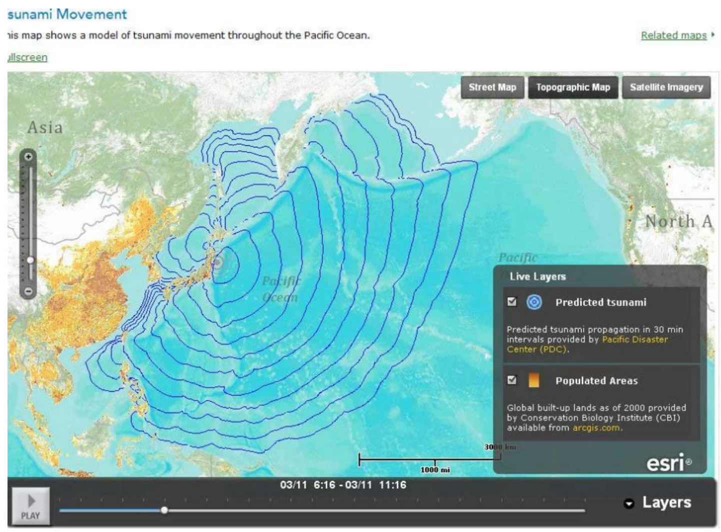
Connecting GIS to STEM Education



Modeling and analyzing the spatial pattern, time, distance, and direction of a tsunami stemming from Japan using a GIS. The above map was created using using ArcGIS Online (www.arcgis.com).

Introduction

GIS allows students to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts. STEM (Science, Technology, Engineering, & Math) fields require students to develop skills in collecting and analyzing data, but also in how to ask and answer questions based upon that data and the problem addressed. A GIS helps students answer questions and solve problems by enabling them to look at their data in a way that is quickly understood and easily shared.

12 Linkages Between GIS and STEM Education

How can STEM be more effectively taught and learned using GIS? GIS and STEM education are inextricably linked. Let's start with STEM as a whole and then move to the contributing disciplines.

First, STEM is a logical joining of four disciplines because of their common connections. Just as STEM disciplines share such goals of using the scientific method to solve problems, employing quantitative techniques, and integrating technology including multimedia, so too can GIS be used across these disciplines. GIS by its very nature a multidisciplinary tool. Not only can GIS take advantage of data and maps stemming from a variety of disciplines, but its statistical and analytical toolkit draws deeply from decades of research and development in a variety of fields. Therefore, students and educators using GIS in STEM are using a tool to study phenomena from a wide variety of disciplinary perspectives.

Second, STEM is career focused. Students using GIS in the classroom and in the field gain key skills that will help them secure careers that are in demand in the workforce. A key reason why is given by the national science education standards (Center for Science, Mathematics, and Engineering Education 1996), which state that "More and more jobs demand advanced skills, requiring that people be able to learn, reason, think creatively, make decisions, and solve problems. An understanding of science and the processes of science contributes in an essential way to these skills." GIS was created as a tool to solve problems and make decisions. Therefore, students using GIS tools are primed for STEM-based careers as wildlife biologists, soil scientists, seismologists, geographers, program managers, landscape architects, civil engineers, environmental scientists, and in hundreds of other positions. STEM occupations are projected to grow by 17% percent from 2008 to 2018, compared to 9.8% growth for non-STEM occupations. STEM workers command higher wages, earning 26% more than their non-STEM counterparts. More than two-thirds of STEM workers have at least a college degree, compared to less than one-third of non-STEM workers (U.S. Department of Commerce 2011). GIS, too, has enjoyed a steady growth rate from its origins in the 1960s through the present.

Third, using GIS adheres to the national science education content standards (Center for Science, Mathematics, and Engineering Education 1996). These outline what students should know, understand, and be able to do over the course of their primary and secondary education. Particularly well connected with GIS are the first two categories of standards: (1) unifying concepts and processes, and (2) science as inquiry. Unifying concepts and processes include systems, order, organization, evidence, models, explanation, change, constancy, measurement, and equilibrium. GIS software includes the ability to set up and test models, to measure distances, slopes, and areas, and to detect change in variables and across space. Furthermore, the "S" in GIS stands for "system", so systems thinking is embedded in spatial analysis. The mapped layers may or may not be related in theme, scale, proximity, and process to each other. For example, soil in an area is influenced by the bedrock geology, local weathering, and regional climate, and in turn influences the local land use, vegetation, and animals supported, influencing the ecoregion and the threats to that ecoregion. By being able to ask questions of multiple data sets, students can analyze concepts and processes in a holistic fashion. Let's consider climate as one example.

Climate underpins our agriculture, biodiversity, and our very civilization. GIS is a perfect tool for studying climate first because GIS was created to be an inquiry-based, problem-solving toolkit. Second, climatic variables are intricately tied to locations and are therefore affected by spatial relationships—of mountains to ocean currents, from depressions to soil types, from vegetation to human impact, and much more. Through GIS, students use maps, satellite images, graphs, and databases that are focused on the question of "where," to analyze patterns, trends, and influences, in the past, present, and future.

GIS is also well connected to the content category of "science as inquiry," as we have seen, because GIS provides a framework to model, to query, to run simple to complex analyses on maps, satellite images, 2D and 3D surfaces, databases, and more. These data sets can cover such topics and themes of climate, ecoregions, elevation, ocean and air currents, earthquakes and volcanoes, watersheds, habitat, wildlife migration routes, soil chemistry, surficial and bedrock geology, and many others. Therefore, GIS is also well connected to the content categories of physical science, life science, earth and space science, and science and technology. Finally, GIS is well-connected to the content category of “science in personal and social perspective” because students using GIS need to continually question the accuracy, validity, source, purpose, and appropriateness of the data they are using. Maps, like other data, are useful, but contain inaccuracies, distortions, and missing data. Error needs to be understood and managed. Finally, GIS is not a closed system, but rather, an open one that can be customized and shared.

Fourth, GIS meshes well with the mathematics content standards (National Council of Teachers of Mathematics 2000). The value of visualizing numbers is affirmed throughout the standards. Representing numbers, understanding patterns, relationships, and function, 2-D and 3-D geometric and spatial relationships, probability, statistics, change, models, measurements, problem solving, reasoning, connections, and communications are critical concepts. Every one of these can be explored using GIS tools and methods. For example, data can be mapped as raw numbers, as graphs, or as ratios. Data can be classified as equal interval, quantile, standard deviation, or with other methods. Geodatabases can be queried and variables can be created and calculated as in any spreadsheet.

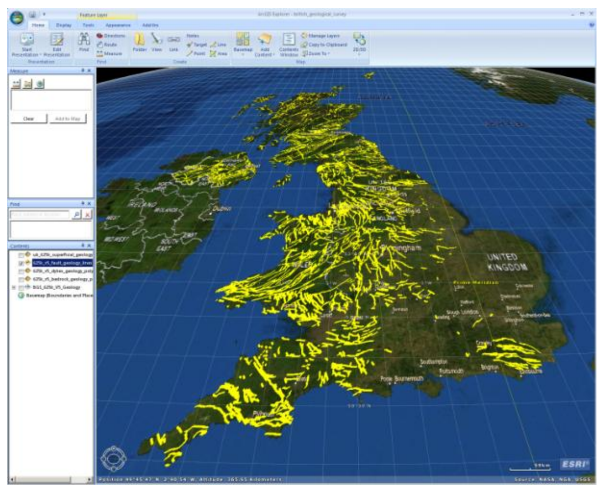
Fifth, every major key issue of our time, from climate change to analyzing environmental variables and beyond has a scientific component, and therefore, those issues can be examined from a STEM perspective using GIS. Each of these issues occurs somewhere, and typically occurs in multiple locations and at a variety of scales. For example, natural hazards have experienced much change in how they are perceived and managed throughout history, and across the globe. The same could be said about many other STEM processes—they exhibit a spatial pattern. Each arose somewhere, diffused somehow, and each changes over space and time. Each affects the ways that other phenomena interact. The geographic perspective is therefore important in understanding scientific issues, and GIS provides a rich toolset in which to use the geographic perspective. GIS allows for the multiple variables necessary in scientific analysis in two dimensions, three dimensions, and even four dimensions (including time). For example, pH in soil can be mapped as hills and valleys on a map of a field or region, with test points mapped with different symbols and cartographic techniques on that same “pH surface.” These points could be symbolized differently based on how the pH changes over time.

Sixth, not only are STEM-based enhanced by GIS, but conversely, the use of GIS is enhanced by a firm grounding in STEM. This grounding provides the framework by which questions can be formulated and problems designed. Asking questions is the first part of scientific inquiry: It forms the basis for knowing what types of social data to collect, what data to analyze, and what decisions to make. The GIS does not ask the questions. Rather, it is the user that has a firm foundation in understanding such STEM topics as plate tectonics, symbioses, mutualism, erosion, energy production, and others, who asks the questions. Systems such as watersheds and biomes have shaped human behavior and interaction, and conversely, humans have profoundly affected these natural systems. Understanding these interactions is fundamental to asking questions and solving problems with GIS.

Seventh, investigating STEM topics with GIS lends relevancy and real-world contexts to the topics. The central themes that scientists have studied for decades have recently become topics on daily newscasts. These include the loss of life and property from natural hazards, severe weather events and long-term climate change, how chemistry affects soil productivity, and many other topics have raised awareness to the need for studying these issues not in isolation but rather through the context provided by STEM education.

In recent years, three aspects of STEM education have become evident:

1. First, STEM concerns have become global issues.
2. Second, STEM concerns increasingly impact the everyday lives of everyone on the planet.
3. Third, STEM issues are complex and require a different kind of thinking, a thinking that not only crosses borders of countries or ecoregions, but also that crosses traditional disciplinary boundaries.



Eighth, students who use GIS in tandem with STEM education develop key critical thinking skills. These skills include understanding how to carefully evaluate and use data. This is especially critical in assessing scientific data, due to its increasing volume and diversity, and given its often sensitive and politically-charged nature. In addition, "crowdsourced" data is now appearing from "citizen science" initiatives all over the world, where ordinary people collect information on pine beetle infestation in a forest, the sighting of the first monarch butterfly of the season, the position of the terminus of the glacier with each passing season, and a host of other data. These data are more frequently being tied to real-world coordinates, mapped, and analyzed. Students and graduates using GIS and who are grounded in STEM will be in demand to help make sense of this deluge of incoming data.

Ninth, as the 21st Century makes abundantly clear, we live on a dynamic planet, ever changing on a variety of scales. Many of the science teaching and content standards incorporate the concept of change. Conditions may change quickly or slowly, and may come from natural or human processes. One way GIS enables change to be examined is through satellite images, assigning different colors to different combinations of wavelengths to enable particular patterns to be seen. Vegetation under drought stress or insect damage can be explored, or changes in land use from urbanization or agriculture. Climate change can be seen in the retreat of glaciers and shifts in coastlines of low-lying regions. GIS also offers a rich array of animation and other time-enabled functions to visualize and understand change.

Tenth, students who are well grounded in the spatial perspective through GIS are better able to, during school and after graduation, use data at a variety of scales, in a variety of contexts, think systematically and holistically, use quantitative and qualitative approaches to solve problems. In short, these graduates are better decision makers. Students engaged in GIS and STEM make heavy use of the inquiry process. This involves asking questions, acquiring resources, analyzing data, assessing and making decisions from resulting information, and acting on that information. This often leads to additional questions, and the cycle continues. Much of science has an applied nature—it leads to action. As issues such as water quality and availability and sea level rise transcend cultures and regions and become increasingly complex, an integrative decision-making tool such as GIS is critically needed. Students using these tools can make the kind of decisions that will positively impact people and the planet.

Eleventh, GIS through STEM adheres to the tenet that learning is often most effective when it takes place outdoors. Fieldwork has such a long and rich history within science that it is almost stating the obvious. However, in a world where outdoor education is often cut due to budgetary constraints, and when a frighteningly large proportion of the population has almost no connection with the outdoors, it bears emphasizing. In STEM, conducting research is often best done in the field. In the field, students can collect data on a myriad of phenomena, gaining a better understanding of processes, scale, and the region in a way that they might not be able to do in the classroom or laboratory. They can sketch, record audio and video, take photographs, use probes, or simply use their five senses, and bring that data into the GIS environment for analysis.

Twelfth, given the widespread concerns faced by the modern world, it is imperative that students study and understand STEM not only to equip them for life in the 21st Century, but to ensure that we emerge at the end of the 21st Century in a sustainable way. How can we expect decision-makers to care about the planet and its people unless they have learned about the planet and its people as students? And how can they learn about our world unless they engage in science and use GIS as students?

Resources Connecting GIS to STEM Education

Esri develops and connects educators to resources that enable the effective use of GIS in STEM education. Many of these resources, such as lessons, data sets, and tools, can be accessed via the Esri Education Community (http://edcommunity.esri.com). Let's explore just a few of these resources.

EdCommunity Blog

Every few days, the Esri education staff writes a column in the EdCommunity blog (http://edcommunity.esri.com/blog) about the application of GIS to education, and frequently these columns focus on STEM education. Topics include examining the resource needs of a world of 7 billion people, mapping natural hazards, examining human health variables, and much more.

ArcGIS Online

ArcGIS Online (http://www.arcgis.com) offers a free, powerful, and easy-to-use web-based toolkit where students and educators can construct, save, and share their own customized maps on an infinite variety of topics and scales. These maps can be compared in a variety of ways and panels, all using a standard web browser (see lesson http://edcommunity.esri.com/arclessons/lesson.cfm?id=641). The content is rich, ranging from population, demographics, natural hazards, land use, agriculture, food expenditures (see lesson http://edcommunity.esri.com/arclessons/lesson.cfm?id=563) to unusual imagery around the world (http://edcommunity.esri.com/arclessons/lesson.cfm?id=558), and much more. Data can be compared in many ways, such as in side-by-side maps, through altering the transparency or symbology of specific variables, and through analyzing the attributes. For more rigorous analysis with additional tools, ArcGIS Desktop (http://www.esri.com/arcgis) offers further capabilities.

Lessons

Numerous lessons on the ArcLessons library, (http://edcommunity.esri.com/arclessons) can be used in STEM education. Educators can use these activities to encourage spatial thinking, to teach and learn STEM content, and to foster GIS skills. For example, building an analytical story (http://edcommunity.esri.com/arclessons/lesson.cfm?id=650) shows how to use ArcGIS online to create, analyze, and present a map-based story about an issue.

A series of videos on the Esri Education Team's YouTube Channel and on a geography channel describes the process of gathering field data with GPS and mapping and analyzing it with GIS in educational contexts. The videos feature explanations and demonstrations not only on the technical procedures involved with gathering data on locations and characteristics of data and then analyzing its spatial patterns, but also the pedagogical advantages to using these technologies within the context of spatial thinking in instruction. In short, they focus not only the "hows", but also the "whys". Embedded throughout the series are issues of data and project management, scale, accuracy, precision, metadata, and appropriateness.

Excellent starting points include the Esri Earth Science and STEM resources pages, the careers page, and the mathematics resource page.

Case Studies

Numerous examples exist showing how STEM educators are helping expand their students' futures with GIS on http://edcommunity.esri.com. For example, in Science, a Wisconsin teacher uses GIS to encourage higher-level thinking. In Technology, Texas students use GIS to track H1N1 flu, while in Engineering, California teachers help get students in career pipeline, and in Mathematics, a Kansas teacher and students combine, math, science and GIS. These studies show the ease and power with which GIS can be incorporated into STEM education. It is imperative that we engage 21st Century issues with 21st Century perspectives and 21st Century tools such as GIS.

References

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