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Three Simple Questions, Three Surprising Answers: How to Provoke Curiosity and Understanding of Earth Systems as Part of Learning Fundamentals of Sustainability

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Lightning Talk: Three Simple Questions, Three Surprising Answers:
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1. Introduction

As I continue to learn about sustainability and how to teach it, I become continually more convinced of the need to learn and teach the basics of earth systems, biogeochemical cycles, and planetary boundaries. The direct reason is to establish the baseline conditions of the Holocene which then allows a proper understanding of how human behavior has impacted the environment and climate, leading to the Anthropocene. More generally, earth systems science simultaneously provides an excellent opportunity to introduce systems thinking and to develop scientific literacy, such as the ability to think across different time and space scales. Several introductory topics on sustainability include these topics and perspectives [1].

Meanwhile, I regularly use active learning techniques, including inductive learning and concept-based pedagogy [2]. A particular technique is to pose leading conceptual questions at the outset of a topic, when the students are not expected to know the result, providing an opportunity to engage with a misconception and to reflect on their own intuition as the topic unfolds [3], [4]. With this in mind, I will present a brief intervention that I have recently developed to introduce the topic of earth systems science as part of activities or courses that involve an introduction to sustainability. Three short questions are posed that are designed to reveal student misconceptions, phenomenological primitives, or expectation failures, motivating curiosity and critical thinking.

2. Description of the Intervention

The three short questions are provided in Table 1, together with comments about why they are used. The correct answers to each question are highlighted in green.

Table 1. Description of the Three Questions and Commentary.

Question	**Commentary**
Question 1. All of the matter used in modern life was present on earth when it was formed approximately 4.5 billion years ago. a. True b. False	This question anticipates the notion that Earth is essentially a closed system with respect to matter – that is, essentially all matter stays within earth's gravitational field (with small exceptions such as space vehicles, escaping helium, and impacting asteroids). This leads to the broader realization that all matter is recycled within the earth system. This is part of the general discussion on

	open, closed, and isolated systems (including that earth is an open system with respect to energy).
Question 2. When a plant grows, most of its mass is derived from … a. the atmosphere b. the soil c. groundwater	This question anticipates the discussion of photosynthesis, its central importance to life, and CO_2 cycling. Photosynthesis is the process by which plants use sunlight to convert water and atmospheric CO_2 into sugar (which is later converted to the lignin, cellulose, and hemicellulose that provide the plant's structural material). Thus, the plant's primary mass is derived from the atmosphere (nutrients from soil constitute a much smaller portion of plant matter). Photosynthesis, and the opposite process of respiration, introduce the question of how CO_2 is cycled between the atmosphere and biosphere, leading to other discussions about climate change. As a parallel benefit, this discussion helps students improve their insights to chemistry.
Question 3. Where is most of the world's oxygen stored? a. the atmosphere b. the crust and mantle c. the oceans	The majority of the world's oxygen is stored in the crust and mantle, with over 90% in solid form (in minerals as oxides, silicates, etc.) [5]. This question anticipates the discussion of the Gaia Hypothesis, which is the (surprisingly recent) understanding that Earth's climate system is regulated by an interplay between living (biotic) and nonliving (abiotic) entities. This leads to a more detailed discussion of the relatively fast cycling of matter between the atmosphere and surface due to the presence of living organisms, versus the relatively slow cycling of matter due to geological processes between the surface and solid earth.

These questions best map to the Engineering for One Planet Framework [6] topic "Environmental Literacy", particular outcome Core 3: "Discuss key global ecosystem services (i.e., water, carbon, energy, and nitrogen cycles, as well as nutrient cycling, soil formation, pollination, waste decomposition, etc.) and how they are interconnected". Per the Framework, this outcome maps to ABET student outcomes 2 ("an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors") and 4 ("an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts").

3. Deployment of Questions and Early Results

I have deployed these questions in three settings: (1) in an undergraduate course that I teach called *Creating a Sustainable World*, which consists of nearly 100% engineering students from a wide range of majors and years of study; (2) in a mixed undergraduate/graduate course called the *Global Food Energy Water Nexus*, co-taught by multiple instructors at multiple universities in the US, China, and India, with a diverse registration across many STEM and non-STEM disciplines; and (3) in outreach activities to high school students who are prospectively seeking undergraduate programs. It is assumed that few students in any of these cohorts have advanced backgrounds in earth sciences.

The modes of deployment vary. For outreach events, the questions are deployed via Kahoot in a group setting, often in conjunction with other questions about sustainability. No data has been formally collected in this context, but from experience, students seem to be surprised and intrigued.

In the *Global Food Energy Water Nexus*, for Fall 2025, a total of 168 students were enrolled, including 98 from the US/Puerto Rico, 53 from India, and 17 from China; approximately 80% were undergraduates. The questions were deployed during class lectures via PollEv, with only aggregate polling data collected. In this setting, no formal instructions are provided, other than to respond to the posted question in real time within about 30-60 seconds. Table 2 provides a summary of this data from Fall 2025.

Table 2. Results of Three Questions from the *Global Food Energy Water Nexus*, Fall 2025.

Question 1	**Question 2**	**Question 3**
True 42 (87.5%) False 6 (12.5%)	The atmosphere 19 (21%) The soil 59 (66%) The groundwater 12 (13%)	The atmosphere 15 (20%) The earth's crust & mantle 9 (12%) The oceans 51 (68%)

For *Creating a Sustainable World*, Spring 2026, 23 students are enrolled, including 16 male and 7 female. All students are undergraduates from different engineering programs, including 7 Civil Engineering/Surveying, 5 Industrial Engineering, 4 Chemical Engineering, 3 Mechanical Engineering, and 4 Electrical or Computer Engineering/Computer Science. The course has 1 1st year student, 9 2nd year students, 7 3rd year students, and 6 in their 4th year or beyond. I have conducted prior research related to this course in conjunction with an NSF grant [7], [8].

During the 4th week of the course, the three questions were deployed as part of a short pre-quiz prior to the topic on Earth Systems Science (via Google Forms). In addition, each question was followed by a short written response ("Please briefly discuss or explain why you chose your answer to the previous question."). The quiz was introduced with the following instructions: "Please respond to the following questions related to earth systems science. Please complete these questions with NO INTERACTION with anyone or anything else (no communication with anyone else, no web searches, no AI queries, etc.)". Of the 23 enrolled students, 16 responses were collected, the results of which are reported in Table 3. Strikingly, the answer distributions are nearly identical to those from the Global Food Energy Water Nexus, suggesting that students have relatively well-formed impressions about earth sciences.

Table 3. Results of Three Questions from *Creating a Sustainable World*., Spring 2026

Question 1	Question 2	Question 3
True 13 (81.3%) False 3 (18.7%)	The atmosphere 4 (25.0%) The soil 10 (62.5%) The groundwater 2 (12.5%)	The atmosphere 5 (31.3%) The earth's crust & mantle 3 (18.7%) The oceans 8 (50.0%)

Based on Question 1, it is clear that students have a good sense of the notion that the total mass within the earth's atmosphere is essentially constant. Several students cited "conservation of mass" or the "first law of thermodynamics" as reasons for selecting "True" (the latter reason refers to energy, not mass, but still represents understanding of conservation law). Of students who answered "False", they still tended to cite conservation, but thought that things like meteorites entering the atmosphere, or nuclear reactions in which mass is converted to energy, would mean that the basic mass has changed. While this is strictly true in a detailed sense, it represents the need to think about things at appropriate scales.

Based on Question 2, students who selected "atmosphere" were able to cite directly or implicitly photosynthesis or using CO2 as an ingredient. Some who selected "soil" associated the plant's mass with direct transfer of mass from the ground. Some who selected "groundwater" reasoned that the majority of the mass of a living body is water; this suggests that clarity in the question phrasing could be improved to distinguish between plant matter and embedded water.

Based on Question 3, the small number of students who selected "earth's crust & mantle" had a good appreciation that oxygen is an element of many naturally occurring minerals. Those who selected "atmosphere" typically associated oxygen with breathing, while those who selected "oceans" either because of its sheer vastness or because oxygen is a constituent element of water.

These preliminary findings suggest that student misconceptions have some basis in reasonable argumentation. A further study is planned to delve into these findings and map them back to improved teaching approaches.

4. Conclusions

I developed these questions because they reflect key waypoints where my own intuition conflicted with reality ("expectation failure") along my recent journey to learn this topic well enough to teach it in a coherent, responsible, and hopefully engaging manner. Based on the preliminary results (correct answers are highlighted in green in the prior tables), at least Questions 2 and 3 appear to be identifying common misconceptions. My ultimate goal is to help students draw a picture of how earth materials cycling and climate were in relative balance during the Holocene, and how human activities have disproportionately upset these cycles, leading to what we now refer to as the Anthropocene, which includes climate change.

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