What Every Student Ought to Know About the Ocean
A Compilation of Key Concepts

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Introduction

The national education standards for teaching science provide little guidance for teaching about the ocean and atmosphere. As a result, information about the oceans, atmospheres, and hydrology are usually taught in separate, unconnected modules. Worse, many texts include much trivia, neglecting the most important issues.

To provide teachers with better guidance, we have outline what, in our opinion, every high-school student ought to know about the oceans on graduation.

The following is our preliminary document listing key concepts in oceanography. The document is open for comments and revisions by all who are interested in teaching oceanography. What is appropriate, what is not? Is the list complete? At what level should the different concepts be taught?

Regarding Earth System Science

1. "We are not merely inhabitants of a planet, adapting ourselves to it. Life has verily constructed the planet. It would not behave as it does, even in its deep interior, were it not for life." [Most of that life was in the ocean.] —Oldroyd (1996: 297)
2. Earth processes are the result of many different, interacting biological, chemical, and physical systems, many of which are strongly influenced by the ocean.
3. The ocean stabilizes climate and makes the Earth habitable, sending moist winds to bring rain to the vegetation on land.
4. Because we are now geologic agents capable of interfering with the processes that make Earth a habitable planet, we have become custodians of planet Earth.

Regarding Physical Geography

1. The ocean covers 70 percent of Earth's surface and is on average 4 km deep.
2. The continents are surrounded by shallow shelf seas, from 0 to 100 m deep.
3. There is only one ocean, and all its parts are interconnected. The largest part is the Pacific, which is half of the ocean. The rest are the Atlantic, Indian, Antarctic, and Arctic Ocean.
4. The location of important seas: Japan Sea, the Sea of Okhotsk, the Bering Sea, the Gulf of California, the Caribbean Sea, the Gulf of Mexico, the Hudson Bay, the Norwegian

Sea, the North Sea, the Mediterranean, the Black Sea, the Caspian Sea, the Arabian Sea, the Red Sea, the Persian Gulf, and the Bay of Bengal.
5. The locations of some of the most important currents: Where the Gulf Stream flows and that it moves heat into the northern North Atlantic. Where the California Current flows, and that it brings cold water all the way down to the shores of Baja California. The location of the subtropical gyre, north and south equatorial currents, and Alaskan Gyre.
6. Sea level is lower by 70 m than it would be if there were no ice caps.

Regarding Chemistry

1. Chemical studies of the distribution of isotopes and trace chemical in water and sediments is leading to a new understanding of climate change over the past hundreds to hundreds of million years.
2. Ocean water contains about 36 grams of salt (dissolved material) per kilogram of sea water (3.6% by weight). The ratio is called salinity.
3. The main ingredients of sea salt are sodium and chlorine.
4. Elements required for life that are in limiting supply in the ocean are phosphorus, nitrogen, silicon and iron.
5. Salinity varies little, but is slightly higher in regions of evaporation and slightly lower in rainy regions, and near the mouth of rivers.
6. The salt in sea water increases the water density by 3.6%, it lowers the freezing point to -2 degrees C, so the the most dense water is at the freezing point, it greatly increases the conductivity, so sea water is a good conductor, and it alters osmotic pressure.

Regarding Biology

1. In contrast with the land, the ecology of the ocean is microbe based. A large fraction of the biomass and biological activity in the ocean is microscopic, and it is an important part of earth's carbon cycle. There are more bacteria in the ocean than stars in the known universe, and there are a thousand times more viruses than bacteria. Yet we know little about the microbial ecology of the ocean because only one tenth of one percent of the bacteria have ever been cultured.
2. There are a million bacteria of a thousand different types in a milliliter of sea water.
3. There are more viruses in sea water than all organisms combined, and they are a normal, essential, and integral part of the food web.
4. The entire ocean food web relies on photosynthesis by phytoplankton, single-celled, microscopic bacteria and protists living in the in the upper 200 meters of the ocean, that turn carbon dioxide, nutrients, and sunlight into organic matter.
5. About half of the photosynthesis (net primary productivity) on earth occurs in the ocean.
6. The burial of organic carbon, mostly in the oxygen-poor areas of the ocean and in marshes and swamps along the sea, maintains the oxygen in the atmosphere over millions of years.
7. The oceanic food web is micro-centric. The traditional “diatom-copepod-fish” food chain has been expanded to include a vast microbial food web whose ecology is only poorly known.

8. Bacteria are a critical part of the marine food web, processing more than half of all the flow of organic carbon.
9. Photosynthesis in the ocean is for the most part limited by the availability of light, N, P, Si, and Fe.
10. Nutrients in surface waters tend to have the highest concentrations along coasts, in shallow seas, and along the equator, and they are much less abundant elsewhere.
11. The deep ocean is filled with life, of great diversity, most of which depends on the rain of carbon from above.
12. There are deep ocean ecosystems that rely on chemosynthesis... that is using chemical energy from hydrothermal vents to synthesize organic carbon.
13. High levels of nutrients due to coastal pollution cause increased productivity, which in turn can cause oxygen depletion in the water and "dead zones."
14. Coral reefs are among the most diverse and productive communities on earth (Turner), they are the richest of the tropical marine habitats, they are an important part of the tropical ocean ecosystem, they protect the shore inland of the reefs from storm waves, tsunamis, and erosion, and they are a beautiful example of how life creates planetary structures.
15. Almost all coral reefs on earth have been altered by human activity. Many have been severely degraded, some have been destroyed. (Pandolfi et al, 2003)
16. Overfishing and pollution are the primary causes of coral reef decline. In addition, the recent rise in sea-surface temperatures in many areas has caused coral bleaching, and the increased CO2 in the atmosphere, and hence in surface waters, is causing dissolution and decline of the reefs.
17. Each transfer to a higher level in the food chain is only efficient 10% by mass.
18. There are typically between 2 and 5 transfer steps from the phytoplankton to large fish. The shortest chain is in upwelling regions, the longest in the open ocean.
19. The abundance of fishes depends on these food chain properties.
20. Students should know some common examples of sea life. They should know the three domains of life: the archea, the eubacteria (bacteria) such as prochlorococcus, and the eucaryotes. For single-celled eucaryotes, they need to know coccolithophorids , diatoms, and dinoflagellates. For protozoans: copepods, euphausids, tintinnids, and the fact that larvae of all major types are present. They need to know that the major large-animal phyla are arthropods, chordates and mollusks. They should know that major multi-cellular organisms are grouped into sponges, cnidarians (corals, jellyfish), echinoderms (starfish, sea urchins), a number of worms (e.g., polychaetes), arthropods (pill bugs, crabs, shrimps), mollusks (squids and octopuses, clams and mussels, snails and slugs) and chordates (sea squirts -- with a tadpole-like larva -- jawless fishes, sharks and rays, bony fishes, snakes and turtles, sea birds, sea mammals). Among the mammals, they need to know that there are whales, sea cows and seals. For whales, they need to distinguish baleen whales from toothed ones.

Regarding Physics

1. Steady winds produce currents. Variations from region to region in the force of the steady winds create geostrophic currents (The currents shown on maps and in textbooks).

2. The top 100 meters of most of the ocean is warmed by the sun, and below that is a vast pool of very cold water that fills the ocean basins.
3. The cold water is formed at high latitudes where seawater is cold and salty, and it sinks to fill the ocean basins. The sinking of cold water at high latitudes in the North Atlantic is an important part of the world-wide "conveyor belt" that transports water and heat around the world.
4. Light can reach only about 130 meters into the clearest water, (the depth where the light intensity is 1% of its value at the surface) and only a few meters into turbid water close to shore, limiting the depths where warming and photosynthesis can occur (Jumars, 1993: 136). The sunlit surface layer is called the daylight (euphotic) zone. Below this there is no sunlight, the very cold midnight zone.
5. Winds and currents mix the upper ocean.
6. The moon and the sun are responsible for making tides, causing sea level to rise and fall every 12 to 24 hours depending on location along the shore.
7. Winds make waves, and storm winds make big waves that can travel great distances.
8. Tsunamis are generated by earthquakes. Big earthquakes can generate waves that cause major damage far away from the earthquake region.

Regarding Economics

1. Most of the economic resources worth considering, mainly a wealth of oil and gas and some fish, are on the shelf and in the continental slope.
2. Much of the trade of the world goes over the ocean.
3. Economic activity along the coast causes pollution and this conflicts with recreational values.
4. The total value of fish landed in the US is only about 4% of the total value of livestock and poultry raised on the land in the US.

Regarding the Law

1. The solutions to serious environmental problems will elude us unless we are all aware of, and respect the profound differences between the world of science and human affairs (See also Hardin, 1968 and 1998, in which he notes that most environmental problems have no technical solution).
2. All countries control access to resources within 200 nautical miles of their shores. This area is called the Exclusive Economic Zone. All ships have the right to free passage through this zone.
3. The largest expansion of territory under US sovereignty occurred when President Reagan issued Proclamation 2030 on March 10, 1983 declaring a 200 mile economic zone for the United States. The proclamation doubled the size of the country. It opened up 3.4 million square miles of new territory, six times the size of the Louisiana Purchase, and 30% larger than the land in the continental US. (Helvarg, 2003: 2; and Wilder, 1998: 81).
4. All countries control all activity within three nautical miles of their shores, their territorial waters.
5. The United Nations Convention on the Law of the Sea, which came into force on 16 November 1994, sets forth navigational rights, territorial sea limits, economic

jurisdiction, legal status of resources on the seabed beyond the limits of national jurisdiction, passage of ships through narrow straits, conservation and management of living marine resources, protection of the marine environment, a marine research regime, and a binding procedure for settlement of disputes between States. The US Senate has not ratified the convention.

Regarding Marine Geology and Geophysics

1. The sea floor is poorly mapped, although recent global maps based on satellite altimeter observations are much better than older maps. Still, we have better maps of Moon, Venus, and Mars than we have of the sea floor.
2. "Marine life changed the planet's appearance through its cumulatively astonishing biomineralization, which has amassed enormous volumes of carbonate sediments, and subsequent tectonic processes turned many of these sediment into Earth's most formidable mountain ranges." —Smil (2003: 230)
3. The sea floor is relatively young compared with the continents. The oldest sea floor is only about 180 million years old, while the oldest continental rocks are more than 3 billion years old.
4. The sea floor is young because plate tectonics continuously regenerates the sea floor. New sea floor is created at mid-ocean ridges and consumed in oceanic trenches.
5. Newly created sea floor is magnetized by earth's magnetic field, recording the many changes in earth's magnetic field over the past 150 million years, and providing key support for the theory of plate tectonics.
6. Crustal rocks below the sea floor cool and become denser as they move away from the mid-ocean ridges. When this cold, dense crust plunges into the mantle under trenches, it pulls oceanic crust with it, helping to drive plate motion.
7. Convection in the mantle brings hot liquid rock to the surface in hot spots such as Hawaii and Iceland.
8. Sediments in the deep ocean come primarily from the shells of microscopic marine organisms such as coccolithophores, diatoms and foraminifera, from cosmic dust (tiny meteorites), and directly precipitated from the water (manganese nodules).
9. Sediments on continental shelves come primarily from the land.
10. A volume of water equal to the volume of the ocean circulates through the sea floor and upper lithosphere in a few million years. It enters into sediments on either side of mid-ocean ridges and exits through hydrothermal vents along the crest of the mid-ocean ridge system.
11. Water circulating through the sea floor extracts minerals from the crust in a manner similar to weathering, and the minerals reach the ocean through hydrothermal vents,
12. The sea floor is not a flat plain. It has a worldwide chain of mountains, the mid ocean ridge, many old and new volcanos, many of which are below sea level, fracture zones, plateaus, and deep trenches.
13. There is more water in the ocean than fits within the ocean basins. The overflow creates the continental shelves. The volume changes over geologic time as does the extent of continental shelves and the biological productivity at the edges of the sea.

Regarding the Role of the Ocean in Weather and Climate

1. We cannot understand climate and climate change without understanding the ocean. The ocean dominates the global energy, carbon, and hydrological systems.
2. Most of the solar energy reaching earth is absorbed by the ocean.
3. The ocean lose heat primarily by evaporation, a process called latent heat release.
4. Heat lost by the ocean drives the atmospheric circulation, mostly when water vapor condenses as rain, mostly in the tropics, especially in the atmosphere above the tropical Pacific and Indian oceans. Evaporation of water from warm seas provides the energy to drive hurricanes.
5. El Niño, the most important cause of changes in global weather patterns, is the result of changes in the way heat is released to the atmosphere in the Pacific.
6. The scientific challenge of predicting El Niño is very different from the challenge of mitigating the impact of an imminent El Niño. A failure to appreciate these differences is one of the main reasons for misunderstandings between scientists and nonscientists.
7. Global climate change due to increases in carbon dioxide in the atmosphere will alter El Nino.
8. The hydrological cycle is dominated by the tropical oceans. Most of the rain that falls on land comes from the tropical oceans.
9. The ocean helps keep earth's temperature constant from day to night and summer to winter by storing and releasing heat and water.
10. Currents help carry heat from the tropics to mid latitudes.
11. Earth's climate has been very different in the past. By collecting information about past climates and climate change we are much better able to understand our present climate and how it might change as we add CO_2 to the atmosphere. (See 1. in Regarding Chemistry).
12. Forty times more carbon dioxide is stored in the ocean than in the atmosphere. The carbon cycle in the ocean and the calcite compensation depth greatly influence earth's climate.
13. Large quantities of methane (a potent greenhouse gas) is frozen in the sediments of the continental margins, posing a threat to climate if warming continues.
14. Changes in the ocean's deep circulation have produced large, rapid changes in the climate during the last 50,000 years.

Regarding Coastal Processes

1. The number of people living close to the ocean grows by about 30 million a year worldwide, putting great stress on coastal ecosystems,
2. Storm waves and currents erode the coasts, and most coasts move slowly inland at a rate of a few feet per century along rocky coats, and several meters per year along low, sandy coasts.
3. Most beach sand is carried to the coast by rivers and redistributed by currents. Damming rivers, and building structures along coasts interrupt the flow leading to increased coastal erosion.
4. The biodiversity of coastal marine areas is threatened by over exploitation and overfishing, as well as by pollution. Example include the effects of deforestation on reefs, along shores where the hinterland has forests. Alien species carried into new areas by people can upset local communities. Coastal pollutants come mostly from the land. They

include nutrients, heavy metals, trash, and pesticides carried from cities and farms by runoff and sewers.
5. Estuaries and salt marshes are important parts of the marine ecosystem. They are home to many plants and animals, and they they are the nursery for many types of coastal and open ocean invertebrates, fish, and wildlife.

Regarding Technology

1. Oceanographers are relying more and more on satellites, drifters, subsea observatories and unmanned submersibles to study the ocean. Fewer and fewer are going to sea. Most do not scuba dive.
2. Ocean-observing satellites have revolutionized our understanding of the ocean by producing global, daily to weekly maps of winds, surface currents, surface temperature, solar heating, and ocean color due to phytoplankton concentration.
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5. Thousands of drifting buoys are now measuring ocean currents, temperature, and salinity in the upper kilometer of the ocean. Thousands of large tagged fish are providing information on their location and environmental conditions.
6. The ocean is so complex oceanographers must use computer models to help understand the ocean. The models process observations; they calculate currents, temperature, and density; and they describe the interactions among systems. “Modeling has become a mainstream activity. Today’s biological oceanography student is more likely to have a model than a microscope.” (Barber and Hilting, 2000: page 19)
7. Models that combine winds, currents, and temperature are being used to produce forecasts of ocean currents many weeks in advance.

Regarding Fisheries

1. The number of large vertebrates in the ocean, including whales, seals, sharks, fish, and turtles, are only a few percent of their original, pre-industrial values (Jackson et al, 2001, Myers and Worm, 2003).
2. The large vertebrates are gone and are not recovering because they or their prey have been caught or continue to be caught by humans. There are almost 40,000 industrialized fishing vessels fishing the ocean.
3. Population growth is driving up the worldwide demand for fish, which has caused the world’s fish catch to declined since the 1980’s.
4. Marine fishes off developing countries are being overfished because the countries lack the ability to enforce fisheries laws.
5. There is an unequal competition for the ocean's fish resources, with the nations having factory ships winning, and small coastal nations using traditional fishing methods losing out.

6. A major culprit in overfishing is the industrialized, pelagic longlining, gill netting, and trawling which indiscriminately fish the ocean.
7. Regardless of gear type, unenforced fishing is unregulated fishing.
8. We get out of this mess through change in policy and science.
9. The primary goal of new policy is to control fishing effort at a sustainable level.
10. The best way to protect fish stocks is to set aside no-fishing zones and perhaps limit the gear to be used. The precautionary principle (in the absence of certain knowledge) must be used to better advantage.

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