Preparing K-12 Educators with a Holistic Reverse Engineering Approach to Exploring Planet Earth (Work in Progress)

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Abstract

Engineering and education students assist in the development of a virtual lab experiment to test hypotheses about the origin and nature of planet Earth. It takes the form of a retrodictive thought experiment or reverse engineering project. The experiment is proposed for a general education earth and space sciences lab course which is regularly taken by future K-12 educators. This project satisfies accreditation requirements for both the College of Education and the School of Engineering. Education students require additional exposure to engineering concepts that they can subsequently take into the K-12 classroom [1]. Engineering students need practice in designing experiments and communicating effectively with a range of audiences [2]. In addition, appropriate content and limits are suggested for teaching at three possible educational levels: elementary, middle school, and high school. This virtual thought experiment [3] is part of a larger effort to develop a new lab manual for earth science courses that will include a variety of more holistic engineering-related lab experiments [4].

A novel feature of this experiment is its holistic approach to understanding the history and nature of Earth. Teacher candidates (and other undergraduate students) are required to investigate the processes by which the planet is thought to have arisen, and the natural laws that govern these processes. They explore the age of the earth and the measurements and calculations that feed into this conclusion, along with the conditions that have led to the evolution of biological complexity. They examine the relational features (affordances) of the Earth, its solar system, and the universe as a whole that result in such unique long-term habitability. But due to humanity's historic tendency to posit a Creator for the Earth, they are also required to consider their own personal presuppositions and worldviews regarding these issues. In effect, they are putting their worldviews to the test by exploring and evaluating multiple versions of Earth's origin story. In this sense, they venture beyond the limits of scientific knowledge to engage with other ways of knowing, and consider the philosophical implications of all the pertinent data. They are introduced to the methodology of reverse engineering and how this approach might be justified in light of the data. They are encouraged to explore the ways in which seemingly contentious scientific and religious aspects might be reconciled. Finally, they are confronted with the current climate crisis, and other sobering environmental issues, and asked to apply principles of good stewardship in determining a preferable path into the future.

Keywords

Engineering Education, Earth Science, Space Science, Reverse Engineering, Pre-College Education, Philosophy of Science, Retrodiction, Thought Experiment, Affordance, Holistic Education

Introduction

A few hundred years ago, explorers such as Christopher Columbus mustered transcontinental sailing expeditions in order to advance what little was known of planet Earth as a whole. But in today's information age, educators and students alike have a wide variety of resources regarding the origin and nature of Earth, literally at their fingertips. Ready access to such a wealth of information allows students to explore deep questions that may have profound influences on their worldviews. The importance of such an investigation calls for a careful and objective presentation of information from all pertinent areas of knowledge, along with an understanding of sources, their reliability, and prevailing presuppositions.

A team of students and faculty members from Engineering and Education areas at Oral Roberts University (ORU) are developing a more holistic approach to the study of planet Earth. Typical earth science courses are limited to a presentation of scientific findings, with virtually no consideration of what to do with these findings. "What does one make of these scientific discoveries?" is a good question, that is asked (in one sense) by engineers and (in another sense) by philosophers and theologians [5]. Both of these senses are pertinent for major life decisions and proper care of the planet, and students are intrigued by the accompanying ethical controversies. An excellent backdrop for framing these discussions has arisen from the field of ecological psychology in the concept of affordances.

Two kinds of affordances are important for pursuing a deeper understanding of these issues. End-user affordances are relationships between an agent and the environment that allow for a potential action to be taken. In more complex systems, such as a life-sustaining planet, part-to-part affordances are relationships between parts of the system that ultimately lead to such potentialities [6]. An example of an end-user affordance is the relationship between animals and bodies of water that allow them to bathe, or cool off on a hot day (positive affordance), while this same relationship also allows for drowning (negative affordance). An example of a part-to-part affordance is the relationship between hydrogen and oxygen atoms that allows for a water molecule to form. Affordances are found in both human-made and natural systems. Norman claims that affordances "provide strong clues to the operation of things" [7]. Indeed, affordances are what engineers attend to in seeking to meet their customers' needs. They do this by ingeniously arranging the elements of multi-component systems into advantageous relationships. Maier has summarized the engineering design process as an attempt to maximize the positive affordances associated with a product, and minimize the negative affordances [8].

In reverse engineering projects, an existing system is dissected and analyzed in an attempt to discover the secrets behind its design. Researchers such as Maier and Norman have recently claimed that affordances are critically important in the reverse engineering of complex systems, including those found in nature. Often, these affordances are found to occur in layers of dependencies, or nested structures, with respect to both space and time. Thus, affordance-based reverse engineering is a process by which a complex system (such as planet Earth) is virtually "dissected" and analyzed in terms of its part-to-part and end-user affordances. The author has provided a detailed description of the application of affordance-based reverse engineering to both artificial and natural systems, including several examples [9], [10]. This is the suggested approach for pursuing a more holistic understanding of the complex questions that continue to swirl around planet Earth. The lab unit under development will be titled "Hacking the Earth," employing the slang term for reverse engineering. Some details regarding the methodology of this "work in progress" are briefly described in the next section.

Methods

The authors of this study have been meeting to discuss the development of a laboratory manual to guide earth science students through the process of exploring the history and nature of planet Earth. Since it is the beginning stages of a work in progress, only a simple first draft of the learning objectives and lab procedures for this unit have been developed by engineering and education students at ORU. The current learning objectives are as follows:

1. Describe the methodologies of retrodictive thought experiments and affordance-based reverse engineering
2. Starting with the Big Bang, summarize the process (from science) by which planet Earth came into existence, and identify the natural laws that govern these processes.
3. Describe the measurements that assist in determining the age of the Earth, summarize how this age is determined, and list the factors contributing to the evolution of biological complexity.
4. Explain fine-tuning and list the evidence of fine-tuning in regards to the Earth
5. Describe the concept of an affordance and explain how affordances in nature suggest a reverse engineering methodology
6. Summarize the current major environmental crises, along with influential factors. Describe how this informs the way we live our lives today in terms of stewardship.
7. Describe the six common models of origins for the universe, life, species and humans.
8. Explain how objective discussions of controversial topics should proceed, and how differences between scientific and religious perspectives on origins might be reconciled.

Admittedly, this seems like a lot of material to cover in a single two-hour lab class, especially since much discussion is anticipated, and encouraged. But the idea is to introduce the students to these issues, while providing plenty of sources for further information on each topic. In addition to the above objectives, one of the primary goals of this unit is to help students approach such controversial subjects with an open and objective mindset that enables respectful and friendly discussion with those who may come to different conclusions. This is the idea behind the last learning objective.

Each of these learning objectives can translate to some degree into the elementary, middle school, and high school learning environments, and some suggestions are offered in this regard. But ultimately, each teacher candidate taking the lab will have to work out this translation for the environment they will be entering. The Next Generation Science Standards for Earth and Space Sciences focus on three disciplinary core ideas: Earth's place in the universe, Earth's systems, and Earth and human activity. The application of these core ideas in Earth and Space Science content varies between elementary, middle, and high school grade levels. While elementary students focus on the acquisition of core ideas and skills central to the Earth and Space Sciences, middle and high school students are expected to use their background knowledge in the core ideas in Earth and Space Science to explain more in-depth phenomena applicable to both the earth and space sciences, as well as life and physical sciences.

As with all humans, students (and faculty members) are susceptible to egocentric and sociocentric thinking, which can make it difficult to avoid bias, or irrational favoritism toward a particular theory. Hence, in the development of this curricular unit, the authors are striving to present the information in a clear and objective manner. Students taking the lab will also be made aware of the importance of maintaining vigilance when it comes to guarding against irrational bias. Help in this regard is obtained from historian Michael Licona who suggests six guidelines for how one might overcome their "horizons" when attempting to create a hypothesis to explain historical facts [11]. A horizon, as Licona defines it, is "how historians view things as a result of their knowledge, experience, beliefs, education, cultural conditioning, preferences, presuppositions, and worldview." This is not unique to historiography but is also true about every discipline where hypotheses are formed in an attempt to explain data.
The first guideline is to craft the method with objectivity in mind. Method is a term covering how data is acquired and how a hypothesis and competing hypotheses are evaluated. The second is to make your horizon and method public. In making these public, you open yourself up to the scrutiny of your peers, which is Licona's third guideline. The fourth is to present your ideas to experts that hold contrary views. The fifth is to take into consideration the "historical bedrock" that is pertinent to the hypothesis. These are statements that have a significant amount of evidence behind them and are taken as facts by the vast majority of critical scholars in the field. The last is to distance yourself from bias as much as possible. By following these guidelines, researchers can be much better equipped to create hypotheses that more objectively explain the data. Students will be encouraged to follow these guidelines as they work through the lab exercises and ultimately test their own hypotheses about the origin and nature of planet Earth.

Results

During the last few years, discussions of the type described above have productively ensued as a regular part of the PSC 215 Applied Earth and Space Sciences course at Oral Roberts University. Student testimonials and other anecdotal evidence suggest that these discussions are helpful as students engage with earth and space sciences, while simultaneously developing and refining their personal worldviews. However, a more formal approach to this type of holistic education is needed. Since the lab manual containing this unit is currently under development, and has yet to be implemented, data as to its effectiveness does not yet exist. The author has been awarded a one-semester sabbatical to work on this unit, along with several other engineering-related lab units, during the spring semester of 2023. This work (including input from students) is expected to continue into the summer and fall of 2023. The resulting lab manual will be introduced into the PSC 215 lab course for use in the spring of 2024. The effectiveness of this approach will be more completely assessed upon introduction and use of the new lab manual at that time.

Summary

A holistic approach to preparing K-12 educators to guide exploration of the origin and nature of planet Earth has been described. The concept of affordance-based reverse engineering is introduced as a framework for conducting this exploration. The curriculum takes the form of a virtual experimental unit within a multi-unit manual of engineering-related labs, with the ultimate goal of bringing more engineering principles into the K-12 environment. An ambitious set of learning objectives is proposed, which assists students in objectively considering the scientific evidence in light of their personal presuppositions and worldviews. Anecdotal evidence suggests that early informal versions of this curriculum have contributed effectively to the accomplishment of multiple important learning objectives. More quantitative assessment is planned for the spring of 2024, when the new engineering-related lab manual will be introduced.

References

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[5] Engineers consider the practical aspects of scientific discoveries and think about what they could literally create that would take advantage of such findings. Philosophers ponder the deeper questions and metaphysical implications of such discoveries, wondering in a figurative sense, what to "make" of them. Engineering students at ORU are encouraged to become "philosopher engineers" who delight in the pursuit of both investigations.

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