Questions of Sustainability: Paper vs Plastic, Meat vs Plant-Based Diets, and Gas-Powered vs Electric Cars

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Introduction and Rationale

An internet search for the term sustainability returns almost 1.6 billion results, including these two simple definitions from Oxford: “the ability to be maintained at a certain rate or level”, and “avoidance of the depletion of natural resources in order to maintain an ecological balance”.[1] Applying the “News” filter to that internet search reduces the results a mere 88 million, and produces articles covering sustainable fashion, sustainable commerce, questions of sustainability, sustainable construction, and even sustainable chocolate, just to name a few. The AP Environmental Science (APES) course description defines sustainability as “humans living on Earth and their use of resources without depletion of the resources for future generations.”[2] The course description goes on to establish factors such as biological diversity, food production, average global surface temperatures and CO_2 concentrations, human population, and resource depletion as guidelines for determining sustainability.[3] Our course textbook defines sustainability as “living on Earth in a way that allows humans to use its resources without depriving future generations of those resources.”[4]

This simple exercise demonstrates three things about sustainability. The first is that it has entered the global lexicon and is no longer exclusively scientific jargon. The second is that there is a range of definitions and applications of those definitions. Finally, it demonstrates that sustainability means different things to different people in different contexts. When different individuals apply these definitions in the same context, or when the same individual applies these definitions in different context, there is inevitably going to be some disagreement. This is exactly the point of this unit: students apply definitions of sustainability to different scenarios and must to choose the best option. Ultimately, the goal is to weigh quantitative analyses with or against value systems to break down the differences in sustainability and arrive at some evidence-based conclusion.

School Profile and Course Specifics

William Penn High School is a public high school in the Colonial School District in New Castle County, DE. It is the only high school in the district and is the largest high school in the entire state, serving roughly 2250 students each year across grades 9-12.[5] The district is considered suburban/urban fringe and serves a diverse population in terms of both race and income. There has been a resurgence in jobs in the district, mostly in the industrial sector. This has created a demand for employees with job-specific skill sets. As such, William Penn has focused on the growth of Career and Technical Education programs that provide opportunities for students to experience a vocational-type education while still being provided with the traditional college preparatory education typical of public schools. Such a shift has allowed the school to retain students who may otherwise attend one of the four area Vo-Tech schools.

William Penn also offers twenty-five Advanced Placement courses, the largest number of any school in the state. This dual focus on college and career readiness has greatly improved the school culture and the school's image in the community, which has translated to the growth in student population. Students entering William Penn choose a degree program to specialize in within one of three college academies: Business, Humanities, or STEM. Degree programs within the Business College Academy include Air Force JRTOC, Business Administration, Culinary Arts, Financial Services, and Accounting. Degree programs with the Humanities College Academy include Behavioral Sciences, Communications, Teacher Academy, Legal Studies, International Studies, and Visual and Performing Arts. The STEM College Academy offers degree programs in Agriculture, Allied Health, Computer Science, Construction, Engineering, Manufacturing, Mathematics, and Science.

This growth in student population and interest in the sciences helped me justify the need for adding APES to the course catalog in the 2016/17 school year. Students enrolled in the Agriculture degree program can specialize in the Environmental Science pathway, which requires them to take two years of on-level environmental science before enrolling in APES as their capstone course. I am now teaching the course for the fourth year, and this is the first year I have students who are in their final year of the Environmental Science pathway. At this point I feel comfortable enough with the course curriculum to identify weaknesses and areas for improvements. I also feel that is necessary to re-tool the course to provide students with more value, especially since many of them will be coming with two years of experience in the content. One such weakness is in the theme of sustainability. In the course description, sustainability is presented as an overarching theme. Yet after being introduced in the early stages of the course it is only infrequently referenced in the remaining units. Additionally, the sustainability definition that is presented is grounded in specific value judgements without room for much flexibility. These shortcomings are limiting for a few reasons: 1) the definition of sustainability is going to vary from textbook to textbook; 2) sustainability doesn't mean the same thing to all people and all cultures; and 3) whatever the agreed upon definition of sustainability is, it should be applied again and again throughout the course as a way of building connections between course topics.

Learning Objectives

This unit applies principles of sustainability to three big questions in environmental science: paper versus plastic, meat versus plant-based diets, and gas-powered versus electric vehicles? For each question, students rely on information from specific course topics. To answer the question of paper versus plastic, students draw on information from pollution, waste, and global change. To answer the question of meat versus plant-based diets, students use information from land and water use and global change. Finally, to answer the question of gas-powered versus electric vehicles, students use information from energy resources, pollution, and global change. This unit serves as the conclusion to my course curriculum since it provides a natural opportunity for students to review key course concepts in advance of the national AP exam and apply their knowledge to real-world problems.

Where possible, students are asked to establish quantitative explanations for how they arrive at the sustainable choice. Ultimately this unit aims to help students understand that sustainability does not have a one-size fits all definition and instead is specific to an individual's value judgements. It also aims to aid students in making sustainable choices by helping them understand the social, political, and economic factors that contribute to judgements of sustainability.

Content Objectives

Students are introduced to the College Board's definition of sustainability in the very first chapter of the textbook in the first week of school. As they read in the textbook, they are assured that principles of sustainability will bleed into each topic they learn about the rest of the year. Yet there are few instances where explicit discussion of sustainability occurs (save for brief discussions of sustainable yield and sustainable land use). This is a major flaw that does a great disservice to students in their preparation for the AP exam, as well as their growth as eco-conscious citizens and consumers. To address this flaw, students will answer the three big questions of sustainability throughout the year as they navigate through the course content, ultimately drawing on information from several course topics and their own personal values to answer those questions at the end of the course.

Sustainability

There is an almost endless number of different definitions for sustainability, as demonstrated by the internet search discussed in the Introduction section. Since students are ultimately held accountable by the College Board, this unit will loosely adhere to their definition of sustainability, which is similar to the definition presented in the course textbook. Under these definitions, sustainability is defined as humans living on Earth and their use of resources without depletion of the resources for future generations.[6,7]

Paper versus Plastic

One of the biggest questions in environmental science concerns the use of paper versus plastic. This issue hit the spotlight when videos of turtles with plastic straws in their nasal cavities hit the internet, followed by videos of deceased marine mammals such as whales and dolphins with large amounts of plastic waste in their guts. Additionally, several cities, states, and countries have proposed or passed legislation to ban plastic grocery bags or even single-use plastics altogether. More than 400 states or cities in the US have bag bans on the books, including Delaware, whose ban goes into effect in January 2021.[8] The motivation behind such bans is to eliminate these products from waste streams and encourage the switch to paper or even reusable bags. So, which is more sustainable, and how do reusable bags factor in?

CO_2 Emissions

Paper bags are touted by many as the greener option, yet the production of paper bags adds twice the amount of CO_2 to the atmosphere than the production of plastic ones.[9] In addition, the CO_2 that the trees could have taken from the atmosphere and stored as biomass now remains in the atmosphere. A study by the United Kingdom government determined that a paper bag must be used at least three times to make it worth the extra CO_2 compared to plastic.[10]

Pollution, Disposal, and Water Use

Aside from carbon footprint, there are several other factors that should be considered when judging the sustainability of paper and plastic bags. These include the pollution and waste they create and how much water they use during their production. Growing trees for paper requires a great deal of fertilizer, pesticide, and herbicide use. Excess fertilizer use has been linked with contamination of groundwater and eutrophication of surface waters. Pesticide use and herbicide use are associated with a number of negative environmental outcomes, including reduced biodiversity, evolution of resistance in target species, and cancer in humans.[11] Once the trees are cut down, the milling and processing of the trees requires harsh chemicals that pose a threat to local surface and groundwater. The growing, milling, and processing of trees/paper also has a large water footprint: it takes four times as much water to make paper bags than plastic ones.[12]

Plastic bag production is heavily linked to the oil and natural gas industries. The environmental impacts of these are discussed in more detail in the Gas vs Electric Vehicle section below. While this requires the acceptance of the environmental impacts of extracting oil and natural gas, it is important to note that plastic production was the solution to the waste generated by the industry. Prior to the widespread production of plastic, the raw materials were simply disposed of or flared off. Decades of efficiency improvements have significantly streamlined the production process and minimized the waste produced as a result of plastic production.[13]

Still, single-use plastics represent an ever-increasing percentage of the total waste stream, tallying 12% as of 2016. This number is much larger than it appears given the small size and mass of a single plastic bag. In fact, 100 billion plastic bags are used in the

US every year, which is roughly one bag per person per day.[14] Unfortunately, these bags are not readily recycled due to being made from low-durability compounds. Many individuals reuse them as wastebasket liners or to clean up pest waste, but these uses are limited in nature and still result in the bags ending up in the landfill.[15] What may be worse is that in many countries, plastic bags (and countless other types of waste) end up in local waterways, ultimately making their way to the ocean where they can negatively impact marine organisms such as turtles and large marine mammals such as whales and dolphins.[16] Even though paper bags are much more recyclable than plastic bags, they are not immune to issues of post-use waste. When not recycled and instead landfilled, paper bags add five to seven times the tonnage to the waste stream and require more energy to transport and take up more space in landfills.[17] What's more is that when they break down in landfills, they do so under anaerobic conditions. This process releases methane, which is a greenhouse gas roughly 25 times more potent than CO_2.[18]

How do Reusable Bags Factor in?

One thing missing from the debate so far are reusable bags, which have gained in popularity in the wake of bag bans and efforts to be more sustainable. When subjected to the same scrutiny as paper and plastic bags, the UK government determined that a reusable bag must be used 131 times have the same environmental impact of a single-use plastic bag.[19] The factors that contribute to this surprising fact include the pesticides and water used to grow the cotton used to make the bag, the high-quality plastic used to coat the bag to make it more durable, the excess weight that requires more energy and carbon to ship and transport, and the water used to wash them during their lifetime.[20]

Sustainability Judgement

From a CO_2 emissions perspective, single-use plastic bags are the clear sustainable choice. However, the choice becomes more difficult when including the pollution, disposal, and water use of the different options. As mentioned in the Introduction, the sustainable choice is dependent upon an individual's value system. If an individual cares most strongly about CO_2 emissions, the plastic bag is the sustainable choice, even though its production is linked directly to the fossil fuel industry and its disposal contributes to aquatic pollution. If the health of our planet's oceans is what matters most to another individual, then the sustainable choice is the paper bag, even though it emits more CO_2 and takes up significant landfill space. It is hard to ultimately compare the sustainability of reusable bags to paper and plastic ones given that it takes so many uses for their benefits to outweigh their environmental costs.

Meat versus Plant-Based Diets

The Food and Agriculture Organization released a statement in 2010 that defined sustainable diets as "those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations." They went on to say that sustainable diets should consider biodiversity, ecosystems, be culturally acceptable, fair and affordable, nutritionally adequate, safe, and optimize natural and human resources.[21] This complicated definition has increasingly been put to the test by wave after wave of food movement proclaiming to be healthy for people and for the planet. A recent example of this is the advent of plant-based proteins such as Beyond Meat products and the Impossible Burger. Relying on the "Rule of 10" principle from ecology (the idea that each trophic level can only access 10% of the energy available at the level below it), it has long been stated that plant-based diets are inherently more sustainable than meat-centered ones.[22] On the surface, this makes sense: it requires significantly fewer resources (including land, fossil fuels, and manpower) to raise 2000 plant-based kilocalories than 2000 meat-based ones. However, given the complexities of global agriculture and the food industry, is a plant-based diet really the most sustainable choice?

Land Use

From a land-use perspective, a plant-based diet is indeed more sustainable. As of 2018, agriculture covered roughly 43% of the world's ice-free and non-desert land.[23] In the US alone, cropland covers 391.5 million acres, which is roughly 20 % of US land area. Yet of that nearly 400 million acres, only 77.3 million acres, or just under 20% is dedicated to growing food directly for human consumption. That is a paltry 4% of total land area in the US, equal to roughly 121,000 square miles (or the size of the state of New Mexico). Land dedicated to growing crops for livestock feed accounts for 127.4 million (or about 33% of agricultural land area). Pasture or rangeland takes up an additional 654 million acres, making it the largest land use by far in the US. When considering the land being used for growing food for livestock and the pasture or rangelands for livestock to graze on, more than 780 million acres of land in the US is dedicated to raising livestock.[24] That figure is more than 10 time more acreage than that dedicated to growing food directly for human consumption and roughly 32% of the total US land area. What's more is that in developing regions of the world, clearing of land for grazing of livestock (mainly for export to developed regions) is a leading cause of deforestation, a major land use change and driver of soil depletion and erosion, as well as biodiversity loss and climate change.[25]

Water Use

The disparity in diets is even greater when considering the water use that goes into raising livestock. It is estimated that one pound of beef requires 1800 gallons of water (this figure includes the water used to grow the feed for the cattle). In comparison, it takes 300 gallons to produce one pound of tofu (a soy-based alternative to meat). Traditional raw foods, such as fruits and vegetables use even less water on average (Waterfootprint.org, 2019).[26] It is estimated that meatless burgers, such as the Impossible Burger, uses 80-90% less water and about 95% less land versus a traditional meat patty.[27]

Carbon Emissions

The energy use and carbon emissions associated with the production of meat are vastly greater than from the production of plants. One four-ounce serving of beef emits 6.61 lbs of CO_2, while an equivalent serving of legumes emits just 0.11 lbs of CO_2.[28] Not all meat has the high emissions of beef; pork and chicken are considerably less CO_2 intensive, emitting 1.72 and 1.26 lbs of CO_2 per four-ounce serving.[29] Still, these are orders of magnitude greater than legumes, and about two orders of magnitude larger than carrots and potatoes (0.07 and 0.03 lbs of CO_2 per serving, respectively).[30] Since meat contributes to roughly 57% of all CO_2 emissions in an average diet, cutting out or even back on meat can have a dramatic impact on an individual's carbon footprint.[31]

Local and Specialized Diets

However easy it might be to justify plant-based diets as more sustainable using the Rule of 10 and CO_2 emissions, the answer to the question of sustainability is much more complex due to the global nature of the food supply, seasonal demand for crops, and regulatory policy and oversight of agricultural production, etc.[32] Emerging research demonstrates that local and seasonal diets have lower overall impacts on the planet. Such diets limit the distance food has to travel from source to market to consumer, thus reducing the amount of energy inputs and carbon outputs from those food items. An example of such a diet include the 100-mile diet, where an individual only eats food grown or raised within a 100-mile radius of where they live, with an emphasis on fresh fruits and vegetables.[33] Another example is the omnivorous diet rich in fresh fruits and vegetables with occasional meat espoused by renowned author Michael Pollan.[34,35] The increased sustainability of such diets has much to do with the reduction in energy use and associated CO_2 emissions associated with transporting food thousands of miles in refrigerated trucks or ships.

Sustainability Judgement

Using the food sustainability definition offered by the FAO, such a local and seasonally varied diet wins as more sustainable overall, even if it consumes more water, occupies more land, and has potential issues with food diversity and security. Students should understand there is no clear winner here precisely due to such limitations, but that reducing their meat consumption (specifically beef and pork) can dramatically limit their impact on the environment.[36] As with the paper versus plastic question, value judgements are critically important – if individuals value low costs and reliable access to food (an entirely plausible value), then a standard American diet of processed foods and meat at every meal is justifiable. If a different individual values water conservation and land use preservation, then a plant-based diet is equally justifiable.

Gas versus Electric Cars

Nearly every major auto maker in the world has an electric vehicle in their fleet or in the concept phase of development.[37] Such cars have been praised for their ability to reduce CO_2 emissions from the transportation sector because they run off of electricity and thus do not emit CO_2 from their tailpipes the way traditional gas-powered cars do. However electric vehicles have come under scrutiny for the impact the mining of raw materials for their batteries has on the environment. This begs the question, which type of vehicle is more sustainable?

Resource Extraction and Pollution

The extraction and processing of both oil and lithium/cobalt for use in vehicles have extensive impacts on the environment. This discussion is limited to the extraction of the resources to power such vehicles, and does not extend to the extraction of raw materials that go into making the vehicles' bodies and other components.

The primary impact from conventional gas-powered vehicles comes from the extraction of crude oil and subsequent gasoline refining. The impacts of extraction of crude oil differ based on the nature of oil being extracted. For instance, offshore oil drilling has the potential for large-scale oil spills such as the Deepwater Horizon disaster in 2010, while conventional land-based oil drilling has less dramatic impacts mostly limited to land use changes and construction of infrastructure. Unconventional methods of oil extraction, such as those used to extract oil from tar-sands, have far greater impacts on the environment, including destruction of large swaths of virgin Boreal forest and habitat for numerous species and contamination of local surface and groundwater.[38] Another potential impact from the extraction and refining of oil is spills from a complex network of overland and underground pipelines such as the Keystone XL and Dakota Access Pipelines, or from transport ships such as the Exxon Valdez.

The impacts from resource-extraction related to electric vehicles stem from the mining of lithium and cobalt (integral components of the batteries) and from mining coal or fracking for natural gas to generate the electricity that power the vehicles. Any large-scale mining operation significantly impacts land use, biodiversity, and local air and water quality. Lithium was typically sourced from mineral deposits of spodumene, petalite, and lepidolite in traditional pit mines. However, the increased demand for lithium for use in devices such as laptops and cell phones caused a shift towards brine mining. This mining technique involves pumping lithium-rich groundwater to the surface and letting the water evaporate, leaving behind high concentrations of recoverable lithium. However, this material must be rinsed and processed with immense amounts of water. In the Lithium Triangle in Chile, Bolivia, and Argentina, where the world's largest lithium deposits are thought to be held, the arid temperatures make for easy evaporation. But those arid conditions also mean that water is scarce in the region, and using it to process lithium restricts use elsewhere.[39] Cobalt is typically mined from subsurface mines, mostly in the Democratic Republic of the Congo in central Africa, where health and safety regulations are weak and where much of the work is done by child laborers under oppressive and unsafe working conditions.[40] In addition to the ecosystem disruption associated with cobalt mining, mobilization of heavy metals into the air and water can have severe health impacts for local residents.[41]

Coal can be mined via many different methods, each with specific impacts, ranging from destruction of surrounding habitat and losses to biodiversity to increases in heavy metals in soil and water to acidification of ground and surface water and an increase in particulate matter in the surrounding air.[42] A common problem in all mining operations is the storage of waste generated from the operations, which poses a long-term threat to water quality and biodiversity. Like conventional oil drilling, fracking for natural gas has less visible and obvious environmental impacts. These include land use changes due to construction of drilling operations, accidental releases of methane from wells, contamination of groundwater (both from operations and from spills, leaks, or other releases), and a large water footprint (including the generation of toxic wastewater generated from the operation).[43]

CO_2 emissions

This question of sustainability, like those above, does not have a cut-and-dry answer. Instead, the sustainability of electric vehicles depends on where the electricity that ultimately powers them comes from. The general consensus from the US Department of Energy is that in geographic regions where renewable sources of energy contribute significantly to the overall production of electricity, electric vehicles emit less CO_2 than their gas counterparts. In regions where coal dominates electricity production, gas vehicles are believed to emit less CO_2.[44] The question has become even more difficult to answer in recent years with the emergence of natural gas as an electricity source since natural gas power plants emit significantly less CO_2 per kilowatt-hour in the production of electricity than coal-fired plants.[45]

This question is also complicated by the range of types of electric vehicles on the market. For example, in 2017 most EVs in the global market were 100% battery electric vehicles (BEVs) such as the Tesla Model 3 and a smaller proportion were plug-in hybrid vehicles (PHEVs), such as the Chevrolet Volt.[46] The difference between the PHEV and BEV is that PHEVs can only run on electricity for a limited range before switching to a gas backup, while BEVs run on electricity alone and do not have a gas backup. According to the National Renewable Energy Laboratory, PHEVs in regions with low-carbon electricity profiles emit 3.9 – 4.6 lbs. of CO_2 per day. BEVs in the same region emit 3.5 to 4.0 lbs. of CO_2 per day. In regions with high carbon electricity profiles, PHEVs emit 9.3 – 9.5 lbs. of CO_2 per day. In the same region, BEVs emit 11.7 – 12.2 lbs. of CO_2 per day.[47] This compares to an EPA estimated average emission of 13 lbs. of CO_2

per day for conventional gas-powered vehicles.[48] These data conflict with the consensus from the US Department of Energy. While driving a BEV in a high-carbon region approaches the same emissions as a conventional gas-powered vehicle, it is still one pound fewer per day, amounting to 365 lbs. fewer per year. Regardless of the electricity profile of the region, the more commonly driven PHEVs emit less CO_2 than their conventional counterparts, mostly due to their above average fuel economy when driven in gas mode.[49]

Sustainability Judgement

The hard data back driving electric vehicles as the sustainable choice in terms of CO_2 emissions. However, there is a lot of gray area in the answer to the question of gas versus electric cars because of the impacts of extracting the resources required to run each type of vehicle. The extraction of oil and its impact on local and even regional ecosystems is a significant factor that must be weighed against the environmental and human toll of mining lithium and cobalt. Once again, values play a huge role in making a judgement of sustainability. Like with paper versus plastic, the answer is clear if CO_2 emissions are the only contributing factor – electric vehicles are more sustainable. However, if an individual values the human rights and quality of life of those living in the Congo River basin of Africa where cobalt is predominantly mined, then driving a gas-powered vehicle is the better choice.

Strategies

In order to instill in students that science is not merely a body of isolated facts but a systematic process for acquiring new knowledge, I always try to incorporate real aspects of the scientific process into the classroom. The National Research Council (NRC) lays out a framework for how to ensure that under NGSS, students have authentic scientific experiences in their classrooms even as they learn the bodies of knowledge of the specific sciences. When implemented properly, this framework of "supports a better understanding of how scientific knowledge is produced and how engineering solutions are produced… help[ing] students become more critical consumers of scientific information."[50] This focus on process, according to the NRC, improves upon previous practices that reduced scientific procedures to isolated aims of instruction, rather than a vehicle for developing a meaningful understanding of the true scientific concept. Additionally, the process of discovering scientific truths allows students to engage in the types of critical thinking necessary to understand why the right is answer is right, and perhaps more importantly, why the wrong answer is wrong.

This emphasis on developing a strong evidence foundation supports student understanding of fundamentals of scientific truths instead of the traditional model of asking for rote memorization of facts that doesn't serve students well in their post-secondary education or in the workforce. In fact, the NRC designed the NGSS model with this specifically in mind, citing that in the past "rather than learning how to think scientifically, students were generally being told about science and asked to remember facts," whereas the new standards focus on student understanding by "linking concepts and practices that build coherently over time throughout K–12, thereby helping to ensure that students who meet the NGSS will be prepared to succeed in science courses in both 2- and 4-year institutions."[51] The presentation of content in this unit is phenomena-based, another hallmark of NGSS that helps students deepen their content understanding. In this unit, I make use of a flipped classroom, hands-on learning, and the Learning Focused strategy of Higher Order Thinking in order to engage students in the content presented above.

Using a Flipped Classroom

Because I have so much material to cover in advance of the AP exam and I don't dedicate class time to lecture or direct instruction, students must come to class with the background information already under their belt. This model, known as the flipped classroom, frees up time in class to be spent on authentic science experiences through lab experiments, collaborative learning, and peer review. Using the flipped classroom model effectively requires a great deal of advanced planning and buy-in from students. It involves more than just assigning readings and expecting students to complete them. Students need to find value in the at-home assignments and then be held accountable for completing them. In order to promote engagement with the flipped materials, I have brief daily quizzes based on the previous night's material. I allow students to use their notes and annotations to my outlines on these quizzes. For highly motivated students, this strategy works well. Less intrinsically-motived students often struggle early on with this model until they begin to see the value in coming to class prepared.

Hands-on Learning and NGSS Practices

In my classroom, I am more a facilitator of learning than I am a source of information and correct answers. To that end, my teaching toolkit is full of strategies that get students *doing* science rather than *learning* science. I employ a wide range of the NGSS SEPs in my classroom. In this specific unit, I will ask students to obtain and evaluate information, analyze and interpret data, construct explanations, engage in argument from evidence, and use mathematical thinking. The biggest challenge I find when employing the SEPs is wanting to interject. But it is important for me to limit my interruptions and let students struggle and find solutions on their own or in their small groups. Like with the flipped classroom, this has to be managed and not every student is going to be successful right away. But by not giving in to student demands and providing answers right away, I hope to train them to think creatively, work together, and develop their scientific "muscles" for use on the AP exam in May.

Higher Order Thinking

Like the flipped classroom and NGSS SEPs, Higher Order Thinking is a strategy that challenges students to go above and beyond. As this is an AP course, I do not shy away from challenging my students to analyze, reason, and apply information to different scenarios. Higher Order Thinking is a hallmark of my classroom and often bleeds into everything I ask my students to do, including as they design and conduct experiments, analyze and interpret data, communicate information, and engage in evidence-based argument. By forcing students to go beyond rote memorization or simple representation, students become better critical thinkers. By using this strategy, I train my students to compare and contrast, determine patterns, analyze relationships, evaluate information, and propose solutions. These are all skills espoused by the NRC framework and the College Board. Not using this strategy to challenge my students would do them a complete disservice.

Classroom Activities

In each topic, students complete required textbook readings and select supplemental readings as independent assignments. In class, students are posed with a simple question of which option is more sustainable. To answer this question, students first engage with case studies and current events. Then they participate in student-moderated classroom debates on the sustainable choice. Finally, students demonstrate understanding by answering and scoring released FRQs related to the specific topic.

Case Studies and Current Events

Paper versus Plastic

Students are first presented with this question: which is more sustainable, paper or plastic? I suspect that many students will default to paper, since plastic has almost become a four-letter word for much of today's youth. Students are then challenged to investigate deeper into the subject by examining information related to the categories by which the sustainability of paper and plastic are evaluated. They start by reading an article from the *New York Times* entitled "Plastic Bags, or Paper? Here's What to Consider When You Hit the Grocery Store"[52] and making a pros and cons list for both options. Students then review the Executive Summary from the 2006 UK life-cycle analysis report on paper and plastic[53] and write a two-sentence reflection. Finally, students engage with data on plastic pollution from the website Our World in Data.[54] On this site, they analyze the growth of plastic production, the geographic distribution of plastic production, consumption, and waste. While examining the data, students are asked to identify trends they see, do practice math calculations like percent growth and project future values, and ultimately summarize the key points. Students pause here to transition to a sustainability debate, described below.

Meat versus Plant-based Diets

Like in the previous case, this section starts with the simple question of which is more sustainable: meat or plant-based diets? I suspect that most students will side with plant-based diets based on prior lessons on agriculture and the environmental issues associated with producing meat. Students then engage with more detailed information on how land, water, and energy use and carbon emissions factor into making sustainable food choices. First, students are asked to reflect on their own food choices by taking an online quiz from the *New York Times* about what they eat on a typical day.[55] Then, they obtain more detailed information from a student-friendly interactive *Times* source.[56] Students are asked to pay special attention to the numerical data and to complete some basic mathematical exercises as practice for the national exam. Students again turn to Our World in Data to see how land use worldwide is almost exclusively associated with agriculture[57] and the amount of water consumed by agricultural activities.[58] Finally, students learn the local food options available in our area, including from our very own Penn Farm, through a discussion with our farm manager. At this point students pause to prepare for a debate, as described below.

Gas versus Electric Vehicles

As with each of the previous topics, this one begins with students voting on which is more sustainable: gas or electric vehicles. And as in each of the previous topics, I suspect that students will lean heavily in one direction – towards electric vehicles. Students dive deeper into this topic by examining the CO_2 emissions data for gas and electric vehicles from the National Renewable Energy Lab presented above. Students then watch video clips on the recent Keystone XL Pipeline spill[59] and cobalt mining in the Congo.[60] They then return to their textbook for general information on the mining and mineral extraction processed associated with coal and oil. Finally, students consider the infrastructure needs associated with gas and electric vehicles by making and discussing a simple map of the gas stations and charging locations available in our school's area.

Classroom Debates

After completing the readings, viewing videos, and guided web-inquiries, students use the information they have obtained to advocate for one choice as the sustainable option. Since I have a small class, students are grouped in teams of three, with one debate moderator. Remaining students are judges that are tasked with choosing the sustainable option based on the information presented by the teams during the debate. Students have a chance to play each role, as this format is used multiple times throughout the unit.

Each team prepares a one-minute opening statement to be read to the audience. Then, the moderator asks questions of the teams during a five-minute lightning round. These questions are sourced from the audience with my help, and are based on the information presented in the case studies and current events. After the lightning round, each team has one minute to deliver a closing statement to the audience. The audience then anonymously votes on which option is most sustainable. Finally, all students are asked to consider the totality of the information they have engaged with, and to reflect in writing on how their own values shape their judgements of sustainability.

FRQ Analysis

Answering previously released FRQs is an incredibly important part of my curriculum. Doing so provides students with opportunities for valuable practice and exposure to the types of integrated questions they will see on the national exam.

In the Paper versus Plastic section, students answer question 3 from the 2016 exam, available here: https://secure-media.collegeboard.org/digitalServices/pdf/ap/ap16_frq_environmental_science.pdf.

In the Meat versus Plant-based Diets section, students answer question 2 from the 2005 exam, available here: https://secure-media.collegeboard.org/apc/_ap05_frq_envir_sci_45691.pdf

In the Gas versus Electric Vehicles section, students answer question 1 from the 2002 exam, available here: https://secure-media.collegeboard.org/apc/envir_sci_frq_02_10393.pdf

I allow 25 minutes for students to answer the question. Then each student is given a copy of the rubric and grades themselves by highlighting on the rubric and in their answer where they earned points. Students then switch with a peer and grade their response. I provide support for judgements on whether someone did or did not earn points on a particular question. I also look for common misconceptions and provide an opportunity for students to reflect on how they can improve moving forward.

Appendix A

This unit covers all or significant portions of the following Learning Objectives as outlines in the 2019 APES Course and Exam Description:

Topic 5.12 Introduction to Sustainability
STB-1.A: Explain the concept of sustainability

Topic 1.10 Energy Flow and the 10% Rule
ENG-1.C: Determine how the energy decreases as it flows through ecosystems

Topic 5.4 Impact of Agricultural Practices

EIN-2.D: Describe agricultural practices that cause environmental damage

Topic 5.7 Meat Production Methods
EIN-2.I: Describe the benefits and drawbacks of different methods of meat production

Topic 5.9 Impacts of Mining
EIN-2.L: Describe ecological and economic impacts of natural resource extraction through mining

Topic 6.2 Fuel Types and Their Uses
ENG-3.C: Identify fuel types and their uses

Topic 6.5 Fossil Fuels
ENG-3.F: Describe the effects of fossil fuels on the environment

Topic 7.1 Introduction to Air Pollution
STB-2.A: Identify the sources and effects of air pollutants

Topic 8.2 Human Impacts of Ecosystems
STB-3.B: Describe the impacts of human activities on aquatic ecosystems

Topic 9.4 Increases in the Greenhouse Gases
STB-4.E: Identify the threats to human health and the environment posed by an increase in greenhouse gases.

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