Perceptions of Time Matter: The Importance of Geoscience Outreach

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Most people, at some time in their life, are faced with making decisions that would be better informed with basic knowledge of the interactions between the Earth's systems. This basic knowledge is critical for all people who must understand topics as diverse as the interactions between humans, their large animal symbionts, large-scale agriculture, and the Earth, including climate evolution; the availability of fresh water; issues of land use and development; preparing for natural disasters; and the supply of natural resources to support our current technological standard. Every student and adult, from grade school through university and beyond, should have a basic understanding of the ultimate complex system, the Earth. In addition, there are many opportunities to raise the awareness of the general public to the importance of geological processes at all time and length scales—from catastrophes to waste disposal to natural resource management to evolution. Increasing Earth Science literacy should be a major goal and crucial for the stewardship of the planet. All scientists should be responsible for reaching out, explaining what they do and why they think it is important in an accessible manner.

This book demonstrates that scientists and educators can teach a broad cross section of students about the Earth through diverse and innovative approaches, including field and laboratory exercises and the integration of research and education. As a geochronologist, my own philosophy of education is to make a deeper understanding of geological time central to all geoscience outreach that I do. Otherwise well-educated university students often have no concept of geological time, not because they believe in a young Earth, but because they have never been exposed to or thought about it. Time is central to any historical science from astrophysics to archeology, and I find that contrasting the timescales of post-industrial revolution monitoring of the planet to what we learn from much older records to be

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V.C.H. Tong (ed.), *Geoscience Research and Outreach: Schools and Public Engagement*, Innovations in Science Education and Technology 21, DOI 10.1007/978-94-007-6943-4_2,

a very useful exercise. Getting students involved using real data, including those collected as part of a class exercise, is essential at all levels. The simplest examples might include acquiring and interpreting data such as making temperature measurements taken at the same place and time every day to understand short- and long-term trends or monitoring and quantifying erosion of a nearby slope disturbed by human activities over a period of a few months. More complex problems could include mining and interpreting climate data of different precisions and accuracies over decades and centuries. Public policy related to sustainability and the environment should be based on data, and the world needs citizens with a basic understanding of how data are acquired, evaluated, and interpreted.

Crucial for understanding how we interact with the modern Earth and how we use Earth history to make predictions is an understanding of the timescales of geological processes. These include recurrence intervals of natural hazards such as volcanoes, earthquakes, and hurricanes, accumulation/formation/exploitation rates of fossil fuels and ore deposits, and the timescales of rapid shifts in climate from tens of thousands to hundreds of millions of years ago. Many tend to think of Earth history in terms of human timescales alone and do not always understand or comprehend the enormity of geological time. Our rapid exploitation of minerals and fossil fuels compared to the timescales for their formation should give everyone pause when we think about future generations. Integrating an understanding of time from the last century to the formation of our solar system is essential at all levels of education.

Forty to fifty percent of US citizens think that the age of the Earth is 10,000 years or younger. This is troubling when politicians and policy makers look at climate records for the past 10–50 years or less and use short-term (decadal or shorter) fluctuations in global temperature to evaluate whether or not humans have had a profound influence on climate. If climate records are extended back hundreds of thousands of years using ice cores and even millions of years using climate proxies preserved in the rock record, one can see fluctuations in greenhouse gases, global temperature, and their effects on biological evolution. However, using temporal constraints, we can calculate and compare rates of change and see that the post-industrial revolution changes in total greenhouse gas concentrations and temperature are alarmingly fast. A firm understanding of geological time and insights from the geologic record is essential for policy makers who make politically motivated decisions that can affect the quality of life of the entire planet for generations. Thus, it is imperative that we as scientists and educators do more to teach others about Earth history, deep time, and the fact that geological history can be used to better understand the impact of humans on the planet and to make predictions. In addition, we have much to learn from non-analogue or unpredictable events that may happen only once in the history of a planet. These include the oxygenation of Earth's atmosphere ca. 2.4 billion years ago, the apparently rapid diversification of animals ca. 540–525 million years ago, and the end-Permian extinction when, 252 million years ago, approximately 90 % of marine life went extinct.

It is puzzling that we find ourselves in this position, as young students are often indirectly fascinated with evolution by learning about dinosaurs as well as invertebrate fossils. Dinosaurs roamed the planet for at least 166 million years and went out with a bang 66 million years ago, making a nice contrast with the relatively short duration of human existence. It is imperative that we build on this natural attraction to include other deep time topics such as mass extinctions, global (Snowball) glaciations, the origin and rise of animals, and major perturbations to Earth's climate system. In fact, one could argue that for at least the last 580 million years, the environment has played a major role in evolutionary processes and the history of life. For example, most extinction events are linked to major changes in the environment and almost always involve climate perturbations. When we consider the changes humans have brought to the planet since the industrial revolution in the context of major events in deep time, we see that we have greatly perturbed the system.

A good example of a major climate event in deep time occurred approximately 56 million years ago, when CO_2 concentrations in the atmosphere were at least twice what they are today and global average temperatures were >5 °C warmer than today, an event referred to as the Paleocene–Eocene Thermal Maximum (PETM). The poles were ice-free and sea surface temperatures in Polar Regions were in excess of 20 °C. While an exact cause is still debated, the amount of CO_2 injected into the atmosphere over a period estimated at less than 10,000 years is comparable to the amount we will inject in a much shorter time period by consuming most of the known fossil fuels (approximately 4.5 trillion tons of carbon); rates matter!

The biological effects of the PETM were profound; deep-sea fauna suffered global extinction and some terrestrial mammals became extinct, while modern mammalian orders such as horses and primates first emerged. There were major migrations of mammals and a remarkable decrease in body mass. Mammals thrived by rapid evolutionary adaptation, although their total population was likely a small fraction of the seven billion humans we have today, not to mention large animals that live symbiotically with us (e.g., >20 billion chickens, ca. 1.5 billion cattle). Today, many humans have congregated in massive cities with complex infrastructure for distribution of food, medical care, and energy, requiring great expense to relocate. Thus, we are faced with a future that has the potential to be most unpleasant. Humans may survive most climate-induced change, but we could face massive reductions in population, destruction of much of our culture, relocation of large numbers of people due to sea level rise, and a drop in the standard of living even if we start contingency planning now. An appreciation of Earth history from the age of the Earth to the last millennium is essential for all humans to better understand what our future will be and how to plan for it.

A good teaching moment is to have students examine and plot temperature changes as a function of time, including estimates of temperature in deep time. Those who do not think humans have caused or are causing changes in global climate will often point to relatively short periods of time from, for example, last winter or summer being very cold or hot or show that temperature increases over the last 5 years are less than predicted by climate models as evidence for or against human agency. When students examine longer time periods the concept of signal vs. noise can be discussed, as can short- vs. long-term trends. While one can point to intervals in deep time when CO_2 levels and temperature changes have been dramatic, none have occurred at the *rate* we have seen since the industrial revolution.

The chapters in this volume provide exciting new approaches to teaching research-enhanced geoscience both within schools and to the public. Approaches include engaging people through field observations, using geoscience databases, and specially designed classroom and public outreach experiences on important topics that span climate evolution, seismology, and geologic time. I advocate making geological time a unifying theme for many of these topics from the timescales of observations to how the past may be used to inform the future. While many students think the Earth is 10,000 years old or younger, many others have just not thought about its age or how the age of the Earth is estimated. When asked how we know the age of the Earth, the response of many students and educated citizens is "carbon dating." While encouraging because a geochronometer is invoked, it exposes a lack of awareness of deep geological time and that ^{14}C dating is used for carbon-bearing materials that are ~50,000 years and less in age. However, this misconception can be used to segue into teaching about geochronology, half-lives, and choosing the right decay system for a problem. The discovery of radioactivity is barely 100 years old, and its application to determining the age of the Earth is without doubt one of the most remarkable accomplishments in the history of science.

Geochronology is the science of determining the ages of rocks and includes a variety of methods, from the decay of radioactive isotopes, to linking sedimentary rocks deposited in cycles to dynamical models of the solar system such as proposed by Milankovich, to using the pattern of reversals in the Earth's geomagnetic field. Geochronology can and should be taught as part of Science in primary, secondary, and postsecondary education, and it can be integrated into all aspects of teaching about the Earth system, especially using physics, chemistry, and biology. This can include rates of biological evolution and extinction from the past 100 years through to the rise of animals >580 million years ago, lifetimes of greenhouse gases in the atmosphere, temperature records over the past few 100 years, and the history of polar ice accumulations and climate over millions of years. At more advanced levels, integrating geochronology into other curricula might include demonstrating how measurement uncertainties influence our understanding of data. Involving active research groups in the educational process is a powerful way to provide role models and communicate the excitement of data gathering, interpretation, and hypothesis testing.

As part of the EARTHTIME initiative (www.earth-time.org), I led development of an outreach program on geochronology and how it can be used to develop a time line for Earth history (see Chapter "EARTHTIME: Teaching geochronology to high school students in the US" by Bookhagen et al.; this volume) with a hands-on approach. This program has been taught to junior high and high school students and covers basic physics of radioactive decay and how we actually date minerals to why we care about the ages of rocks and what caused major events in Earth history such as mass extinctions. Students enjoy the hands-on aspect and ask many questions related to everything from climate to the origin of the solar system. Many schools do not seem to have the time or resources to make this part of their formal curriculums although this program shows them it can easily be done. I consider it our responsibility as educators to ensure that preuniversity students are exposed to the concept of geological time and Earth history as context for our own existence.

Teaching geoscience necessarily involves the integration of biology, physics, chemistry, and math to better understand geologic processes. A good way to capture the attention of students of all ages is to use the latest data and controversies, “torn” from newspaper headlines and the latest journal articles. The instructors do not have to be active researchers in order to use data and ideas from the literature to stimulate their students. Time is central to geoscience and can be integrated in any discussion or lecture.

In summary, better science education from elementary school through adult learning is the only way to ensure stewardship of the planet for future generations. I advocate making geological time central to all geoscience outreach. Our planet’s future depends on fostering a deep appreciation for the short timescale humans have existed with what we know about evolution and climate evolution on timescales of millions to billions of years. Ultimately, the key is to think not just about change but rates of change—and when we do, we see just how fragile a place we inhabit.