross-national comparison of mathematics and science curricula.[28,41] To ensure reliability, mapping was repeated several times over weeks and months until no further changes were made. Maps were scrutinised for progress towards inclusive generalisations reflecting the powerful knowledge of biology.[4,22,25]

Findings

Tables 2 – 6 show the content mapped onto topics identified in Table 1 linked to each TIMSS knowledge category and its associated big idea or SDG.[25] The purpose was to assess whether and to what extent each syllabus builds towards powerful knowledge in biology.

Table 2 shows that human organ systems, other than reproductive systems, are included in the syllabi of three of the four jurisdictions, with South Africa being the exception. Plant organ systems are present in only the Singaporean syllabus. Topics related to cells and their functions are absent in Kenya, while only the processes of photosynthesis and respiration are addressed in South Africa. British Columbian and Singaporean syllabi include cell structure and function, osmosis and diffusion, thereby contributing to big idea 1 far more comprehensively than the syllabi of Kenya and South Africa.

Table 3 shows that all four jurisdictions provide opportunities to build towards big idea 2, relating to interactions in ecosystems. Kenya provides the least exposure to topics related to ecological interactions, while South Africa, British Columbia and Singapore address ecosystems in some detail, nutrient cycles and some aspects of population dynamics. The topic Competition and Predation is indirectly addressed as interdependence among organisms.

Table 4 shows that three of the four jurisdictions provide foundations for big idea 3, which relates to heredity and reproduction, with British Columbia being the exception. Human reproduction is included in the syllabi of Kenya, South Africa and Singapore, with South Africa also including reproduction in flowering plants in considerable detail. Heredity is addressed only in South Africa and Singapore, with Singapore linking sexual reproduction to genetic variation. Thus Singapore provides the best access to big idea 3.

Table 5 shows that all four jurisdictions provide some access to the TIMSS knowledge category Diversity, Adaptation and Natural Selection, which forms the foundation of big idea 4, which is that evolution is responsible for biodiversity. Diversity and classification are present in the syllabi of three jurisdictions, with Kenya being the exception. South Africa provides the most comprehensive coverage of classification and the biological species concept. Variation and species survival as a topic lays a foundation for the process of natural selection. It is addressed through adaptations in three jurisdictions, British Columbia being the exception. South Africa and Singapore link intraspecific variation to survival and extinction. Overall, South Africa provides the most comprehensive access to big idea 4, although none of the jurisdictions mentions the term evolution. British Columbia provides the least opportunity to access big idea 4.

Table 6 shows progression towards the two SDGs. All four jurisdictions provide access to SDG3 relating to good health and well-being for all. Contraception and sexually transmitted infections and/or the link between pathogenic organisms and disease feature in all four jurisdictions. Contraception and STIs are related to the inclusion of human reproduction in three jurisdictions – Kenya, South Africa and Singapore. British Columbia provides less comprehensive coverage of human health than the other jurisdictions. Kenya and South Africa make specific mention of HIV and AIDS, which are omitted in other jurisdictions.

Climate action, which is the focus of SDG13, was not addressed in any syllabus, but topics related to the impact of human activities on the environment were identified in all four jurisdictions. The impact of pollution on the environment and the importance of conservation were common topics.

Table 7 summarises the selection of content in each jurisdiction. Singapore selects content matching 15 of the 17 topics and all six

Table 2: Selection and progression towards big idea 1: Living organisms are composed of cells and have a finite lifespan

Knowledge category		**1: Life processes of living things**		**2: Cells and their functions**		
Topics		**Structure and function of human organ systems**	**Structure and function of plant organ systems**	**Biologically important molecules**	**Cell structure and function**	**Photosynthesis and respiration**
Kenya	Std 7	Circulatory system; blood; blood vessels; heart				
	Std 8	Excretory organs' structure and functioning in humans				
South Africa	Gr 7					
	Gr 8					Descriptions and word equations; raw materials and products
British Columbia	Yr 7					
	Yr 8	Structure, function and interactions between selected human organ systems, eyes, immune system		Osmosis and diffusion	Cell theory; cell types; structure and function of organelles; microscope; tissue, organ, organ system	
Singapore	Lower Sec	Transport and circulatory systems and their interaction with other systems; digestive system	Plant transport system structure and function; diffusion and osmosis in plants	Digestive enzymes; diffusion in animals and plants	Structure and function of cells; tissues, organs, systems; plant and animal cells; division of labour in cells	

Table 3: Selection and progression towards big idea 2: Living organisms depend on or compete with each other for a supply of energy and materials

Knowledge category		4. Ecosystems				
Topics		**Biosphere**	**Ecosystems**	**Nutrient cycles**	**Competition and predation**	**Population dynamics**
Kenya	Std 7		Biotic and abiotic components of the environment; simple food chain		Interdependence between organisms; parasites	
	Std 8		Mammalian feeding habits – herbivores, carnivores, omnivores			
South Africa	Gr 7	Components of biosphere				
	Gr 8		Ecosystems; biotic and abiotic components; energy and matter flow during photosynthesis and respiration; trophic levels; food chain; food webs; energy pyramids	Microorganisms' role in recycling		Balance in an ecosystem; limiting factors; imbalance
British Columbia	Yr 7		Food webs; habitats; food pyramid; energy transfer; interactions between biotic & abiotic factors.	Decomposers and nutrient cycles	Interdependence of plants, animals and decomposers	Suitable environment for organisms; factors favouring healthy populations and ecosystems; effects of habitat loss
	Yr 8					
Singapore	Lower Sec		Ecosystem definition; abiotic factors; role of photosynthesis and respiration in energy flow through food chains and food webs	Decomposers and nutrient cycles	Interactions among organisms in a community	Reasons for depletion or extinction of species

Table 4: Selection and progression towards big idea 3: Genetic information passes from one generation to another

Knowledge category		3: Life cycles, reproduction and heredity	
Topics		**Reproduction, growth and development**	**Heredity**
Kenya	Std 7		
	Std 8	Human reproduction	
South Africa	Gr 7	Sexual reproduction in humans and angiosperms	Inherited characteristics
	Gr 8		
British Columbia	Yr 7		
	Yr 8		
Singapore	Lower Sec	Puberty; human reproduction; menstruation	Heredity and genetic variation through sexual reproduction; genetic material

Table 5: Selection and progression towards big idea 4: Evolution is responsible for the diversity of organisms, living and extinct

Knowledge category		5: Diversity, adaptation and natural selection	
Topics		**Diversity and classification**	**Variation and species survival**
Kenya	Std 7		
	Std 8		Plant adaptations; bird adaptations to feeding and movement
South Africa	Gr 7	Species concept; Linnaean classification system; diversity of animals and plants	Intraspecific variation; adaptations
	Gr 8	Classification of viruses, bacteria, protists and fungi	Adaptations, survival and extinction
British Columbia	Yr 7		
	Yr 8	Characteristics of living things; kingdoms	
Singapore	Lower Sec	Biodiversity and its importance; classification	Intraspecific variation; adaptations and survival

knowledge categories – a wider range than any other jurisdiction. South Africa selects content that matches 12 topics, omitting the knowledge category Life Processes entirely and giving scant attention to Cells. British Columbia restricts content selection to the theme for each year of study, being Ecosystems in Year 7 and Cells and Systems in Year 8. It addresses 10 topics, omitting the knowledge category Reproduction and Heredity. Kenya addresses eight topics from five knowledge categories, making it the narrowest syllabus of the four jurisdictions. It omits Cell Structure and Function.

Discussion

The biology syllabi for the seventh and eighth years of schooling in all four jurisdictions is dominated by specialised knowledge rather than biology for everyday living. They fit the description of social realism[6] or modest

Table 6: Selection and progression towards SDG3 (Good health and well-being), big idea 5 (applications of science) and SDG13 (Climate action)

Knowledge category		6: Human Health (SDG3)		4: Ecosystems (big idea 5 and SDG13)
Topics		**Diseases**	**Nutrition and health education**	**Human population growth and effects on the environment**
Kenya	Std 7		Types and effects of drug abuse; HIV and AIDS myths and misconceptions; care of HIV-positive people; controlling intestinal worms	
	Std 8	Causes and symptoms of STIs; food poisoning	Nutrition for specific needs; prevention of STIs; controlling HIV and AIDS; preventing food poisoning	Soil pollution; soil conservation; air pollution
South Africa	Gr 7		Concept of contraception	
	Gr 8	Disease-causing organisms	Hygiene; medicines; yoghurt	Human effects on ecosystem balance
British Columbia	Yr 7			Effects of forestry, pollutants and Aboriginal communities on environment
	Yr 8	Effects of pathogens and toxins	Correcting defects in human vision	
Singapore	Lower Sec	Effects of gut bacteria; transmission and treatment of STIs	Ethics and organ donation; hygiene and food; contraception; ethics and abortion and premarital sex	Importance of conservation; sustainable living; human population growth and impact on the environment

realism[7] more closely than human-centred curricula as described by Deng[1]. Powerful knowledge[4] predominates in all four syllabi, although human health and human effects on the environment are present in all jurisdictions.

There is overall agreement in the broad knowledge categories selected in the seventh and eighth years of study in biology, but considerable diversity in the range of topics included. Three topics – ecosystems, disease and human effects on the environment – were represented in all four jurisdictions. By contrast, three topics were addressed in only one jurisdiction: plant organ systems and their functions in Singapore, the processes of photosynthesis and respiration and the components of the biosphere in South Africa. Big idea 2 featured prominently in all four jurisdictions, indicating general agreement that students at this age and stage of schooling should be exposed to the basic concepts of ecosystems, including human effects on the environment. There was also agreement among at least three jurisdictions that students should learn about human life processes, reproduction, diversity and/or classification, variation and survival, and health education.

Big ideas 3 and 4 correspond with the apex of Johnson et al.'s[24] triangle showing the hierarchical organisation of knowledge in the discipline of biology. The most inclusive generalisation applicable in biology is evolution by natural selection (big idea 4) which is mediated through heredity (big idea 3). While adaptations were included in three jurisdictions, South Africa and Singapore provided the best foundations for big ideas 3 and 4. Nevertheless, all four jurisdictions omitted the process of natural selection and the nature of genetic material. Thus, there was general agreement that those topics were not appropriate for the seventh and eighth years of schooling.

With regard to progress towards powerful knowledge, Singapore emerged as the jurisdiction that provided access to the widest range of unifying themes as represented by Harlen's[22] big ideas. However, the biology content is scattered in multidisciplinary themes and progress towards big ideas may not be evident to students. They experience the biology content as isolated topics, thereby losing their potency to fit those facts into inclusive generalisations of biology.[4] Nevertheless, Singapore has been successful in achieving high levels of scientific literacy as indicated by performance in international studies.[30,31]

South Africa provides comprehensive access to three of the four big ideas, omitting most of the topics related to big idea 1. It does not identify a theme for each year of study, thereby concealing the relationship between individual topics and inclusive generalisations. Students may experience the curriculum as a list of facts to be remembered thereby reducing the potency of this knowledge-rich syllabus.[4,28] The South African curriculum contains abstract concepts such as the species concept, inheritance, intraspecific variation and considerable detail of the Linnean classification system in Grade 7 while Grade 8 is more concrete. This is contrary to the expected sequence of concrete to abstract.[27] Despite its strongly knowledge-focused curriculum, South Africa has had limited success in improving scientific literacy.[8,17]

British Columbia achieves access to powerful knowledge by explicitly centring content around a unifying theme[4] in each year of study. Restricting the breadth enables the topics to be dealt with in considerable detail, but it reduces the scope of big ideas that may be addressed. Thus British Columbia devotes considerable attention to big ideas 1 and 2 but little attention to big ideas 3 and 4 in years 7 and 8. The unifying themes identified in British Columbia do not closely match Harlen's[22] big ideas, supporting the contention that big ideas may be identified differently by different groups of experts.[22] The knowledge-focused syllabus in which breadth is limited in favour of depth, is associated with successful acquisition of scientific literacy in this jurisdiction.[33]

Kenya covers few topics scattered across knowledge categories without an evident unifying theme. Although it provides foundations for three of the four big ideas, the topics lack the depth of the other three jurisdictions. The knowledge is discipline-centred and organised around topics rather than concepts. Biology is interspersed with agricultural science and health education, making it difficult for students to link facts into inclusive generalisations. Kenya omits most of the foundational topics for big ideas relating to the cellular basis of life, inheritance and diversity and classification (big ideas 3 and 4). Variation and survival, the foundation of natural selection, are addressed only through several examples of adaptations. Thus Kenya's syllabus for Standards 7 and 8 provides limited access to powerful knowledge.[4]

Kenya's content selection is markedly different from those of the other jurisdictions in that it includes so many topics relevant to agriculture and/or everyday life. These topics relate to the SDGs and have worth in the context of rural Kenyan students, but do not apply beyond those contexts.[4,5] The syllabus is not future-oriented, nor does it fully cultivate human powers in the same way as deep engagement with disciplinary knowledge can do. Although Kenya does not participate in international studies of scientific literacy, its success in the foundational skills of reading and numeracy surpass those of South Africa and indicate a healthy education system.[34]

Table 7: Selection of biology topics for years 7–8 in four jurisdictions. Shaded blocks show omitted topics.

		Kenya		South Africa		British Columbia		Singapore
Knowledge category	**Topic**	**Std 7**	**Std 8**	**Gr 7**	**Gr 8**	**Yr 7**	**Yr 8**	**Lower Sec**
1. **Life processes**	1.1 Human organ systems		✓				✓	✓
	1.2 Plant organ systems							✓
2. **Cells**	2.1 Molecules						✓	✓
	2.2 Cells						✓	✓
	2.3 Photosynthesis and respiration				✓			
3. **Reproduction and heredity**	3.1 Reproduction, growth and development		✓	✓				✓
	3.2 Heredity			✓				✓
4. **Ecosystems**	4.1 Biosphere			✓				
	4.2 Ecosystems	✓	✓		✓	✓		✓
	4.3 Nutrient cycles				✓	✓		✓
	4.4 Competition and predation	✓				✓		✓
	4.5 Population dynamics				✓	✓		✓
	4.6 Human population growth and effects		✓		✓	✓		✓
5. **Diversity, adaptation and natural selection**	5.1 Diversity and classification			✓	✓		✓	✓
	5.2 Variation and survival		✓	✓	✓			✓
6. **Health**	6.1 Disease		✓		✓		✓	✓
	6.2 Health education	✓	✓	✓	✓			✓

British Columbia and Singapore provide the best access to specialist knowledge and greater depth of engagement with the topics included in biology. The British Columbian curriculum has been revised since 2014[42], as has the Singaporean curriculum.[43] The two poorer countries, South Africa and Kenya, expect less depth than the two wealthy countries. The Kenyan curriculum does not progress towards inclusive generalisations. In terms of Young and Muller's[6] concept of the powers of powerful knowledge, the developing countries provide less opportunity for academic equity and social justice than the wealthier countries.

Should Kenya and South Africa increase the depth of their biology syllabi with a view to contributing to the development of citizens' human potential?[5] The Kenyan Integrated Science curriculum was revised in 2022 and separates agriculture and health education from integrated science, which encompasses physics, chemistry, biology and technology.[44,45] More detailed analysis will indicate whether the revision provides better access to powerful knowledge than its predecessor. South Africa is the only jurisdiction that has not revised its syllabus since the study was conducted in 2014 and this study shows that its biology syllabus for Grades 8 and 9 adequately addresses concepts that lead to inclusive generalisations, although the sequence could be revised. Both South Africa's and Kenya's 2014 syllabi would benefit from explicit identification of unifying themes.

Biology is a small but potentially powerful component of the school curriculum because it enables access to specialist knowledge. Curriculum alone does not explain success in science. Other factors such as widespread poverty, teacher quality and professionalism, and school resources affect academic success.[17,34] Classroom pedagogies such as rote learning and whole-class teaching detract from the potential of the curriculum to enhance social equity.[8,34] Nevertheless, this study illustrates how biology is selected, sequenced and how it progresses towards powerful knowledge in different ways in four diverse jurisdictions.

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Competing interests

I have no competing interests to declare.

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