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Human Population Over Time - Analyzing the Demographic Transition Model

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Introduction and Rationale

In July 2021, India announced that it was considering a two-child policy in order to keep its growing population under control, even offering cash benefits to those who are voluntarily sterilized. Such a policy is reminiscent of China's one-child policy that helped curb and plateau its population. Now, with the Chinese population growing much more slowly, India is projected to be the most populous country before 2030.[1] But this proposal raises several questions: why does this matter? Why would a government want to limit the size of its population? How does the population growth in India compare to other countries? These are all questions I suspect my AP Environmental Science (AP-ES) students would ask were we to read about this proposal as a current events activity. The answer to such questions lies in an a deep understanding and analysis of a phenomenon known as the Demographic Transition, which helps explain how populations respond to changes in their country's modernization.[2] Understanding the Demographic Transition is critical to students' overall success in AP-ES, as it sets the stage for the remainder of the course. But currently my lessons on it include the presentation of facts and figures and vocabulary terms. I think this topic deserves to be told as a story, one with a focus on the who, the how, and the why of this phenomenon.

If I were to ask my students what they thought the greatest human invention was, I would expect responses like the internet, cell phones or other modern electronics. Some may chime in with fire, agriculture, or the written word. But I bet that I could go far down their list of amazing inventions without coming across the newborn incubator. By number of years of life added, these medical devices are arguably the most important medical innovation of the 20th century. As Steven Johnson details in his book *Where Good Ideas Come From*, this invention had a dramatic impact on infant mortality rates in the modern world. Successive iterations of the rudimentary device originally developed helped decrease the infant mortality rate by 75% in the US from the end of World War II to 1998. What is so amazing about the newborn incubator is its simplicity. Essentially, it is designed to keep newborn babies warm (although modern versions are much more than that). Before this invention, infant mortality rates were incredibly high, even in what is considered the developed world.[3] Sadly in many "developing" countries, infant mortality remains high due to lack of access to proper medical care or adequate public health infrastructure. In such places, communicable diseases are especially deadly to newborns and children. The lack of medical technology and public health infrastructure represent significant constraints to life expectancy and quality of life.

Because of such constraints, throughout the vast majority of our species' existence, the human population was largely stable. Major growth did not happen until the advent of agriculture. Even then, the growth of human population was centered in regions where agriculture provided enough food to allow for permanent settlement. It wasn't until the Industrial Revolution began in the 1800s that our population began growing immensely. And even that growth was eclipsed by the massive growth brought on by the modernization of economies in the 20th century.[4] These are facts that students may learn in their introductory geography classes in 9th grade. But for most students this is largely the upper limit to which students study how, why, and where populations change, and what happens to countries, economies, and people as a result of those changes. This unit, designed to replace an existing one in AP Environmental Science (AP-ES), focuses in greater detail on the driving forces and consequences of such population changes. It focuses mostly on the historical human population, the Demographic Transition in particular, and environmental consequences of population change.

School Profile

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 between 2,000 and 2,300 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. Several years ago, William Penn began focusing on the growth of Career and Technical Education (CTE) 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. Students entering William Penn chose 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. William Penn also offers 25 Advanced Placement courses, the greatest 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 the student population.

Rationale

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. Since the course is officially part of a CTE program, students are expected to finish the course with some sort of job-applicable skill. A unit on the Demographic Transition and its connections to biotechnology offers me a recruiting chip to students in the Allied Health field. They have an opportunity to apply what they learn in their pathway courses in a different setting. Likewise, they can use their experiences in my class as context for the material from their pathway courses. To me, getting students to think critically about environmental problems and potential solutions is my primary goal, but I am always looking for ways to address those job skills as well. Learning how to find, select, scrutinize, and analyze data in order to construct an evidence-based argument or conclusion certainly falls under that umbrella.

Content Objectives

This unit is divided into three major sections. The first focuses on human population over time, including the environmental conditions and constraints that kept populations from growing significantly. The second and largest section of the unit focuses on the Demographic Transition Model and how it predicts and explains the demographic changes a country undergoes as a result of economic growth and development. This section will also cover concepts such as fertility, the Human Development Index, and population pyramids, as those topics will help students develop a deeper understanding of the Demographic Transition Model. The third and final section provides an overview of the environmental consequences associated with population change (though this is limited to an overview and leads into a separate curriculum unit). After completing this unit, students are able to: explain how human populations change in reaction to a variety of factors, including societal and cultural factors; explain the socioeconomic and environmental issues that arise from a changing population; and describe patterns or trends in data and use them to support evidence-based analysis and conclusions related to environmental concepts, processes, or models.

Human Population through Time

Throughout most of human history, the world population was around 1 million individuals, kept in check by scarce resources, disease, and climate fluctuations.[6] Scientists have even discovered several bottlenecks where the global population likely dipped into the tens of thousands.[7] The advent of agriculture allowed populations to grow slightly to around 2.5 million by 10,000 BCE. As is spread into multiple regions, the world saw the population continue to rise steadily, reaching 115 million by the year 1 BCE. 1000 years the later the population had reached nearly 300 million. This means that during this time the population was doubling about every 400 years. The world population reached the 1 billion milestone in 1804 and was now doubling every 240 years. The 2 billion milestone was reached in 1927, just 123 years later. Human population was now growing exponentially larger, and doubled to 4 billion people only 47 years later in 1974.[8] As of June 2021, the world population is 7.88 Billion.[9] While this number is astronomically higher than the roughly 1 million individuals that the planet is most used to, it does show that growth has slowed, as we have not yet doubled in the past 47 years. The growth in human population described above can be modeled using the Demographic Transition.

Demographic Transition

The Demographic Transition Model (DTM) is the phenomenon by which developing countries undergo specific, predictable changes in population as they modernize.[10] There is some debate on the number of phases of the DTM, but for the purposes of AP-ES, there are four: the Pre-Industrial Phase, the Transitional Phase, the Industrial Phase, and finally the Post-Industrial Phase. Each phase is characterized by the country’s birth and death rates (as shown in Figure 1). It is also useful to discuss fertility rates and some key economic and technological characteristics exhibited by countries in each stage.[11]

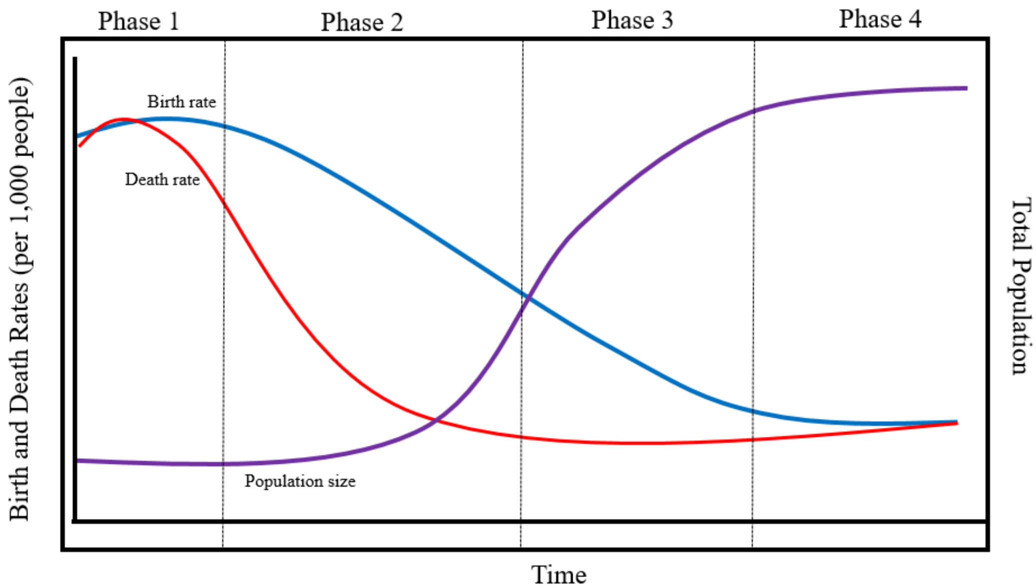

Figure 1: The Demographic Transition Model describes the observable trends in human population metrics as a country's economy undergoes modernization.

Demographic Vocabulary

Before students can dig deep into the DTM, they need to understand some specific vocabulary terms. These include crude birth and death, population growth rate, total fertility rate, replacement-level fertility. It is also useful to introduce the terms developed and developing country here (the limitations of these terms are discussed later). A country's birth rate is defined as its number of live births per 1,000 individuals. Likewise, its death rate is the number of deaths per 1,000 individuals. Ignoring immigration and emigration, population growth equal to the crude birth rate minus the crude death rate, divided by 10. A country's total fertility rate (TFR) is defined as the average number of children that each woman will bear throughout her childbearing years. Replacement-level fertility is the TFR required to offset the average number of deaths in a population in order to maintain the current population size. Developed countries are defined as those with relatively high levels of industrialization and income, while developing countries are those with relatively low levels of industrialization and income.[12] These definitions provide students the necessary vocabulary to understand and then analyze the DTM.

Phases of the DTM

The first phase of the DTM is the Pre-Industrial Phase. A country in this phase experiences little to no population growth due to nearly equal birth and death rates. The populations may also experience contraction for a several reasons, including epidemic, war, famine, etc. Birth rates are high because of high infant and child mortality. Demographers have made generalized observations that because parents know it isn't likely that each child will survive, they have as many as possible.[13] Children represent economic value in that they can work on farms or other labor settings (like cobalt mines in the Democratic Republic of the Congo) and are expected to provide care as their parents age. TFR is high to compensate for a high degree of infant and child mortality. Currently *no entire country* is in this phase; however, indigenous tribes in the Amazon or in Sub-Saharan Africa likely exhibit these characteristics (along with remote populations of various countries). Economically, this phase is characterized by subsistence agriculture or hunting/gathering, little (if any) access to modern sanitation and public health infrastructure, and an overall scarcity of resources. This phase is the "default setting" for the human species (recall that it took over 100,000 years for the global population to reach one billion people).[14]

The next phase is the Transitional Phase. The Transitional Phase is perhaps the most important because of its impact on population and the associated strain on societal and environmental resources. In this phase, advances in technology allow for a rapid decline in mortality. Examples of such technology range from agricultural improvements such as irrigation and mechanization that increase food supply and security to public infrastructure. Population growth rates accelerate in this phase because although death rates have dropped due to improvements in public health infrastructure, birth rates are still high. TFR is still high, though typically less than in Phase 1. This can largely be explained by two phenomena: a lag in economic shifts away from traditional agriculture and other forms of subsistence activities where children provide labor, and a lag in the cultural views on having many children. This still-high birth rate in turn leads to rapid population growth because birth rates remain high above death rates.[15] Nigeria, Pakistan, Mozambique, and India are prime examples of countries in the middle of the transitional phase.

As countries move into an industrial economy, their population enters into the Industrial Phase. Here, birth rates begin to fall as families decrease the number of children they have. There are several factors that result in this drop: the increased education of women, use of modern family planning and contraception, and a cultural and economic shift in the perspective of children. Death rates approach their minimum during this phase, and population growth slows and eventually begins to level off. TFR begins to approach RLF in this phase as the birth rate converges on the death rate.[16] Urbanization, access to technology, and quality of life are typical in this phase. Examples of countries currently in this phase of the DTM include the US, Mexico, and Canada.

Finally, in the Post-Industrial Phase of the DTM, birth rates equal and may decrease below death rates. Populations stabilize or even contract during this phase as TFR equals or is sometime less than RLF. Italy, Japan, and Germany are examples of countries that have entered the Post-Industrial phase and experienced population stagnation or contraction. Whereas countries in Phases 2 and 3 are worried about growing populations, those in Phase 4 are concerned on the negative effects of a stagnant or contracting population, which include higher costs of social security, pensions, and healthcare for an aging population, a smaller tax base, and a shortage of workers.[17]

Encouraging a Deeper Analysis of the DTM

It is important for students to understand that the DTM is merely one model with certain generalizations and limitations. Perhaps the biggest flaw in the DTM is the tendency to use it in order to separate countries into two poorly defined categories: developed and developing. These terms rely on income and industrialization levels, which is problematic for several reasons. First, it results in otherwise impossible associations. For example, Mexico and Mozambique are both considered developing countries, despite being vastly different in virtually every other aspect. Second, the terms imply that developed countries are in a sense "finished" and the gold standard, while developing countries should aspire to be like their developed counterparts. Third, beyond the narrative that higher incomes lead to better quality of life, these terms do little to account for the personal experiences of those who live there.[18] Instead of strictly using developed and developing, it is more prudent to use the Human Development Index and think of development less in terms of binary and more as a spectrum.

The Human Development Index (HDI) is a more comprehensive indicator of a development than income and industrialization alone. It factors in life expectancy, education, and standard of living into a figure that can be compared with other countries. The UN explains it as a “summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and having a decent standard of living. While Mexico and Mozambique may both be considered developing countries, they have very different HDIs. Mexico has an HDI of 0.779 and Mozambique comes in at 0.456. Mexico ranks in the high human development category, while Mozambique is in the low human development category. Further analysis reveals that Mozambique lags behind Mexico in all three factors but has shown significant growth since 1990. India lies somewhere between these two countries, with an HDI of 0.645, even though it is also considered a developing country. Digging deeper into the data reveals that Mozambique has significantly less education than both Mexico and India. As the DTM indicates, education (specifically of girls and young women) is critical to improving outcomes. Knowing this, organizations such as the UN and World Bank can target their efforts more specifically to increasing educational infrastructure and opportunity in Mozambique.[19]

Country	Economic Classification	HDI	DTM Phase
Germany	Developed	0.947	4
India	Developing	0.645	2*
Mexico	Developing	0.779	3
Mozambique	Developing	0.456	2
USA	Developed	0.926	3*
* There is some debate about current phase based on recent population figures; these are the phases according to the AP-ES curriculum.			

Table 1: Demographic and economic indicators for case study countries[20], [21]

Even with those limitations in mind, there are several reasons why the DTM remains a hallmark of demography. Perhaps the most important reason to understand the DTM is to close the gap in terms of the HDI and usher in a higher quality of life in developing countries. Currently there is a significant gap in the health status between developed and developing countries. In most developed countries the leading causes of death are noncommunicable diseases (illnesses that are not spread from person to person) like cancer, ischemic heart disease, and stroke. In the developing world, deaths from communicable diseases (illnesses that spread from person to person) like tuberculosis and malaria are far more prevalent. For example, a child in a developed country is more than 1000 times likely to die from a measles infection than one born in a developed country, owing largely to the lack of preventative medicine and access to adequate treatment. Malnutrition is also rampant in developing countries, which only compounds the effects of infectious diseases and other illnesses.[22] Additionally, providing populations with adequate reproductive technology (including contraceptives) is vital to slowing the rapid population growth countries undergo during the DTM. Providing such technology eases the population bomb that occurs in Phases 2 and 3 until cultural shifts begin to take hold and families begin choosing to have fewer children.[23] A comprehensive understanding of the DTM can also help governing agencies plan for the future with regards to infrastructure, agricultural needs, and environmental consequences.

Connecting Demographic Concepts: the DTM and Population Pyramids

Like many of the topics in AP-ES, knowing the phases of the DTM and how countries move from one to the next is only the beginning. Students should be able to make connections between other concepts and the DTM. The most obvious of those connections is with Population Pyramids (or Age-Structure Diagrams). This tool is an excellent way of visualizing the population of a country and making predictions about where it lays on the DTM and where it is likely to go in the future. They are visual representations of the number of individuals within specific age groups for country, expressed for males and females. Most diagrams split age groups into five-year increments, which are then represented on the y-axis. The x-axis of the diagram is the percentage that demographic represents in the whole population.[24] In previous years I have spent extensive time teaching students how to generate such diagrams from population data, but haven't gone much deeper. However, I think it is more important for students to be able to interpret and analyze the diagrams, make connections to the DTM, and then think about the environmental, social, and economic consequences of a particular diagram shape. Much can be said about these consequences by examining and comparing population pyramids for different countries, such as in Figure 2 below.

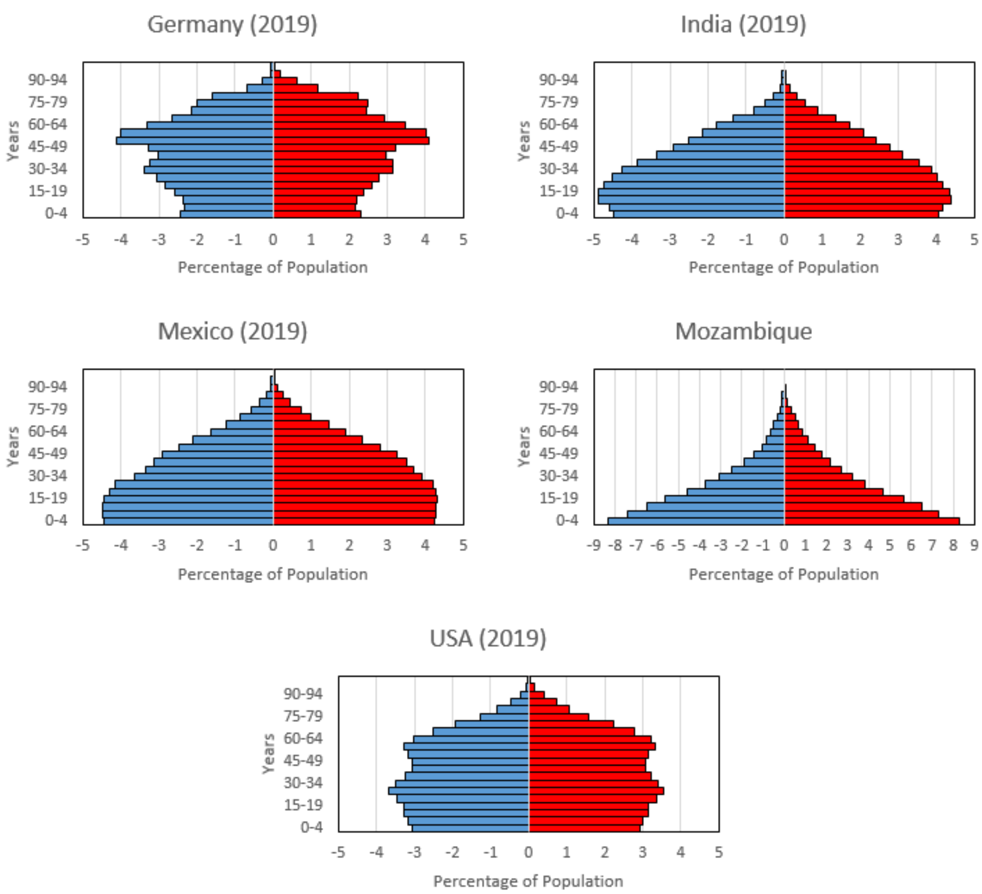

Figure 2: Population pyramids for case study countries (data from US Census Bureau International Database)[25]

For example, the economic, social, and environmental pressures faced by a rapidly growing Mozambique are vastly different than those facing an aging and declining population in Germany. These differences should be front and center when designing or adapting technologies to alleviate such pressures. These diagrams are also an excellent link between demographic concepts because their shapes fit nicely with the population growth aspect of the DTM. For instance, Mozambique's classic pyramid shape indicates rapid population growth, putting it in Phase 2 of the DTM, while Germany's slightly inverted pyramid is consistent with Phase 4. These next-level connections are a hallmark of the AP-ES curriculum.

Role of Biotechnology in Improving HDI

Biotechnology is critical in Phases 2 and 3. Of specific interest are those technologies that decrease the transmission and severity of infectious diseases because they dramatically increase the survival of infants and children under five years. Vaccines are chief among these developments. They work by stimulating the immune system to enhance the body's natural defenses, and are classically defined as a preparation of all or part of an infectious agent that primes the immune system to recognize a disease *without causing the disease*. For instance, the development and dissemination of vaccines has successfully eradicated Smallpox, even in countries in the early phases of the DTM. Efforts are also underway to eradicate polio worldwide with a focus on countries such as India, Pakistan, and Somalia. Vaccination against tuberculosis has already greatly reduced incidences and deaths in many countries in this phase.[26] Additional engineering innovations for ensuring access to clean water and sanitation have gone a long way towards reducing risk of death from communicable diseases. Doing so requires the expansion and improvement of sanitation. Such innovations have provided a roadmap toward increased health and quality of life for individuals living in economies that lag behind in terms of modernization.[27]

Adeptly applied biotechnology can also offer solutions to limit the population explosions often seen here through access to contraceptives, as well as improve the quality of life for individuals in lower HDI countries suffering from noncommunicable diseases like asthma or diabetes by developing low-cost and technologically appropriate preventative, diagnostic, and treatment options. Even more critical is that many countries, specifically in Sub-Saharan Africa and Southeast Asia are seeing dramatic increases in noncommunicable diseases as their life expectancy increases. Currently their public health infrastructures are not capable of dealing with high levels of both communicable and noncommunicable disease.[28] Additionally, as cities become more crowded with cars, trucks, and buses, and as climate change worsens, the negative environmental consequences will only exacerbate certain illnesses, including chronic respiratory diseases like asthma, chronic bronchitis, and lung cancer.[29]

Environmental Consequences of Population Change

The two biggest current environmental consequences of a growing population are CO_2 emissions and urban land use.[30] Both of these consequences are individual topics in my AP-ES class, so this unit provides only a preview of them. IPAT and ecological footprints are also introduced as a way of measuring the impact of population changes on the environment.

CO_2 Emissions

Increased CO_2 emissions are of concern because of their connection to global climate change. As the UN reports, CO_2 emissions have increased in lock-step with population growth since the 1700s. As more people exist on the planet, they consume more resources, many of which emit carbon at some point during their production and/or consumption. For example, more people means more agricultural production, which in modern times is carbon intensive due to synthetic fertilizers and a de-localized supply chain. Additionally, as countries modernize their reliance on cars and energy consumption increase, significantly increasing their CO2 emissions. Aside from a systematic reduction in food waste along the agricultural supply chain, lowering population growth has the most potential to reduce CO_2 emissions worldwide. In fact, population growth is such a concern that the IPCC declared it a significant impediment to limiting global warming by 1.5 $^{\circ}$ C by the end of the century.[31]

Urban Land Use

Urban land use poses a variety of challenges to the environment, including increased stormwater runoff, urban heat islands, degraded water quality, and losses of biodiversity.[32] As natural or agricultural lands are converted to urban or suburban lands, their percentage of impervious surfaces increases dramatically. In response, that area becomes subject to increases runoff and localized flooding, both of which have negative environmental consequences, including erosion of stream banks, alteration of stream/river hydrology, transfer of surface pollutants into local surface water bodies, and damage to critical infrastructure.[33] Urban heat islands occur when areas with a great deal of human infrastructure are considerably warmer than their less developed surroundings.[34] The biggest historical consequence of a growing population is deforestation and biodiversity loss, especially in Western Europe and North America.[35] When virgin forests are cleared to make room for human developments or agricultural lands, those ecosystems are permanently degraded. While this issue is less pronounced in countries further along the DTM (in fact there is some evidence of reforestation) it remains a critical environmental threat in the Amazon, Central African, and Equatorial Pacific rainforests.[36] Each of these impacts are discussed in future units of study in my AP-ES curriculum.

IPAT and Ecological Footprints

Since CO_2 emissions and urban land use constitute their own units, students need another way of discussing the environmental impacts of population growth. There are two methods of measuring and analyzing this impact with which students should be familiar: IPAT and ecological footprint. The IPAT equation is one way of estimating the impact of a human lifestyle on the environment by considering population, affluence, and technology. While it appears as a mathematical equation, IPAT is more of a conceptual representation of environmental impact. As population increases, so does environmental impact. More affluent people consume more resources than less affluent ones, thereby increasing impact.[37] Typically, increases in technology lead to more impact, though this not is always true as engineers increasingly factor in environmental impact into the design and manufacturing processes.

While limited by assumptions and generalizations, the IPAT equation is a solid way of comparing the impacts different countries have on the environment. It is especially powerful when it leads into a discussion of ecological footprints. The Global Footprint Calculator has produced data in line with what we would expect from an analysis of IPAT: countries with a lower HDI (specifically lower income) have a lower per capita footprint. India has a per capita footprint of 1.1 hectares, while Mexico and the US have footprints of 2.6 and 8.6 hectares, respectively.[38]

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."[39] 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.

In 2019, the College Board did a soft redesign of the AP-ES curriculum to better align the course with the NRC philosophy and provide students with a better educational experience, improve their assessment performance, and promote college readiness. This included the development of a more specific set of standards that revolved more around process than product. To that end, the course standards are now split by Science Practices and Course Content. The idea is that teachers engage students in the Science Practices as a means of developing mastery of Course Content. For those familiar with the Next Generation Science Standards, it is similar to the use of Science and Engineering Practices and Cross Cutting Concepts as a means of covering Disciplinary Core Ideas. Because of this shift in curriculum structure, I have had to rethink my instructional approach to the AP-ES course. Previously I held the view that we needed to cover all the content to whatever degree of depth time would allow for. However, since the redesign I have begun using strategies that better engage students in the specific Science Practices. Several of them are outlined below.

Blended Learning and the Flipped Classroom

Because I have so much material to cover in advance of the AP exam I don't dedicate much class time to lecture or direct instruction. Instead, I expect students to come to class with a certain level of background information that prepares them for hands-on and application based learning in the classroom. This background information comes from reading sections in our course textbook, watching Bozeman Science videos, and/or reading articles newspapers or other digital resources. This model frees up time in class to be spent on authentic science experiences through lab experiments, collaborative learning, and peer review. Effectively using this model requires a great deal of advanced planning and buy-in from students and their parents or guardians. 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 these do-it-yourself materials, early in the year I use frequent quizzes based on the assigned 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. After the third or fourth unit I begin phasing this out in favor of quick class discussions on the assigned material, and that seems to work very well for most students.

Hands on Learning through AP-ES Science Practices

In my classroom, I act as more a facilitator of learning than 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 use a wide range of the pf the Science Practices in my classroom. In this specific unit, I will ask students to explain environmental concepts, processes, and models through written expression, analyze sources of information about environmental issues, analyze and interpret quantitative data represented in tables, charts, and graphs, and propose, evaluate, and justify solutions to environmental issues. The biggest challenge I find when employing these practices is wanting to interject. But it is important to limit my interruptions and let students struggle and find solutions. Like with the blending learning and flipped classroom model, the Science Practices approach has to be carefully managed and not every student is going to be successful right away. 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.

Collaborative Learning

I use collaborative learning for two reasons: to foster a sense of community in my classroom and because studies show that peers teaching and learning from one another to be highly effective. Collaboration and group work, whether in pairs, small groups, or more complicated jigsaw groups, is a staple in my classroom. It leads to development of high order thinking and communication, self-management, and leadership skills. It also allows me to meet with more students in less time to check for common misunderstandings and provide immediate feedback. Working collaboratively allows exposes students to diverse perspectives and prepares them for real life social and employment scenarios.

Direct Instruction

While most of my class time is spent engaging students in authentic science practices and thoughtful discussion, the nature of my course does require a certain amount of direction instruction. I try to limit myself to 15 minutes of direct instruction a class period and make it as interactive as possible by using guided notes, check in questions, turn-and-talks, quick-writes, and other progress checks. I prepare PowerPoint slides as a guide for my direct instruction. I then post those slides on our learning management system for students to review.

Effective Questioning

Since my district adopted NGSS and the College Board rolled out the Science Practices for my course, I have made a concerted effort to provide opportunities for students to discover answers rather than providing them. One such way is through effective questioning, which I liken to the back and forth between a lawyer and her well-prepared witness. I have the answer in the back of my head, but I want to lead students with purpose, using simple questions that require only simple responses. It is a great way of engaging students in higher order thinking without them realizing it. They are connecting individual dots of knowledge in order to develop a larger picture of deep content understanding.

Design Thinking

In addition to preparing students to take and succeed on the AP-ES exam, I want them to develop tangible skills while in my classroom; this desire fits in nicely with the school's shift towards a CTE model and ultimately makes them more competitive in the job market and an on college applications. Of the Science Practices described above, proposing and justifying solutions to environmental problems is perfectly suited to get students thinking about the human-centered design of biotechnology.

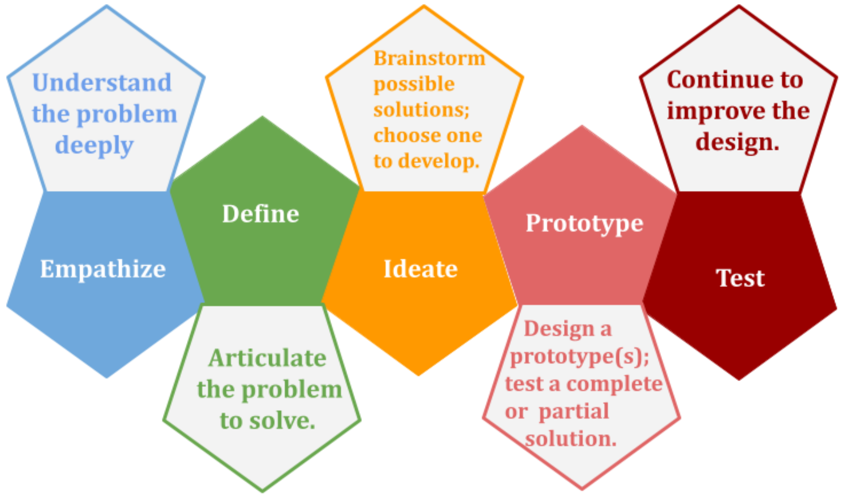

Figure 3: The human-centered design process[40] helps students understand what goes into the development of "appropriate" technology

Students work with the diagram in Figure 3 of the design process to focus on developing potential solutions to the problems and challenges posed by the DTM. This requires extensive scaffolding. I am fond of the "I do, we do, you do" strategy of introducing a topic like this.

Classroom Activities

This unit takes place over seven 90-minute class periods, with some activities taking more than one class period to complete.

Day 1: Introduction

On the first day of this unit, students are charged with completing three tasks: determining their "population awareness," reading the article about India's proposed two-child policy, and creating and revising a unit learning map.

Awareness Quiz

In their introduction to his book *Factfulness*, Hans Rosling asks readers to take a short quiz to benchmark their understanding of the world.[41] The quiz is thirteen multiple choice questions on topics ranging from the percentage of girls who finish primary school to global population distribution and access to modern technologies like vaccines and reliable electricity. Students start the same way Rosling starts his book, with this quiz and a debrief on the results. This activity should take between 15-20 minutes.

India's Proposed Two-Child Policy

Students read the article from the introduction to the unit. They use annotating strategies as they read to mark important information and vocabulary, as well as point out content that they have questions about. We discuss the article as a class, and students pull from their annotations to establish common understandings and lingering questions. This should take about 10 minutes in total.

Create Your Own Learning Map

Students are given a brief introduction to the concepts and terminology associated with the DTM and then complete their own learning maps using those concepts and terms. An example of a map is provided in Figure 4. Students start by organizing the key concepts surrounding the DTM, including the phases, causes, population pyramids, consequences, and designing solutions. Then, they attempt to organize the sub-categories for each. Students are encouraged to collaborate with one another on their learning maps. These maps serve as a useful self-assessment tool throughout the unit as a sort of roadmap to understanding and at the end of the unit when students should be able to explain all of the concepts and terms from their learning map in some level of detail.

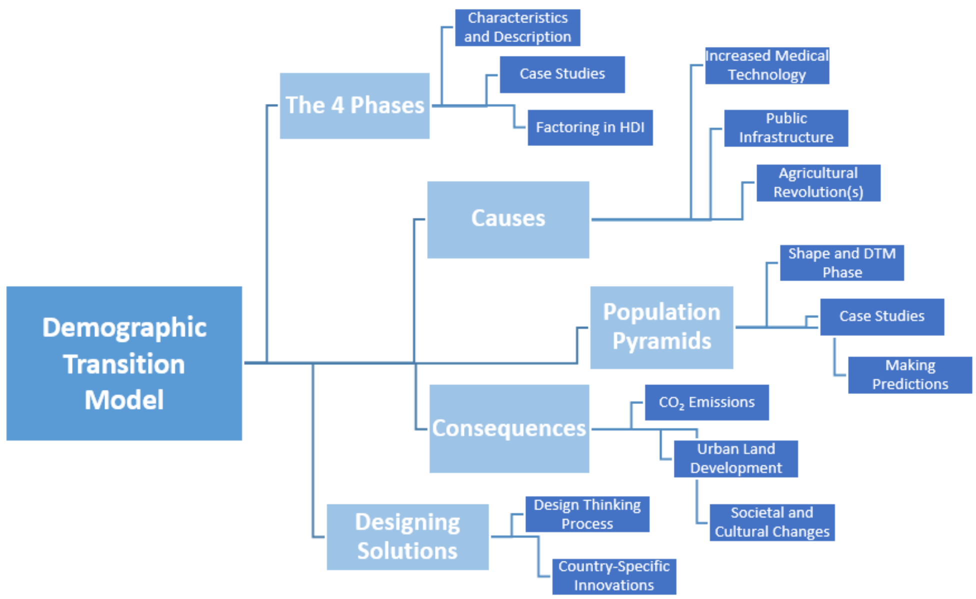

Figure 4: Example learning map for the Demographic Transition Model unit.

Students are encouraged to make use of digital learning tools such as Google Jamboards, Google Drawings, or Prezi. However sticky notes/poster board learning maps are also encouraged for students who wish to have a physical document rather than an electronic one. When students finish their maps they share with the larger class community. At this point I share my own version and we work towards a single, agreed-upon map that covers the scope of the entire unit. This document does not get graded as it is more useful as a self-assessment tool than an end-product. Completing this activity should take between 30-40 minutes.

If time allows, I conclude class is concluded by showing students a video clip of human population through time from the American Museum of Natural History website.[42] Otherwise, students watch the video for homework in order to prepare for the next class.

Days 2-4: Digging Deeper into the DTM

Over the next three days, students explore the details of the demographic transition, digging deep into the phases, causes, criticisms/modifications, connections to other concepts, and the consequences of the demographic transition.

Day 2: Phases and Causes

The first part of this day is dedicated to examining the four phases of the DTM and their causes. Students complete guided notes from an interactive lecture. At this point they have already completed the textbook section on this topic, so the lecture is limited in detail and more to address any early misconceptions and to provide clarification where necessary. The second part is for students to examine the case study countries. Students work in small groups and use population data and other indicators from Data Commons place explorer[43] to identify the phase of the DTM their country is in. Students then identify and explain the indicators they used to make their determination and record it on poster-size sticky notes. The class engages in a gallery walk to gather information. They also add sticky notes with observations or questions for each group as an extra layer of peer review. Each group must answer any questions for the whole class.

Day 3: Connecting the DTM to HDI and Population Pyramids

It is important for students to understand that the DTM doesn't exist in isolation. Instead it is part of a larger demographic analysis that should include connections to other socioeconomic indicators like the HDI. Students read a short article about the HDI from Ourworldindata.org and examine the following graphs from the site: "Human Development Index," "Children per woman vs Human Development Index", and "Human Development Index vs GDP Per Capita."[44] Students record a list of observations and questions about each graph. As a class, we discuss what conclusions can be made from these graphs and what connections we can make to the DTM. Specifically, students connect their case study country's HDI with its phase in the DTM (their findings should match those in Table 1). This activity should take about 15-20 minutes.

Then students move on to population pyramids. Like with the phases of the DTM, this is a topic they have already read about in their text, so they are relatively familiar with it. Students are first given population data and an Excel tutorial to generate a pyramid for their case-study country. Some groups are likely to be more proficient with Excel and the commands, while others may struggle to move from step to step. For that reason, I go through each step on the projector with the class using my own data so that students can see what to do and what to expect for each step. Those who don't need that level of support can use the written instructions to work at their own pace. Once students have completed their pyramids, they share the diagram with the entire class so that everyone can see the differences between our case study countries. Since they already know what phase of the DTM each country is in, they can make quick connections to the shape of each country's diagram and its DTM phase, freeing up time to dig deeper into the pyramids and what we can interpret from them. Students are asked to consider the symmetry and what leads to such lop-sided pyramids and any consequences that may arise. Students are also asked to project future population growth given the shape of the diagrams. Finally, students are asked to consider the connection between HDI, phase of the DTM, and the shape of their country's pyramid. This activity should take 60-65 minutes.

Day 4: Consequences

Because the environmental consequences of the DTM are independent units in my course, students only get a preview here. Students are first asked to come up with a list of potential environmental issues that might arise from a growing population. In my experience they are good at picking out the big ones, like climate change and pollution. In some cases, they may even dance around the idea of urban land development or deforestation depending on the year. But when pressed for details about why a growing population causes those things they struggle. This is an opportunity to engage students in some higher order thinking that will eventually provide excellent context for the forthcoming units on those topics. Engaging them in this process revolves around getting them to think in terms of cause and effect. They know the larger cause (population growth) and the larger effects (climate change, pollution, and urban land use). Now they just need to connect the dots. I help them connect those dots using simple questions, similar to a lawyer examining a well-prepared witness.

For climate change, it might go like this: Q1) what happens as there are more people on the planet? A1) we need to produce more food for them to eat. Q2) what happens as we increase food production? A2) more land is cleared for agriculture. Q3) does that increase or decrease the ability of that land to store carbon? A3) decrease. Q4) what does most modern agriculture rely on? A4) fossil fuels. Q5) what do you think happens to the number of cars, buses, trains, and other transportation vehicles as the population increases? A5) they increase. Q6) and what do most of those vehicles emit? A7) CO_2. At this point I summarize their responses and provide them with a written or diagrammed version. The questions I ask are greatly dependent on the prior knowledge of my students and vary any time I use this technique. But in order to ensure that students are successful in an activity like this I make sure to sprinkle in nuggets of information in prior units or in discussions.

Pollution and urban land use are probably best kept together for this exercise. A series of questions and answers might look like this: Q1) what happens as more people drive cars? A1) they emit more “stuff” Q2) do you think that “stuff” is good for the planet, or for human health? A2) no. Q3) and all those people are probably consuming more electricity right? A3) yes. Q4) and where does most of that electricity come from? A4) fossil fuel combustion. Here it would be useful to pause and introduce some of the major pollutants and their secondary products, including sulfur and nitrogen oxides, particulate matter, ozone, and smog. Q5) and what are those people driving and parking on? A5) asphalt or concrete. Q6) and do those materials allow water to infiltrate? A6) No. Q7) So where does that water go? A7) it runs off. Q8) Do you think that is good for local streams and other bodies of water? A8). No. Here then is a good place to stop and briefly introduce the idea of urban flooding and the issues it can cause, including back-ups of combined sewer systems, stream bank erosion, and the transfer of contaminants like sediment, oil, and other urban runoff products into local waterways. Again, these questions and their responses vary, and students are given a lot of leeway in order to keep their confidence high. As before, I provide a recap to the questions and answers and written and/or diagram for students. Completing both sets of questioning and summarization should take about 20-30 minutes.

Students conclude the day by reading about the IPAT concept from their textbook and exploring ecological footprints on footprintcalculator.org.[45] Since the website is a bit dense, students are given considerable time to explore their own footprint before being given license to modify their answers to see how their footprint responds. Together these activities should take 30-40 minutes.

Days 5-6: Design Thinking

After learning about the details of the DTM, students learn about how the design thinking process can help solve some of the problems associated with a large-scale demographic shift.

Day 5: Introduction to the Design Process

To start, students are shown the design thinking process in Figure 3 and asked to consider it one step at a time. Students should consider the following questions: why is it important to begin with the empathize step?

What does it mean to fully articulate the problem before deciding how to address it with technology? What does “ideating” mean to them? and Why is important to prototype and test whatever technology you develop? How is that an iterative process? Then, I lead students through an example of how this process plays out using the anecdote of the development of the infant incubator and its subsequent modification for use in places with technological limitations.

Now that students have examined the design thinking process and seen an example, it is their turn to address a problem associated with the demographic transition phase that their assigned country is currently in. They can design solutions to environmental, social, cultural, or economic problems that their country may face. Students work in small groups to begin the empathizing and defining stages. They are given 10 minutes to complete each process. By the end of this class period they need to have a well-defined problem that they can begin ideating around. Students are encouraged to begin the ideating process before the next class period begins.

Day 6: Design Something “Technologically Appropriate”

Student groups start this class period by sharing their problem statements with the larger class community using elevator pitches (90 second segments where they need to communicate the most important information related to their problem statement). The class is encouraged to ask clarifying questions and provide constructive feedback where appropriate. The idea behind this activity is to make sure each group has a solid understanding of the problem they are going to ideate and innovate around before moving to the next step. This should take about 20 minutes in total.

Once each group presents and gets feedback on their problem, they then move to the ideating phase. Hopefully they began this process informally for homework and have some general ideas about solutions to their problem that can be explored and refined given the feedback from the problem statement sharing. Groups are given 15 minutes to complete this process.

Students then move to the proto-typing stage of the design process, which will take place three 10-minute rotations. They are encouraged to work on paper and pencil or the notepad tool on their Chromebook. After each 10-minute rotation, groups must share their progress with a partner group. During this process groups provide immediate feedback to one another, ensuring that the design is grounded in the work they have done in empathizing, defining, and ideating. Groups then complete another 10-minute rotation. By the end of the period they will have had thirty minutes to complete their design and three rounds of feedback to use on improving it.

The final step is then to prepare a short 5-minute presentation on their design process. The presentations should be grounded in the demographics of that specific country. That is, the birth rate, death rate, growth rate, fertility rate, and stage of the DTM should set the stage for whatever prototype the group presents. Groups should explain how they used the demographic information to decide on a problem to solve and how their product will solve it. Students are given the remainder of the period to prepare these presentations, which should be around 15-20 minutes.

Day 7: Review, Revise, and Update Learning Maps and Design Presentations

The final day of the unit is split between two major activities. First, students revise their learning maps. Then, they present on their country, design process, and product.

Learning Maps:

Students start the final day of the unit by reviewing their learning maps from Day 1. Their task is to ensure that they have increased their understanding of the DTM as a whole by being able to explain the phases and their characteristics, the causes and consequences of the DTM, and how human-centered design can address some of those consequences. This activity is intended to be an open-ended question and answer sessions aimed at filling knowledge gaps or correcting misconceptions. I typically allot 15-20 minutes for activities such as this.

Design Presentations

The bulk of the final day is allotted for student groups to present their country and their design to the class. As stated above, the presentation should cover the demographic basics of their country, how they used that information to inform the selection of the problem and solution, and how their design can solve that problem. They are graded on a simple 3-2-1 rubric for each of those categories, along with a "professionalism" category. Each presentation should be between 5-7 minutes, with a few minutes allowed for questions at the end.

Appendix on Implementing District Standards

Completing this unit requires that students have met the following Learning Objectives according to the College Board's Curriculum and Exam Description: EIN-1.A - explain age structure diagrams, EIN-1. B - explain factors that affect fertility rate in human populations, EIN-1.C - explain how human populations experience growth and decline, and EIN-1.D - explain the demographic transition. Each of these standards can be broken down into Essential Knowledge statements that are more specific to the content of this unit. As students read and participate in the interactive lecture on the DTM, as well as work with their case-study country they satisfy EIN-1.D.1 and EIN-1.D.2, as well as EIN-1.C.1-4 and EIN-1.B.1-3. When students connect their understanding of the DTM to population pyramids they satisfy EIN-1.A.1 and EIN-1.A.2.

Throughout the unit, students also cover several Common Core State Standards (CCSS) for literacy in science and technical subjects. These include CCSS.ELA-Literacy.RST.11-12.1 on citing specific textual evidence to support analysis of science and technical texts, CCSS.ELA.Literacy.RST.11-12.7 on integrating and evaluating multiple sources of information in diverse formats and media, and CCS.ELA.Literacy.RST.11-12.9 on synthesizing information from a range of sources into a coherent understanding of a process, phenomenon, or concept.

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American Museum of Natural History. 2016. "Human Population Through Time." Amnh.Org. October 2016. https://www.amnh.org/explore/videos/humans/human-population-through-time.

This is an excellent video to show students at the beginning of the unit to get them thinking about why population growth was so slow up until the Industrial Revolution.

Bongaarts, John. 2009. “Human Population Growth and the Demographic Transition.” *Philosophical Transactions of the Royal Society B: Biological Sciences* 364 (1532): 2985–90. https://doi.org/10.1098/rstb.2009.0137.

This is a good article for teachers to read more about the details of the DTM.

Butler, Colin, and Stephen Dovers. 2015. “Population and Environment: A Global Challenge - Curious.” *Australian Academy of Science*. https://www.science.org.au/curious/earth-environment/population-environment.

This a good teacher resource for brushing up on the details of how population growth impacts the environment. It good also be a good enrichment resource for students who finish work early.

Data Commons. n.d. “Place Explorer.” https://datacommons.org/place.

This is a student-friendly website with a plethora of graphs, tables, and summaries of many different demographic and economic metrics. Teachers using this resource should provide specific links to pages of interest so students don't get lost on the site.

Delaware Department of Education. 2021. “Penn (William) High School Snapshot.” Delaware Report Card. 2021. https://reportcard.doe.k12.de.us/detail.html#aboutpage?scope=school&district=34&school=490.

Friedland, Andrew, and Rick Relyea. 2019. *Environmental Science for the AP Course*. 3rd ed. New York: Bedford, Freeman, and Worth.

This is my course textbook. It is the framework for all of my instruction and is well-aligned to the College Board's standards. Students are expected to read specific modules from the text in advance of class, as well as complete some of the quizzes and progress checks throughout traditional units.

Galor, Oded. 2012. “The Demographic Transition: Causes and Consequences.” *Cliometrica* 6 (1): 1–28. https://doi.org/10.1007/s11698-011-0062-7.

This is another good resource for teachers wishing to learn more about the DTM.

Global Footprint Network. 2021. “Footprint Calculator.” 2021. https://www.footprintnetwork.org/resources/footprint-calculator/.

This is the most widely-used footprint calculator among AP-ES teachers because it is so user friendly. Students can spend a lot of time altering responses to their questions to see how their lifestyle impacts their footprint. It also provides a good breakdown for where the largest impacts are coming from, allowing students to explore ways to reduce their footprint.

Gonzalez, Anjelica. 2021. “Design Thinking Crashcourse.” Modified from https://citl.illinois.edu/paradigms/design-thinking

This figure was shared in national seminar. It is a good resource for both teachers and students.

Hawks, John, Keith Hunley, Sang Hee Lee, and Milford Wolpoff. 2000. “Population Bottlenecks and Pleistocene Human Evolution.” *Molecular Biology and Evolution*. Society for Molecular Biology and Evolution. https://doi.org/10.1093/oxfordjournals.molbev.a026233.

Johnson, Steven. 2010. *Where Good Ideas Come From: The Natural History of Innovation*. New York: Riverhead Books.

This book has a lot of great information for teachers, though it is a technical read. While it doesn't contribute much direct information to understanding the DTM it has great ancedotes that can be shared with students.

Joshi, Manish, Harmeen Goraya, Anita Joshi, and Thaddeus Bartter. 2020. “Climate Change and Respiratory Diseases: A 2020 Perspective.” *Current Opinion in Pulmonary Medicine* 26 (2): 119–27.

Kaplan, Jed O., Kristen M. Krumhardt, and Niklaus Zimmermann. 2009. “The Prehistoric and Preindustrial Deforestation of Europe.” *Quaternary Science Reviews* 28 (27–28): 3016–34. https://doi.org/10.1016/j.quascirev.2009.09.028.

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This is a must read for any teacher who wants to learn about NGSS and the philosophy behind the sea change it brought about in science education.

Olopade, Dayo. 2014. “The End of the ‘Developing World.’” *The New York Times*, 2014. http://www.nytimes.com/2014/03/01/opinion/sunday/forgetdevelopingfatnationsmustgolean.%5Cnhtml?_r=1.

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Richards-Kortum, Rebecca. 2012. “Emerging Medical Technologies: High Stakes Science and the Need for Technology Assessment.” *Biomedical Engineering for Global Health*, 1–20. https://doi.org/10.1017/cbo9780511802744.003.

Roser, Max. 2019. “Human Development Index.” 2019. https://ourworldindata.org/human-development-index.

This an excellent teacher and student resource. Teachers can grab graphs, tables, and brief analyses to share with their students on basically any topic. Students can interact with the website to look at multiple data sets on similar topics and compare countries or time periods. Students should be provided with specific links or a set of specific instructions avoid getting lost on the site.

Rosling, Hans, Ola Rosling, and Anna Rosling Ronnlund. 2018. *Factfulness: Ten Reasons We’re Wrong about the World - and Why Things Are Better than You Think*. New York: Flatiron Books.

Like other materials put out by Rosling, this resource is a gem. The quiz in the intro is a great starting point for students. The general optimism is also great to share with students considering most of the content in AP-ES is rather negative.

Teh, Cheryl. 2021. “India Is Proposing a 2-Child Policy to Keep Population Down.” Insider. 2021. https://www.insider.com/india-2-child-policy-population-control-2021-7.

This article is the intro to the unit itself because it begs a lot of really good questions that will lead students into a study of the DTM.

United Nations. n.d. “Global Human Development Indicators.” Human Development Reports. http://hdr.undp.org/en/countries.

US Census Bureau. 2021. “Country Dashboard.” International Data Base (IDB). 2021. https://www.census.gov/data-tools/demo/idb/#/country?YR_ANIM=2021.

US EPA. n.d. “Heat Island Impacts | Heat Island Effect | US EPA.” Accessed October 9, 2020. https://www.epa.gov/heatislands/heat-island-impacts.

Weber, Hannes, and Jennifer Dabbs Sciubba. 2019. “The Effect of Population Growth on the Environment: Evidence from European Regions.” *European Journal of Population* 35 (2): 379–402. https://doi.org/10.1007/s10680-018-9486-0.

“World Population Clock: 7.9 Billion People (2021) - Worldometer.” 2021. Worldometer. June 2021. https://www.worldometers.info/world-population/#ref-1.

This is a novelty resource to show students once and then ingore (otherwise it can induce some stress as it constantly ticks up and up).

Notes

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