Chief Reader Report on Student Responses:

2023 AP® Environmental Science Set 1

Free-Response Questions

- Number of Students Scored 209,757
- Number of Readers 686
- Score Distribution

Exam Score	N	%At
5	17,357	8.27
4	59,527	28.38
3	35,689	17.01
2	55,358	26.39
1	41,826	19.94

- Global Mean 2.79

The following comments on the 2023 free-response questions for AP® Environmental Science were written by the Chief Reader, Dr. Laura J. Hainsworth, Professor of Chemistry and Environmental Science, Emory & Henry College. They give an overview of each free-response question and of how students performed on the question, including typical student errors. General comments regarding the skills and content that students frequently have the most problems with are included. Some suggestions for improving student preparation in these areas are also provided. Teachers are encouraged to attend a College Board workshop to learn strategies for improving student performance in specific areas.

Question 1

Task: Design an Investigation
Topic: GMO Green Bean Experiment and Irrigation
Max Score: 10
Mean Score: 5.14

What were the responses to this question expected to demonstrate?

The intent of this question was for students to demonstrate an understanding of the broad categories of agriculture, succession, populations, and pest control. Students were presented with an experimental design and data table comparing crop yields from genetically modified green beans with unmodified green beans [Topic 5.3 The Green Revolution].

In parts (a–c) students were asked to describe and identify experimental design components, as well as provide an explanation for how the results of an investigation could be altered by the modification of the experiment by reducing the length of time for irrigation from one hour to 20 minutes [Science Practice 4 Scientific Experiments and Topic 5.5 Irrigation Methods]. Students were expected to analyze and interpret quantitative data represented in a table. This included interpretation of experimental data in relation to a given hypothesis [Science Practice 5 Data Analysis].

Parts (d–f) required students to read and interpret data provided in a table, and to use that data to support or refute a given hypothesis [Science Practice 4 Scientific Experiments, Science Practice 5 Data Analysis, Topic 5.3 The Green Revolution, Topic 5.15 Sustainable Agriculture].

In parts (g–i) students were asked to describe how communities and populations change following disruptions such as burning, floods, and the introduction of a new species [Science Practice 1 Concept Explanation, Topic 2.7 Ecological Succession, Topic 2.1 Introduction to Biodiversity, Topic 3.1 Generalist and Specialist Species, and Topic 3.2 K-Selected r-Selected Species].

In part (j) students were asked to describe a realistic method to prevent the spread of a new beetle [Science Practice 7 Environmental Solutions, Topic 5.6 Pest Control Methods, and Topic 5.14 Integrated Pest Management].

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

- Most responses in part (a) correctly identified Plot D as the control group researchers used in the experiment, although some responses incorrectly identified amount of fertilizer, which is a constant in the experiment.
- In part (b) students were able to correctly apply their understanding of Science Practice 4 Scientific Experiments to identify the scientific question for the given investigation, e.g., “Will genetically modified green beans have higher crop yields than unmodified green beans?”
- In part (c) students were asked to explain one way that decreasing the spray irrigation from 1 hour to 20 minutes per day could alter the results of the study. Many responses successfully explained that with less water there would be a lower crop yield harvested from all plots. Responses that did not earn

a point in part (c) often stated that “there would be less growth from the beans” which did not earn a point because the researchers were not investigating plant growth.

- In part (d) the majority of students correctly interpreted the experimental data to identify the plot with the lowest soil temperature as plot D.
- In part (e) students were asked to describe how sediment runoff and fertilizer runoff compare between the unmodified green beans and the genetically modified green beans. Many responses accurately described “sediment and fertilizer runoff are lower with the genetically modified beans.”
- In part (f) many students successfully stated that the given hypothesis was supported because there was less fertilizer in runoff from plot B so the beans in plot B absorbed more fertilizer. Students also provided additional evidence by citing fertilizer concentrations from the data table.
- In part (g) students described the ecological process that occurred on the plots after the crops were burned. Many students correctly responded, “secondary succession occurred on the plots after the crops were burned. New species were reintroduced to an uninhabited area that was previously inhabited by the old bean crops.”
- In part (h) students were asked to explain why a community with more plant diversity would recover more quickly from the flooding. This was challenging for students because the task verb “explain” requires the use of evidence or reasoning to support a claim. In order to earn the point in part (h) responses needed to include a characteristic of a diverse plot along with the reason that characteristic would enable a quicker recovery from flooding. For example, plots with higher diversity have more species so the floods harm a smaller proportion of species.
- In part (i) students explained why a new beetle species could be better able to successfully populate the plot than the existing beetle. Correct responses had an explanation that included a characteristic of the new beetle or the plot, that allowed the new beetle to be more successful and the effect that the characteristic had on the existing beetle population.
- In part (j) students were asked to describe one realistic method to prevent the new beetle from spreading beyond the experimental plot. Students earned the point with a description of a realistic method, with predators, pesticides, or physical removal to kill beetles, being the most common methods.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• A common knowledge gap was the difference between primary succession and secondary succession.	• "The ecological process that occurred after the crops were burned was secondary ecological succession, as soil still remained after the burns but pioneer species like small plants had to emerge to begin the process."
• A misconception that often occured was a description of resilience rather than an explanation of the reason for higher plant diversity causing a faster community recovery.	• "A community with more plant diversity has a higher species and evenness, meaning there are more species and about the same amount of each. Therefore, the community is more resistant, withstanding disturbances, and resilient, recovering faster, since one species struggling does not affect the community as much because there are many more species."
• Another common misconception was that irrigation distributed fertilizers. "The results of the experiment could be altered by the irrigation time being reduced to 20 minutes because less irrigation of the fertilizer. This would lead to inaccurate data due to higher plant mortality."	• "Due to a reduced spray time of 20 minutes, there will be a greater difference in the crop yield of modified vs. unmodified green beans. The scientists had modified the GMO varieties specifically to produce high yields in arid conditions. Thus, the GMO strains will still have a high yield, while the unmodified strain will have a dramatically decreased crop yield due to reduced irrigation."

Based on your experience at the AP® Reading with student responses, what advice would you offer teachers to help them improve the student performance on the exam?

- Starting in the first few weeks of the school year, introduce and provide frequent student reminders throughout the year regarding the differences required by the task verbs. While "identify" requires a very short response and does not need further description or support to earn a point, "explain" often requires multiple parts in a response, to provide information about how or why an outcome occurs using evidence and reasoning to qualify a hypothesis. Most students are familiar with writing CERs (Claim-Evidence-Reasoning), which provide the basic outline for addressing an "explain why" question, which asks students to support or refute a given hypothesis.
- Students should not simply repeat the prompt to generate their answer. Responses that simply repeat the prompt do not earn points. Encourage students to provide additional information in their descriptions and explanations. In part (f) many responses provided "use fertilizer more completely than the other varieties." The phrase is found in the prompt and does not represent an understanding of the

reasoning for utilizing the evidence of "lower fertilizer runoff from plot B" as an explanation to support the researchers' hypothesis.

- The skills in Science Practice 5 ask students to analyze and interpret quantitative data represented in tables and graphs. Short summaries of current research studies and complex quantitative tables from free sources that can provide opportunities for student practice include Data Points from HHMI BioInteractive and Data Nuggets. Both are available online. Introduce students to the I2 Strategy (Identify and Interpret), which provides a method for students to break down the information in tables and graphs into the smaller parts of observations first, and then interpretation of student observations.

- For Science Practice 4, students should be given opportunities to design, carry out, and analyze laboratory and field experiments that investigate environmental problems. Students should be able to identify variables, including a control group, as well as a scientific question for an investigation. Have students practice designing or discussing scenarios that add a modification that could alter the results of a given investigation and explain how the specific modification could alter the results. Students need to think about what the results are from the study. In part (c) "crop yield" is the result being used in the investigation, so "reduced growth" would not earn a point.

- Teachers are encouraged to continually remind students to read all parts of each free-response question carefully, including the short passages (often one to two sentences) that precede the individual prompts. These may contain information that could qualify or set limits on accepted responses. In part (j) methods such as intercropping to prevent the new beetle from spreading did not earn a point because the passage described that "the researchers burned the plots to remove the crops."

- Students should have a clear understanding of concepts from the Course and Exam Description such as "ecosystems that have a larger number of species are more likely to recover from disruptions" [Topic 2.1 Introduction to Biodiversity]. Students are expected to be able to identify the ecosystem characteristics or processes that support this concept.

- Teachers will find sample student responses for this question on the exam information page on AP Central, along with commentary explaining why each point was or was not earned. Teachers can use these samples to better understand how each question was scored and to work with students to help practice writing correct responses.

- Teachers will find scoring guidelines for this question explaining how the question was scored on the exam information page on AP Central. Teachers can use and adapt these scoring guidelines throughout the course so that students become familiar with how their responses will be scored.

- Teachers can have students practice with the examples of FRQ 1 on the released 2021–2023 AP Environmental Science Exams found on the exam information page on AP Central. Student samples and scoring guidelines are also available for those questions.

- Teachers can have students practice, score, and review the examples of FRQ 1 found on the three AP Environmental Science Practice Exams that can be accessed in AP Classroom.

- Teachers can use the labs that are available in AP Classroom with their students. Each lab is designed to target specific Science Practice Skill development.

- In AP Classroom, teachers can access a rich collection of resources that includes formative and summative assessment items for every unit of the course.

- AP Daily videos in AP Classroom provide enriching content for every topic in AP Environmental Science. Teachers can integrate these videos into their instruction in a variety of ways to provide students with additional exposure to content throughout the course.
- AP Daily Live videos found on YouTube provide a comprehensive review of the course content for students. Teachers can assign these videos to students in the weeks leading up to the exam to reinforce content learned throughout the course.
- AP Faculty Lectures are a collection of videos available on YouTube that provide an in-depth look at specific course content from the perspective of higher education faculty at a variety of colleges and universities.
- On the AP Environmental Science Online Teacher Community there are many resources, discussions, tips, and activities that many teachers have found helpful. It is easy to sign up, and teachers can search through topics of discussions from previous years.
- Teachers might consider signing up for an AP Summer Institute (APSI). An APSI is a great way to gain in-depth knowledge about the AP Environmental Science curriculum and exam. It is also a great way to network with colleagues from around the world.
- Teachers might consider applying to be an AP Reader. The AP Reading is considered outstanding professional development by most AP teachers. Besides learning how to accurately apply AP scoring guidelines to score student responses, it is a great way to share resources and network with colleagues.

Question 2

Task: Analyze an Environmental Problem and Propose a Solution
Topic: Seagrass and Manatees
Max Score: 10
Mean Score: 4.12

What were the responses to this question expected to demonstrate?

The intent of this question was for students to identify, describe, propose a solution to the problem of nutrient and sediment runoff causing seagrass decline, and justify a solution to the environmental problem. This question focused on the broad categories of aquatic and terrestrial pollution, atmospheric pollution, and ecosystem structure and energy resources. The content ranged from ecological concepts such as range of tolerance and energy transfer through trophic levels, to aquatic pollution concepts such as thermal, nutrient, and sediment pollution, to atmospheric pollution topics, including photochemical smog formation.

In parts (a), (b), and (c) students were asked to interpret a map of manatee habitat and identify the water temperature range in which manatee movement occurs, identify the characteristic of power plant water that attracts the manatees, and describe a potential negative impact of the waste water from the power plant on other aquatic species [Science Practice 2 Visual Representations, Topic 2.4 Ecological Tolerance, and Topic 8.6 Thermal Pollution].

In part (d) students were asked to describe a characteristic of manatees that increased their vulnerability to the decline of seagrasses in their habitat, and then describe the change in energy flow through the trophic levels because of this decline [Science Practice 1 Concept Explanation, Topic 1.9 Trophic Levels, and Topic 1.11 Food Chains and Food Webs].

In part (e) students proposed a solution to reduce nutrient and sediment pollution in an estuary that is surrounded by urban development, and then justified their solution by providing an additional advantage of reduced nutrients in an estuary (other than one related to manatees) [Science Practice 7 Environmental Solutions and Topic 8.4 Human Impacts on Wetlands and Mangroves].

In parts (f) and (g) students were asked to describe the effects of environmental factors on photochemical smog and to identify an environmental problem resulting from exposure to photochemical smog [Science Practice 7 Environmental Solutions, Topic 7.2 Photochemical Smog].

In part (h) students were asked to describe the effects of the use of hydrogen fuel cells in power generation on the environment [Science Practice 1 Concept Explanation, Topic 6.11 Hydrogen Fuel Cell].

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

- Most students correctly interpreted the data points on the given map to identify the temperature range of 13–19°C. In part (b) most responses correctly identified that increased water temperature or "warmer water" around the power plant was what attracted the manatees.

- In part (c) students successfully described the increased temperature of the water causing either a drop in dissolved oxygen, which aquatic organisms need to breathe, or the increase in water temperature being outside of aquatic organisms' range of tolerance, which impacted their survival/health.

- Correct responses in (d)(i) took information directly from the stimulus of the question, "manatees … primarily eat seagrass," and then connected this information to the consequences of a reduction in food available to manatees. Responses earning a point in part (d)(ii) indicated that less energy flows through the trophic levels with a loss of seagrass, and they further described how fewer consumers or predators could be supported at higher trophic levels/in the food web.

- In part (e)(i) and (e)(ii) students were asked to propose a solution to reduce nutrient or sediment pollution in an estuary that is surrounded by urban development and then justify that solution by providing an additional advantage of reduced nutrients in an estuary, other than one related to manatees. The most common responses earning a point in part (e)(i) described adding plants/trees to slow or reduce urban runoff. In part (e)(ii) students identified a reduction in eutrophication or "fewer algal blooms" as an additional benefit.

- Responses in part (f) connected an increase in the amount of sunlight or increased temperature with increasing atmospheric reactions involving the primary pollutants of photochemical smog. For example, "more sunlight reacts with primary pollutants to form ozone." Responses also earned points for associating increased temperature with an increase in reaction rates of the primary pollutants.

- The most common, correct responses in part (g) identified "reduced plant growth" or "reduced photosynthesis" as an ecological problem associated with photochemical smog. Other correct responses identified respiratory problems in animals.

- Responses in part (h) most commonly described the high cost to manufacture cars with hydrogen fuel cells. Other correct responses provided a description of danger from fire or explosions in an accident, or the need to use fossil fuels to obtain hydrogen.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Part (c) revealed that some students incorrectly associated water discharged from a power plant with specific water pollutants such as heavy metals or nutrients, and not increased water temperatures/thermal pollution.	• "The water from the power plant is warmer."
• Responses in part (f) indicated a knowledge gap regarding the relationship between summertime weather conditions and the generation of photochemical smog. Common incorrect responses referred to increased travel or electricity use for air conditioning.	• "Hotter temperatures increase reaction rates between VOCs and NO_X. This causes an increase in ozone levels in the troposphere."
• In part (g) students sometimes failed to differentiate between an ecological problem and impacts on humans.	• "Photochemical smog reduces photosynthesis in plants."
• Responses in part (h) indicated that students struggled to differentiate between hydrogen fuel cells and battery-based electric vehicles. When asked to describe a potential disadvantage of using hydrogen fuel cells to power automobiles, incorrect responses referred to unavailability of charging stations or problems with batteries.	• "Hydrogen fuel cells can lead to explosions if there is a car accident."

Based on your experience at the AP® Reading with student responses, what advice would you offer teachers to help them improve the student performance on the exam?

- Introduce the task verbs used in the exam early in the school year, then frequently use them in both formative and summative student assessments. "Identify" questions can be answered with only a few words or a short phrase and require no further description. The "describe" task verb requires student to provide the relevant characteristics of a specified topic and requires more information to earn a point.
- Science Practice 2 requires students to describe characteristics and explain relationships between different characteristics of an environmental concept, process, or model represented visually.

Incorporate maps, diagrams, and models into classroom presentations, discussions, and assessments. Create opportunities for students to make analyses.

- For Science Practice 7 Environmental Solutions, students are asked to propose a realistic and fitting solution to an environmental problem based on content knowledge. The solution should demonstrate understanding of an environmental problem at the level of detail in the AP Environmental Science course. This skill can be practiced by reading case studies from environmental science texts, or by reading current newspaper articles, and then discussing possible solutions to the problems presented in those case studies/articles.
- Encourage students to carefully read each part of a free-response question, including the short passage (stimulus) at the beginning, as it may contain useful information for the parts of the question that follow, and it could contain information that can be incorporated into a point-worthy response. This was the case in part (d)(i) of this question.
- Teachers will find sample student responses for this question on the exam information page on AP Central, along with commentary explaining why each point was or was not earned. Teachers can use these samples to better understand how each question was scored and to work with students to help practice writing correct responses.
- Teachers will find scoring guidelines for this question explaining how each question was scored on the exam information page on AP Central. Teachers can use and adapt these scoring guidelines throughout the course so that students become familiar with how their responses will be scored.
- Teachers can have students practice with the examples of FRQ 2 on the released 2021–2023 AP Environmental Science Exams found on the exam information page on AP Central. Student samples and scoring guidelines are also available for those questions.
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- Teachers can use the labs that are available in AP Classroom with their students. Each lab is designed to target specific Science Practice Skill development.
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Question 3

Task: Analyze an Environmental Problem and Propose a Solution Doing Calculations
Topic: Oil Impacts and Gold Mining Calculations
Max Score: 10
Mean Score: 5.13

What were the responses to this question expected to demonstrate?

This question focused broadly on natural resource extraction and impacts of extraction and use of resources on the environment and human health.

In parts (a) and (b) students were expected to demonstrate understanding of the negative effects of oil extraction, transportation, and combustion on marine ecosystems [Science Practice 1 Concept Explanation, Science Practice 7 Environmental Solutions, Topic 6.5 Fossil Fuels, Topic 7.8 Noise Pollution, and Topic 1.8 Primary Productivity] and the atmosphere [Topic 7.1 Air Pollution and Topic 7.4 Atmospheric CO_2 and Particulates].

Parts (c) and (d) required students to propose a solution that would reduce an individual's reliance on refined oil products [Science Practice 7 Environmental Solutions, Topic 6.13 Energy Conservation, Topic 6.11 Hydrogen Fuel Cell, and Topic 6.7 Energy From Biomass] and justify the solution by describing how it could also benefit human health [Science Practice 7 Environmental Solutions, Topic 7.1 Introduction to Air Pollution, Topic 7.2 Photochemical Smog, and Topic 8.14 Pollution and Human Health].

In parts (e), (f), and (g) students were required to calculate answers associated with gold mining [Science Practice 6 Mathematical Routines and Topic 5.9 Impact of Mining]. Part (e) required students to calculate the amount of gold that could be extracted from ore of a given mass and gold concentration. In part (f) the students were asked to calculate the value of gold that could be extracted from a given mass of gold ore. Finally, part (g) required students to calculate the amount of gold ore that would have to be extracted to manufacture a large volume of a consumer electronic product (cell phones) [Topic 8.9 Solid Waste Disposal]. While dimensional analysis based on unit cancellation is recommended, a setup point was earned for responses showing correct values and mathematical operations.

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

- Students demonstrated knowledge about the effects of fossil fuels on the environment, including impacts to the environments from the extraction and transport of the resource, as well as effects on the environment and human health from the combustion of that resource for energy. Students were expected to be able to set up and evaluate basic calculations, showing correct numeric values and arithmetic operations, and report answers with correct units, when applicable.

- In part (a) correct responses described an environmental impact on marine ecosystems associated with extraction and transportation of crude oil. Many students described oil spills limiting sunlight penetration and inhibiting photosynthesis by primary producers or killing/harming marine animals due to oil ingestion, suffocation, or being coated with oil. Some students described how noise pollution from transportation and extraction disrupts animal communication or their ability to mate, eat, and evade prey.

- In part (b) students were highly successful in identifying any atmospheric pollutant, most frequently CO_2, released during combustion of refined oil products.
- In part (c) students proposed adopting modes of transportation that would reduce overall miles driven in a vehicle (e.g., bike, walk, use mass transit, telecommute) or use of an electric or alternatively fueled vehicle (hydrogen cells, biodiesel) as a solution to reduce reliance on refined oil products.
- Responses in part (d) correctly stated how the proposed solution in part (c) would result in fewer air pollutants such as NO_X, VOCs, and smog, thereby reducing rates of respiratory and cardiovascular problems/illnesses and eye irritation. Some students correctly stated that nonmotorized travel (biking, walking) would improve health or reduce risk of cardiovascular disease due to the increased amount of exercise.
- In parts (c), (f), and (g), students calculated the amount of gold that could be extracted from a given amount of gold ore, the value of gold that could be extracted from a given mass of ore, and the amount of gold needed to make a designated number of cell phones, respectively. Many students were able to correctly utilize scientific notation and unit cancellation.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• A common misconception was the identification of methane or CFCs as pollutants generated from the burning of refined oil products.	• "Particulate matter is an air pollutant generated from combustion of refined oil products."
• Some responses generalized that all combustion products from refined petroleum, including carbon dioxide specifically, were respiratory/eye irritants, or otherwise directly impacted human health in a negative way. Some students did not recognize that CO_2 is a pollutant of concern for reasons other than those associated with NO_X, SO_X, VOCs, and PM.	• "By riding a bike instead of driving a car there would be less NO_X from car emissions. This would lead to fewer respiratory problems like asthma since NO_X is a lung irritant."
• Responses lacked a complete setup for dimensional analysis or that showed all numeric values and operations. Responses often just restated the given information as a series of equivalences, such as "1 ton = 5 grams" and "1 gram = \$62.56" but did not show actual calculation inputs with arithmetic operators.	• $1{,}000 \times 5 \times \$62.56 = \$312{,}800$

Based on your experience at the AP® Reading with student responses, what advice would you offer teachers to help them improve the student performance on the exam?

- Remind students of the differences required by the task verbs found on the exam (pg. 227 of the CED). "Identify" requires a very short response and does not require an explanation for a point. On the other hand, students should have practice describing and explaining concepts and answers in preparation for the more detailed answers required from the "describe" and "explain" task verbs.
- Students should learn to write a mathematical expression (or series of expressions) that shows all necessary arithmetic operators. Ideally, students should also be comfortable with dimensional analysis involving several different unit conversions.
- Students should learn that "propose a solution" is a more complex task verb than "identify an action" and requires some additional expository details. Students should assume that the proposal will have an attached "justify the solution" task verb and be prepared to present reasons that the solution not only solves the problem at hand, but also why it might have additional benefits that alternative solutions may not.
- Students should learn to answer the question or respond to the prompt as presented, noting if the prompt specifies a particular type of ecosystem (e.g., marine, aquatic), scope of action (individual vs. community or national scale), location or setting (home/office versus transportation), or type of effect.
- Teachers will find sample student responses for this question on the exam information page on AP Central, along with commentary explaining why each point was or was not earned. Teachers can use these samples to better understand how each question was scored and to work with students to help practice writing correct responses.
- Teachers will find scoring guidelines for this question explaining how the question was scored on the exam information page on AP Central. Teachers can use and adapt these scoring guidelines throughout the course so that students become familiar with how their responses will be scored.
- Teachers can have students practice with the examples of FRQ 3 on the released 2021–2023 AP Environmental Science Exams found on the exam information page on AP Central. Student samples and scoring guidelines are also available for those questions.
- Teachers can have students practice, score, and review the examples of FRQ 3 found on the three AP Environmental Science Practice Exams that can be accessed in AP Classroom.
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