by Chris King

The international geoscience school syllabus and its development

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International organisations focussed on school-level Earth science education decided in 2012 to develop a recommended geoscience syllabus for use in countries across the world. The syllabus was developed on these initial principles: it should be based on the content of existing curricula, be well-structured, be presented as a succinct document with flexible exemplification, and be given as a list of content to be covered by the age of 16. A range of national Earth science curricula submitted by international colleagues was analysed. A first draft of the syllabus was developed from this analysis and circulated for comment; this was modified in response to feedback and recirculated; the final document was endorsed by the organisations and published on their websites in January 2014. This document has the potential to enhance Earth science education across the world, providing crucial background to those who will become the decision-makers of the future.

Background

An international survey of the school-level geoscience education across 34 countries (King, 2012, 2013) found that the compulsory Earth science content of national curricula was very variable. Following a wide invitation, the 34 countries which responded to the survey were: Argentina, Australia, Bangladesh, Belgium, Brazil, Canada, Czech Republic, England, Estonia, Finland, France, Germany, India, Indonesia, Israel, Italy, Japan, Korea, Malawi, New Zealand, Norway, Philippines, Portugal, Romania, Russia, Saudi Arabia, Scotland, South Africa, Spain, Sri Lanka, Taiwan, Trinidad & Tobago, Uruguay and the United States.

One country had no compulsory Earth science whilst in the other countries the content varied from minimal to comprehensive. Earth science was taught through science, geography or a combination of science and geography, whilst the level of teaching varied from only being at primary level to systematic coverage from primary to secondary level and beyond.

It was because of the variability of Earth science education discovered by the survey that a decision was made at meetings of the

International Geoscience Education Organisation (IGEO) and the International Union of Geological Science Commission on Geoscience Education (IUGS-COGE) held at the 34th International Geological Congress held in Brisbane, Australia in 2012, to prepare and publish a recommended syllabus for school-level geoscience education.

A previous attempt to highlight the big ideas of Earth science to be taught in school was formulated and published in the United States (Earth Science Literacy Initiative, 2010), but this was not based on existing curricula or appears to be widely known about beyond the United States.

The following account shows how syllabus was developed and published as an internal report by IGEO and IUGS-COGE (King, 2014).

Principles of syllabus development

The decision was made to base the syllabus on the content of existing Earth science curricula around the world, since such a syllabus was most likely to be widely accepted. Although the structure of the Earth science content of many of the syllabuses around the world was not readily apparent, the new International Syllabus would have clear structure. The syllabus would be presented in a very concise form, since a short syllabus would be most persuasive to future syllabus developers around the world, who were considering the incorporation of Earth science content – so the core syllabus is presented on a single page. However, this brevity may lead to misunderstanding about the meaning of some of the concepts included, so these would be exemplified in a way allowing different countries to develop different emphases to the syllabus. Such an approach would not allow educational progression to be shown – so the syllabus would simply be presented as a series of Earth science content statement for pupils to encounter by the age of 16.

The core syllabus developed on these principles is shown in Table 1 and the core syllabus with exemplification is given in Table 2.

Methodology

Members of the International Geoscience Education Organisation (IGEO) and the International Union of Geological Science Commission on Geoscience Education (IUGS-COGE) were invited to submit the syllabuses being taught in their countries, and nine countries did so (Australia, England, Japan, New Zealand, Norway,

Table 1. The International Geoscience Syllabus, to be encountered by all pupils by the age of 16 – core syllabus

By the age of 16 pupils should develop an understanding of the following:

Earth as a changing system

- Attributes open to energy, almost closed to matter, changing over time, within the solar system, comprising geosphere, hydrosphere, atmosphere, biosphere
- Interactions interaction of geosphere, hydrosphere, atmosphere, biosphere
- Feedback positive and negative
- Processes and products water cycle, rock cycle, carbon cycle
- Energy sources solar, internal

Earth is a system within the solar system, within the universe

- Origins big bang; accretion from dust; stars; planets
- The Sun only external energy source; fluctuations
- Rotational day/night, seasons, moon phases, eclipses effects

Earth is a system which has changed over time

- Geological time span, major events, relative and absolute dating methods, rates of processes

Earth's system comprises interacting spheres –

- geosphere

- Earth materials and properties minerals, fossils, sedimentary, igneous and metamorphic rocks, soil
- Earth processes and preserved characteristics surface processes, sedimentary, igneous and metamorphic processes, deformation
- Structure of the Earth and evidence crust, mantle, core, lithosphere
- Plate tectonics and evidence unifying theory, plate construction and subduction, characteristics of plate margins, mechanism, rates of movement; evidence

- hydrosphere

- Continental water location, processes of movement, uses
- Oceanic water composition, processes of movement

- atmosphere

- Composition evolution, current composition
- Flow processes of movement
- Change greenhouse effect, planetary influences, human influence, impact on sea level

- biosphere

- Evolution natural selection, fossil evidence, mass-extinction
- Impact on other systems role of biosphere in Earth systems

Earth's system produces resources

- Raw materials and fossil fuels naturally concentrated, non-renewable, uses, need careful managing (sustainable development), potentially polluting issues
- Renewable energy

Human/Earth system interactions

- Natural hazards human impact, forecasting, mitigation
- Environmental issues local to global, mitigation
- Impact on human history resource wars; migration due to climate change

Earth's system is explored through fieldwork and practical work

- Observation observation, measurement and recording
- Synthesis of observations interpretation
- Investigation and hypothesis-testing devising and implementing plans, processing data, drawing conclusions, evaluating results and communicating findings

Portugal, Scotland, South Africa and the United States of America). The existing syllabus for the International Earth Science Olympiad (IESO) was added. Meanwhile national curriculum developments were taking place in England and the United States at the time, and the documents containing recommendations on the Earth science content submitted for consideration in those developments were also included (shown with a grey background in the analysis).

A tabulated analysis of all these curricula was developed, based on the structure of the IESO syllabus. The Earth science coverage of each syllabus was added to the table, indexed by page numbers of the syllabus. A penultimate column was added to the table indicating the frequency of the items found across the syllabuses as: F = frequent (more than 4); M = moderate (3 or 4); blank = infrequent (2 or less).

The new draft syllabus was prepared on the basis of this analysis, and cross-checked with the syllabus analysis table by adding a final column, indicating that the new syllabus addressed the items identified in the survey. The results of this analysis are shown in Tables 3 - 9

and the sources of the national syllabus information used are shown in Table 10.

The draft syllabus was circulated to members of IGEO and IUGS-COGE for comment and generated thoughtful and constructive feedback about the structure, scope and detail of the draft syllabus. The syllabus was modified in the light of this feedback and the second draft was similarly circulated, generating further constructive criticism, particularly from those listed in the Acknowledgements section below.

The final draft of the syllabus was endorsed by the Senior Officers of both the IGEO and IUGS-COGE and published on their respective websites in January 2014.

Comment

At the outset of the endeavour to produce an international geoscience syllabus, the point was made that it was very easy to write such a syllabus, but much more difficult to agree the outcome with colleagues across the world. However, whilst sometimes providing

Table 2. International Geoscience Syllabus, to be encountered by all pupils by the age of 16 – core syllabus with exemplification

By the age of 16, pupils should develop an understanding of the following:		Exemplification of the core to indicate the extent of coverage (it is anticipated that this will vary from country to country)
Earth as a changing system		
• Attributes	open to energy, almost closed to matter, changing over time, within the solar system, comprising geosphere, hydrosphere, atmosphere, biosphere	<i>lithosphere/hydrosphere interaction causes coastal processes; hydrosphere/atmosphere interaction causes waves and atmospheric warming; atmosphere/biosphere interaction climatically controls vegetation; lithosphere/biosphere interaction affects soil quality; rates vary from fast to slow positive – increasing area of polar ice sheets gives increased reflection of solar energy, gives increased cooling, gives increasing area of polar ice sheets; negative – the more carbon dioxide is released into the atmosphere, the more that is absorbed in the oceans unique properties of water; evaporation, transpiration, condensation, precipitation; weathering/erosion, sedimentation, metamorphism, melting, igneous activity; photosynthesis, respiration, burial as limestone/fossil fuel, release by burning/weathering internal energy from radioactivity and energy from Earth's formation</i>
• Interactions	interaction of geosphere, hydrosphere, atmosphere, biosphere	
• Feedback	positive and negative	
• Processes and products	water cycle, rock cycle, carbon cycle	
• Energy sources	solar, internal	
Earth is a system within the solar system, within the universe		
• Origins	big bang; accretion from dust; stars; planets	<i>solar energy driving the water cycle and weather; long term fluctuations of energy from the Sun related to climate change</i>
• The Sun	only external energy source; fluctuations	
• Rotational effects	day/night, seasons, moon phases, eclipses	
Earth is a system which has changed over time		
• Geological time	span, major events, relative and absolute dating methods, rates of processes	<i>major events: 4600 million years (Ma) – formation of Earth; 3600Ma – early life; 550Ma – animals with hard parts; 250Ma – major extinction, including trilobites; 65Ma – major extinction, including dinosaurs; 1Ma ice age; dating principles: superposition, cross-cutting relationships, fossil correlation; radiometric dating; processes occur on a frequency-magnitude spectrum from continuous to catastrophic</i>
Earth's system comprises interacting spheres -		
- geosphere		
• Earth materials and properties	minerals, fossils, sedimentary, igneous and metamorphic rocks, soil	<i>definitions of: mineral, fossil, rock sedimentary rock, igneous rock, metamorphic rock, soil; minerals including: quartz, feldspar, mica, garnet, calcite, halite, gypsum, pyrite, galena; fossils including: trilobite, ammonite, dinosaur; fossilisation processes including: burial, replacement, moulds and casts, trace fossils; rock texture, porosity, permeability; sedimentary rocks including: limestone, chalk, conglomerate, sandstone, clay, shale, rock salt; sedimentary features including: layering (bedding), cross bedding, ripple marks; igneous rocks including: granite, basalt, andesite, gabbro, volcanic ash; metamorphic rocks including: slate, schist, gneiss, marble, metaquartzite (quartzite) weathering (physical/chemical), erosion, transportation, deposition, lithification, metamorphism, intrusion, extrusion, folding, faulting, jointing seismic evidence</i>
• Earth processes and preserved characteristics	surface processes, sedimentary, igneous and metamorphic processes, deformation	
• Structure of the Earth and evidence	crust, mantle, core, lithosphere	
• Plate tectonics and evidence	unifying theory, plate construction and subduction, characteristics of plate margins, mechanism, rates of movement; evidence	

Table 2 Contd....

Earth’s system comprises interacting spheres - Contd...		
- hydrosphere		
• Continental water	location, processes of movement, uses	<i>surface water, groundwater, ice caps/glaciers; infiltration, downhill flow; water resource management salinity; surface flow and waves caused by wind; deep flow due to density differences caused by temperature and salinity</i>
• Oceanic water	composition, processes of movement	
- atmosphere		
• Composition	evolution, current composition	<i>outgassing by early volcanic activity; nitrogen, oxygen, trace gasses including water vapour and carbon dioxide</i>
• Flow	processes of movement	<i>unequal heating of Earth, flow due to density differences caused by temperature, oceanic heat source temperature graphs over different time spans; link between temperature change and sea level</i>
• Change	greenhouse effect, planetary influences, human influence, impact on sea level	
- biosphere		
• Evolution	natural selection, fossil evidence, mass-extinction	<i>palaeogeographical effects on evolution; mass-extinction by volcanic activity and impact biological weathering; biological deposition</i>
• Impact on other systems	role of biosphere in Earth systems	
Earth’s system produces resources		
• Raw materials and fossil fuels	naturally concentrated, non-renewable, uses, need careful managing (sustainable development), potentially polluting issues	<i>oil/gas; metal ores; bulk raw materials; local examples of mining/quarrying</i>
• Renewable energy		<i>low pollution, cost, regularity of supply</i>
Human/Earth’s system interactions		
• Natural hazards	human impact, forecasting, mitigation	<i>eruption; earthquake; tsunami; landslide global human impact (causing erosion, pollution, drainage-changes mining/quarrying); burning fossil fuels and greenhouse effect</i>
• Environmental issues	local to global, mitigation	
• Impact on human history	resource wars; migration due to climate change	
Earth’s system is explored through fieldwork and practical work		
• Observation	observation, measurement and recording	<i>environment of rock-formation; geological history; environmental issues</i>
• Synthesis of observations	interpretation	
• Investigation and hypothesis-testing	devising and implementing plans, processing data, drawing conclusions, evaluating results and communicating findings	

Table 3. Matrix of coverage by current school-level Earth science syllabuses – geoscience skills and abilities

Matrix developed from current syllabuses (and recommendations – US and England)															
* Note for Tables 3 - 9: Curriculum recommendations shown in grey columns – not yet implemented															
** Note for tables 3 - 9: F = frequent (more than 4); M = moderate (3 or 4); blank = infrequent (2 or less)															
Statements – derived from the IESO syllabus		IESO	Austra- lia N/C	England N/C	Japan N/C	New Zealand N/C	Norway N/C	Scotland N/C	South Africa N/C	US stan- dards	Portugal N/C	* US frame work	* England rec.	** Fre quency	Covered by proposal
Details of syllabuses		IESO syllabus Page nos.	Australian Curriculum, Science	English National Curriculum S=science, G=geography	Japanese ‘Geoscience basics’ and ‘Geoscience’ syllabuses	New Zealand Curriculum in Geoscience	Norwegian geoscience syllabus	Scottish ‘Curriculum for Excellence’	South African ‘Natural Sciences’ & ‘Social sciences’ syllabuses	US science education standards S = standards, 1996	Personal communication, Luis Marques and Clara Vasconcelos	US science education standards F = Framework, 2012	English recommendations to the Department for Education	Frequency of statement F = frequent M = moderate blank = infrequent	Covered by syllabus proposal C = core; E = exemplars
Geoscience skills and abilities															
	three dimensional thinking	4									X				
	thinking on different timescales including deep time	4									X	F2, F3		M	C
	thinking at different scales, from microscopic to global										X	F3			
	cyclic thinking	4									X				
	systems thinking	4									X	F 3		M	C
	field skills	4		G, KS3 104, 107					SS 48		X			M	C
	construction of a geological history	4									X	F2, F3		M	C

Table 4. Matrix of coverage by current school-level Earth science syllabuses – the geosphere

Statements – derived from the IESO syllabus			IESO	Australia N/C	England N/C	Japan N/C	New Zealand N/C	Norway N/C	Scotland N/C	South Africa N/C	US standards	Portugal N/C	* US frame work	* England rec.	** Frequency	Covered by proposal
The Geosphere			6	4												
Earth materials	Minerals		7	3				S6	S17						M	C
		quartz	7									X				
		orthoclase	7									X				
		plagioclase	7									X				
		biotite	7									X				
		muscovite	7									X				
		garnet	7													
		calcite	7									X				
		clay	7													
		halite	7													
		gypsum	7													
		pyrite	7													
	Soil		7		S, KS2 11				S17					✓	M	C
		soils have properties of color and texture, capacity to retain water, and ability to support growth of plants, including those in our food supply								NS 69	S1					
		soil consists of weathered rocks and decomposed organic material from dead plants, animals, and bacteria. Soils are often found in layers								NS 70	S2					E
										NS 70	S2					E
	Rock		7		S, KS1 5 & S, KS2 11			S6	S17						M	C
		texture			S, KS2 11					NS 69		X			M	E
		permeability			S, KS2 11											
	Sedimentary rocks		7	3						NS 70		X		✓	F	C
		limestone	7									X				
		chalk	7													
		chert	7													
		clay	7													
		marl	7													
		dolomite	7													
		sandstone	7									X				
		phosphorite	7													
		gypsum	7													
		rock salt	7									X				

Table 4. Contd...

Statements – derived from the IESO syllabus		IESO	Austra- lia N/C	England N/C	Japan N/C	New Zealand N/C	Norway N/C	Scotland N/C	South Africa N/C	US stan- dards	Portugal N/C	* US frame work	* England rec.	** Fre quency	Covered by proposal
	Igneous rocks	7	3						NS 70		X		✓	F	C
	granite	7									X				
	rhyolite	7													
	obsidian	7													
	basalt	7									X				
	andesite	7													
	gabbro	7													
	tuff	7													
	Metamorphic rocks	7	3						NS 70		X		✓	F	C
	schist	7									X				
	gneiss	7									X				
	marble	7													
	metaquartzite (quartzite)	7													
	Fossils	7											✓		
	various forms of fossilisation fossils provide evidence about the plants and animals that lived long ago and the nature of the environment at that time	7							NS 63, 70, 72	S1, S2	X X			M	E
	mass extinction								NS 65		X				
Rock structures															
	Sedimentary textures/ structures/ features	7									X				
	layering (bedding)	7			1, 2						X			M	E
	graded bedding	7													
	cross bedding	7													
	ripple marks	7													
	discontinuity planes	7													
	Igneous textures/ structures/ features	7													
	porphyritic	7													
	pegmatitic	7													
	scoria	7													
	volcano	7									X				
	lava flow	7									X				
	dyke	7													
	sill	7													
	Metamorphic textures/ structures/ features	7									X				
	foliation	7													
	lineation	7													
	Structural features	7													
	fold	7									X				
	fault	7									X				

Table 4. Contd....

Statements – derived from the IESO syllabus		IESO	Australia N/C	England N/C	Japan N/C	New Zealand N/C	Norway N/C	Scotland N/C	South Africa N/C	US standards	Portugal N/C	* US frame work	* England rec.	** Frequency	Covered by proposal
Earth processes										X					
	Sedimentary processes						GX4						✓		
		weathering		S, KS3 211							X	F2, F3	✓	M	E
		erosion		G, KS2, 3					NS 69		X	F2, F3	✓	F	E
		deposition		G, KS2, 3					NS 69		X				
		lithification							NS 69						
		landscape formations by glaciers					GX4								
	Fossilisation processes		7								X				
	Igneous processes			S, KS3 211	2		GX4				X		✓	F	C
		volcanic activity			1						X				
	Metamorphic processes			S, KS3 211	2		GX4						✓	M	C
	Deformation processes										X	F2			
		stress fields influence rock	7												
		tensional processes	7								X				
		compressional processes	7								X				
		shear processes													
		earthquakes			1,2						X	F2			
	Past processes										X				
		Earth processes today are similar to those that occurred in the past. Earth history is also influenced by occasional catastrophes								S2	X				
Geological time															
	Deep time		3, 4	4								F2		M	C
		the solar system formed 4.6 billion years ago								S3	X				
		evidence for one- celled forms of life —the bacteria — extends back more than 3.5 billion years								S4	X				
		punctuated by a series of key events									X	F3			

Table 4. Contd....

Statements – derived from the IESO syllabus		IESO	Austra- lia N/C	England N/C	Japan N/C	New Zealand N/C	Norway N/C	Scotland N/C	South Africa N/C	US stan- dards	Portugal N/C	* US frame work	* England rec.	** Fre quency	Covered by proposal
	Relative dating					2									
	using rock strata						GX4			S3	X	F2	✓	F	E
	using fossils						GX4			S3	X	F2		M	E
	using tree rings and ice cores											F2			
	Absolute dating					2									
	by radioactive decay of isotopes						GX4			S3		F3	✓	M	E
Structure of the Earth															
	Characteristics														
	shape and size of the Earth				1						X				
	Earth magnetism				1						X				
	Layers	6			1					S1	X			M	C
	crust								NS 71		X	F3	✓	M	C
	mantle								NS 71		X	F3	✓	M	C
	core	6							NS 71		X	F3	✓		
	lithosphere								NS 71	S1	X			M	C
	evidence for Earth's structure (probes, seismic, magnetic, geological)										X	F3			
Earth cycles															
	Cyclic processes														
	transition between reservoirs where form changes but total amount of matter remains constant	6								S3			✓	M	C
	feedback (positive and negative)	6										F3	✓	M	C
	tight coupling of systems	6											✓		
	rates vary from fast to very slow	6	3						NS 69	S1		F2		F	E
	Earth systems	6	4			2				S3		F3	✓	F	C
	lithosphere	6	4						NS 71			F3	✓	F	C
	hydrosphere	6	4						NS 71			F3	✓	F	C
	atmosphere	6	4						NS 71			F3	✓	F	C
	biosphere	6	4									F3	✓	M	C

Table 4. Contd....

Statements – derived from the IESO syllabus		IESO	Australia N/C	England N/C	Japan N/C	New Zealand N/C	Norway N/C	Scotland N/C	South Africa N/C	US standards	Portugal N/C	* US frame work	* England rec.	** Frequency	Covered by proposal
Earth cycles															
	Earth systems														
	interactions and cycles within and between Earth's spheres		4										✓		
	the many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth's surface and the life that exists on it									S3		F6	✓	M	E
	Earth energy sources	6													
	solar energy	6							NS 71	S3	X	F3		F	E
	internal energy (including radioactive decay)	6								S3		F3			
	gravitational energy from the Earth's original formation.									S3					
	Rock cycle	6		S, KS3 211						S2	X			M	C
	Plate tectonic cycle	6	4	S, KS4 225	2						X			F	C
	lithospheric plates constantly move at rates of centimetres per year in response to movements in the mantle. Major geological events, such as earthquakes, volcanic eruptions, and mountain building, result from these plate motions.				1				NS 71	S1	X		✓	F	C
	tectonic processes continually generate new ocean seafloor at ridges and destroy old seafloor at trenches											F3	✓		

Table 4. Contd....

Statements – derived from the IESO syllabus			IESO	Australia N/C	England N/C	Japan N/C	New Zealand N/C	Norway N/C	Scotland N/C	South Africa N/C	US standards	Portugal N/C	* US frame work	* England rec.	** Frequency	Covered by proposal
		continental rocks (eg >4 billion years old), are generally much older than rocks on the ocean floor (<200 million years old)											F3			
		motions of the mantle and its plates occur primarily through thermal convection								NS 71	S3		F3	✓	M	
		the locations of mountain ranges, deep ocean trenches, ocean floor structures, earthquakes, and volcanoes occur in patterns.								NS 71		X	F4	✓	M	E
		most earthquakes and volcanoes occur in bands that are often along the boundaries between continents and oceans.										X	F4	✓	M	E
		major mountain chains form inside continents or near their edges											F4	✓		
		plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geological history		4									F4	✓	M	C
	Carbon cycle		3	4					S5		S3			✓	M	C

Table 5. Matrix of coverage by current school-level Earth science syllabuses – the hydrosphere

Statements – derived from the IESO syllabus		IESO	Australia N/C	England N/C	Japan N/C	New Zealand N/C	Norway N/C	Scotland N/C	South Africa N/C	US standards	Portugal N/C	* US frame work	* England rec.	** Frequency	Covered by proposal
The hydrosphere		8	4												
Water		8													
	water cycle (transpiration, evaporation, condensation and crystallization, and precipitation as well as downhill flows on land)		3			3		S5	NS 70	S2		F5	✓	F	C
	the geosphere, hydrosphere, atmosphere and biosphere are tightly coupled	8										F3			
	natural water composition is affected by geological processes	8													
	water's unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy; transmit sunlight; expand upon freezing; dissolve and transport materials; and lower the viscosities and melting points of rocks	8				4						F5		M	E
	water availability is affected by atmospheric and geological processes	8										F5			
	the amount of water for human consumption is limited	8													
	water resources need to be carefully managed								NS 70						
	flood	8					GX4						✓	M	
	drought			G, KS2, 3			GX4								
Oceanic water		8													
	oceanic water composition affected by geological processes	8				4									
	the composition of oceanic water evolved over geological time	8											✓		
	ocean currents are the result of unequal heating of the Earth and salinity differences	9			1							F5	✓	M	C
	the ocean exerts a major influence on weather and climate by absorbing energy from the sun, releasing it over time, and globally redistributing it through ocean currents.				2	2, 4						F5		M	E
	tsunamis	8													
	tides														
	storms (hurricane and typhoons)	8													

Table 6. Matrix of coverage by current school-level Earth science syllabuses – the atmosphere

Statements – derived from the IESO syllabus		IESO	Australia N/C	England N/C	Japan N/C	New Zealand N/C	Norway N/C	Scotland N/C	South Africa N/C	US standards	Portugal N/C	* US frame work	* England rec.	** Fre quency	Covered by proposal
The atmosphere		8	4												
Composition		9													
	the geosphere, hydrosphere, atmosphere and biosphere are tightly coupled	9													
	the composition of the early atmosphere was from gases omitted by volcanic activity	9													
	the composition of the atmosphere has evolved over geological time	9		S, KS4 225									✓	M	C
	evolution of the composition of the atmosphere is tightly linked to evolution of life on Earth	9								S4			✓		
	the modern atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapour					4		S5	NS 71	S2			✓	F	C
	the atmosphere protects the earth from harmful radiation and from most objects from outer space that would otherwise strike the Earth's surface								NS 71						
Flow		9													
	the foundation for Earth's global climate system is the electromagnetic radiation from the sun as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems and this energy's re-radiation into space.				1	2	SS8					F6		M	C
	Earth's axial tilt causes differential intensity of sunlight on different areas of Earth									S3		F2			
	atmospheric flows are the result of unequal heating of the Earth	9			1, 2					S3			✓	M	E
Change															
	climate change	1, 2		G, KS3 106				S5					✓	M	C
	global climate is determined by energy transfer from the sun at and near the earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover and the Earth's rotation, and static conditions such as the position of mountain ranges and oceans	S3					GX4								

Table 6. Contd....

Statements – derived from the IESO syllabus		IESO	Austra- lia N/C	England N/C	Japan N/C	New Zealand N/C	Norway N/C	Scotland N/C	South Africa N/C	US stan- dards	Portugal N/C	* US frame work	* England rec.	** Fre quency	Covered by proposal
Change	cyclical changes in the shape of Earth's orbit around the sun, together with changes in the orientation of the planet's axis of rotation, both occurring over tens to hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on Earth. These phenomena cause cycles of ice ages and other gradual climate changes					2						F2			
	greenhouse gases in the atmosphere absorb and retain the energy radiated from land and ocean surfaces, thereby regulating Earth's average surface temperature and keeping it habitable.						S8					F5	✓	M	C
	climate change can occur when certain parts of Earth's systems are altered. Geological evidence indicates that past climate changes were either sudden changes caused by alterations in the atmosphere; longer term changes (e.g., ice ages) due to variations in solar output, Earth's orbit, or the orientation of its axis; or even more gradual atmospheric changes due to plants and other organisms that captured carbon dioxide and released oxygen. The time scales of these changes varied from a few to millions of years											F6			
	changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate											F6			
	if Earth's global mean temperature continues to rise, the lives of humans and other organisms will be affected in many different ways							S5				F8			
	global climate models are often used to understand the process of climate change											F8			

Table 7. Matrix of coverage by current school-level Earth science syllabuses – the biosphere

Statements – derived from the IESO syllabus		IESO	Austra- lia N/C	England N/C	Japan N/C	New Zealand N/C	Norway N/C	Scotland N/C	South Africa N/C	US stan- dards	Portugal N/C	* US frame work	* England rec.	** Fre quency	Covered by proposal
The biosphere			4												
Interactions															
	the evolution and proliferation of living things over geological time have in turn changed the rates of weathering and erosion of land surfaces, altered the composition of Earth's soils and atmosphere, and affected the distribution of water in the hydrosphere.	3, 6										F6			
Evolution				5											
	fossils provide evidence for evolution								NS 63				✓		
	evolution is shaped by Earth's varying geological conditions											F7	✓		
	sudden changes in conditions (e.g., meteor impacts, major volcanic eruptions) have caused mass extinctions, but these changes, as well as more gradual ones, have ultimately allowed other life forms to flourish											F7			
	evidence for theories that explain the diversity of life on Earth and evolution		5										✓		

Table 8. Matrix of coverage by current school-level Earth science syllabuses – the solar system

Statements – derived from the IESO syllabus		IESO	Austra- lia N/C	England N/C	Japan N/C	New Zealand N/C	Norway N/C	Scotland N/C	South Africa N/C	US stan- dards	Portugal N/C	* US frame work	* England rec.	** Fre quency	Covered by proposal
The solar system											X				
Planetary system			10				3								
	the star called the sun is changing and will burn out over a life span of approximately 10 billion years									S3		F1			
	Earth rotation, day/night, daily/seasonal changes, phases of moon		1, 3		2		S4, S6	S6	NS 69	S1, S2, S3		F2	✓	F	C
	eclipses		3							S2		F2		M	C
	tides									S2		F2			
	Earth systems are a subset of planetary systems	10													
	energy balances of planets include external (solar) energy and internal energy	10													
	the solar system has evolved over			S, KS											
	time			4 225											

Table 9. Matrix of coverage by current school-level Earth science syllabuses – environmental geoscience

Statements – derived from the IESO syllabus		IESO	Australia N/C	England N/C	Japan N/C	New Zealand N/C	Norway N/C	Scotland N/C	South Africa N/C	US stand- ards	Portugal N/C	* US frame work	* England rec.	** Fre quency	Covered by proposal
Environmental geoscience															
	global distribution of resources depends upon past geological processes												✓		
	the environment is part of a cyclic world formed of sub-systems (geosphere, hydrosphere, atmosphere and biosphere) that coexist	2													
	humans are an integral part of the natural system	2		S, KS3 211 & G, KS3 103		4						F3		M	C
	all materials, energy, and fuels that humans use are derived from natural sources, and their use affects the environment in multiple ways.								NS 72		X	F7		M	C
	the effects of human activity on the environment			S, KS4 225					SS 88		X				
	explain how crude oil and natural gas have come about and how these substances are used						S8	S4							
	all forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks, as well as benefits						SS9	S4	SS 92/3		X	F7		F	C
	sustainable development		3	S, KS3 212 & G, KS3 103			S8	S4, G6	NS 58/9, SS 92		X	F8	✓	F	C
	renewable and non-renewable resources		3	S, KS3, 212			S8	S4	NS 67, 72			F6	✓	F	C
	environmental problem identification and suggestion of solutions	4	2						G6			X	F8		F C
	the cause of natural disasters, including earthquakes, tsunamis and volcanic eruptions		2			2, 4	GX4		G6	SS 89		X		✓	F C
	natural hazard forecasting and mitigation	5					GX4						F7		M C

Table 10. Sources of information for the matrix of coverage by current school-level Earth science syllabuses given in Tables 3 - 9.

Curriculum	Submission by:	Source details
International EarthScience Olympiad	Syllabus submitted by Nir Orion, Israel	International Earth Science Olympiad (IESO) syllabus, IESO website: http://ieso2012.gl.fcen.uba.ar/index.php/ieso-downloads/syllabus/
Australia	One document précised and submitted by Bronte Nichols, others submitted by Ian Clark and Greg McNamara	‘Australian Curriculum Science: Summary of Earth and Space Science strand; prepared by Bronte Nicholls’ Australian Curriculum, F – 10 Curriculum: Science. Found at: http://www.australiancurriculum.edu.au/Science/Curriculum/F-10
England	Chris King	Geography at KS2 (7-11 year olds): https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/239044/PRIMARY_national_curriculum_-_Geography.pdf Geography at KS3 (11-14 year olds): https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/239087/SECONDARY_national_curriculum_-_Geography.pdf Science at KS1 and 2 (5-11 year olds): https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/239132/PRIMARY_national_curriculum_-_Science.pdf Science at KS3 (11-14 year olds): https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/335174/SECONDARY_national_curriculum_-_Science_220714.pdf Science at KS4 (14-16 year olds): https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/319108/National_Curriculum_Reform_England_Key_Stage_4_Science_consultation_document.pdf%204.pdf King, C. & Bilham, N. (2012) Towards a balanced Earth science Curriculum for England – science and geography perspectives. <i>Teaching Earth Sciences</i> 37.1, 45-48.
Japan	List of national curriculum content submitted by Ken-ichiro Hisada, Japan	‘Geoscience Basics’ and ‘Geoscience’ syllabuses.
New Zealand	Specially prepared document submitted by Glenn Vallender, New Zealand	‘Summary of the New Zealand curriculum in science’ based on the National Curriculum documents available on the following internet pages: http://nzcurriculum.tki.org.nz/Curriculum-documents/The-New-Zealand-Curriculum
Norway	Documents submitted by Merethe Frøyland and Kari Remmen, Norway	Natural science subject curriculum. Found by searching for “Natural science subject curriculum” Norway, on a search engine (‘S’ in Tables 3-9) Social studies subject curriculum [including geography]. Found by searching for “Social studies subject curriculum” Norway, on a search engine (‘SS’ in Tables 3-9) Geosciences – programme subject in programmes for specialisation in general studies. From: http://horselshemmet.vilbli.no/?Lan=3&Program=V.ST&Side=1.2.1&Fag=V.GFG1-01 (‘GX’ in Tables 3-9 – GX is studied by all secondary students)
Scotland	Chris King	Curriculum for excellence; sciences – experiences and outcomes. From: http://www.educationscotland.gov.uk/learningteachingandassessment/curriculumareas/socialstudies/eandos/index.asp (indicated as ‘S’ above) Curriculum for excellence; social studies – experiences and outcomes. From: http://www.educationscotland.gov.uk/learningteachingandassessment/curriculumareas/sciences/eandos/index.asp (indicated as ‘G’ above)
South Africa	Documents submitted by Ian McKay, South Africa	Department of Education (2002) <i>Revised national curriculum statement for grades R – 9 (schools): Natural sciences</i> . D of E, Pretoria. ISBN: 1-919917-48-9. (‘NS’ in Tables 3-9) Department of Education (2002) <i>Revised national curriculum statement for grades R – 9 (schools): Social sciences</i> . D of E, Pretoria. ISBN: 1-919917-47-0. (‘SS’ in Tables 3-9)
United States of America	Documents précised and submitted by Mary Dowse, USA	National Science Education Standards (1996) National Academy Press: Washington DC (‘S’ above) A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (2012), National Academies Press http://www.nap.edu/catalog.php?record_id=13165 (‘F’ in Tables 3-9)
Portugal	Information provided by Luis Marques and Clara Vasconcelos	Personal communication

contrasting points of view and suggesting different approaches and content, colleagues were very constructive, understanding and supportive, with the results shown in Tables 1 and 2.

With this international consensus, it is to be hoped that this curriculum document can be used by curriculum developers, geoscience educators, geoscientists and science and geography educators across the world to develop coherent, well-structured curriculum content in Earth science, flexible enough to be developed in national contexts and therefore with clear relevance to those involved. This then will have the potential to improve teaching and learning in Earth science internationally, developing understanding of the past, present and future of our globe whilst providing crucial background education to the decision-makers of the future.

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