J-READING
JOURNAL OF RESEARCH AND DIDACTICS IN GEOGRAPHY
2, 9, December, 2020, pp. 53-66 DOI: 10.4458/3617-06

J - READING
JOURNAL OF RESEARCH AND DIDACTICS IN GEOGRAPHY
homepage: www.j-reading.org

The Impact of COVID-19 on Geography, GIS, and Education

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Received: October 2020 – Accepted: November 2020

Abstract

The COVID-19 pandemic is affecting the education sector in profound ways. Particularly in the fields of geography and geographic information systems (GIS), educators are responding by using modern, web-enabled GIS with spatial analytical tools, streaming data services, maps and web mapping applications, and virtualization techniques to teach these subjects online. They are also expanding their collaboration with colleagues since increased awareness and use of interactive maps and dashboards by the general public stimulated interest in spatial thinking with a result of GIS technologies being newly incorporated into several academic disciplines. In fact, COVID-19 itself offers a rich opportunity for meaningful lessons in the value of interactive mapping and analytical tools. Outside of the educational process, the pandemic has also inspired increased use of geographic perspectives and technologies in decisions about when, where, and at what scale to reopen educational institutions.

Keywords: COVID-19, Education, Geotechnology, GIS, Health, Mapping, Pandemic, WebGIS

1. Introduction

The importance of geography and Geographic Information Systems (GIS) tools in understanding and responding to emergency situations, past and present, cannot be understated. Analyzing patterns over space and time is a foundation of geography, and, for the past 50-plus years, GIS has been an effective technology for applying geographic thinking in a decision-making environment. Applied geography, through GIS, has been used to conduct research about and respond to natural disasters (such as droughts and earthquakes), human-caused disasters (such as chemical spills), and those naturally-occurring disasters that are exacerbated by humans (such as floods and soil erosion). In the not-too-distant past, when GIS was largely done on standalone computers, it was challenging to share geospatial data and workflows.

Epidemics including SARS, Zika, and Ebola employed GIS to ensure authorities and responders were equipped with up-to-date map-based information about confirmed cases, populations at highest risk, and availability of health-care resources (Geraghty, 2020a). GIS has also been used for decades to manage immunization campaigns around the world (Gammino, 2014; Eccles and Bertazzon, 2015). However, the advent of web-based GIS software tools, spatial data, map-enabled surveys, and interactive visualizations, coupled with the rapidly advancing global nature of the COVID-19 pandemic, further solidified the role of GIS as a critical, broadly useful and efficient tool for response (Kamel Boulos and Geraghty, 2020; Smith and Mennis, 2020). Almost immediately after the COVID-19 outbreak was first identified, GIS was used to analyze, formulate plans, and mitigate impacts. Within weeks, thousands of organizations were deploying GIS to study the situation, and millions more were consuming the resulting maps and data. Esri responded to more than 5300 requests for assistance globally. Many organizations registered their applications to be openly shared on Esri's COVID-19 GIS Hub site (see https://go.esri.com/USApps and https://go.esri.com/IntlApps) and by 31 March 2020 its development operations team tracked almost 10 billion system requests per day more than the same period the prior year.

If there was anything positive about the timing of COVID-19, it was at least that it came at a time when GIS had enough history behind it to have evolved into a web-enabled platform. The result was that from the earliest days of the pandemic, GIS became an essential tool for understanding, problem-solving, and community engagement. This modern web-GIS platform offers the ability to (1) perform spatial and temporal analytics in the cloud (scalable), (2) be built upon by individual users, not just national mapping or health agencies, creating their own web mapping applications (innovation), (3) ingest real-time information from a diverse variety of information feeds and from web mapping services (agile), and (4) engage a diversity of users in a cooperative environment (collaboration).

Specific GIS patterns of use were repeatedly demonstrated as essential to pandemic response. Dashboards were deployed to provide situational awareness for decision-makers and the public, demographic data was analyzed spatially to assess vulnerabilities to the virus, whether through exposure, transmission or disease susceptibility risks, and new forecasting models supported predictions about impacts on hospital bed and ventilator capacity. Many used mobile GIS survey tools to collect new datasets like symptom trackers or citizen reports of food and resource availability. Governments used location-allocation processes to site new resources such as drive-through testing sites and locator apps led residents to those new services. And one of the most common uses of GIS technology for COVID-19 response has been communication with the public through centralized information hubs.

As the COVID-19 pandemic continues to unfold, individuals, universities, government agencies, and private companies extend these patterns through story maps, infographics, and other visualizations. All of these visualizations and patterns of use, enabled by this modern GIS infrastructure, bring into a "clearer focus the complex spatial interactions that have been spreading and aggravating the virus" (Wright, 2020). Going a step further, those same individuals and organizations created geospatial websites to facilitate community engagements and serve data in open and transparent ways. One of the ways they did so was through ArcGIS Hub, a tool that emerged in 2018 as a cloud-based engagement platform. It organizes people (internal staff and community members), data (for open data portals and information sharing) and tools (applications, dashboards, surveys, event calendars) to support information-driven initiatives. Through it, users can provide input and information as citizen scientists.

All of this became possible because of advances in data sharing, particularly spatial data, over the last decade. Data as a service became a new GIS model that was much appreciated by data-using GIS analysts, but also by instructors, educational researchers, and students. Now, the bulk of the time allotted for any instructional lesson or research project could be spent on analysis, rather than data manipulation. Libraries of searchable and filterable online data services began to appear, such as the ArcGIS Living Atlas of the World. These libraries were met with societal advances in the notion of geospatial data as part of the open data movement. Fewer geospatial data sets fell under licensing and a fee structure, and more became freely and openly available because their producers became aware of the value of such data to users in their own organizations and to society as a whole. These two data related advances in licensing and openness, and data as services, resulted in the arrival of truly "big data" for the GIS user.

The implications of these advancements for instructors were many-fold, not the least of which was that they could choose problems for their students that met their instructional goals, as opposed to aiming the instruction at topics and locations for which data already existed. Students in capstone and other project-based courses likewise had more choices about what to study based on these advances. The COVID-19 situation fit squarely into this rich data environment. An early precedent was set compelling data producers to make all COVID-19 related information freely available. While, as always, caution and a critical eye on sensitive data was needed, spatial and tabular information was quickly made available down to neighborhood levels for many parts of the world within weeks following the pandemic announcement.

As a result of the convergence of data, spatial analytics, and multimedia map-based visualizations, the resulting resources were of extreme interest to policymakers delivering guidelines about mask-wearing and social distancing, and to the general public making daily decisions about travel, school, and work. Spatial analysis and data visualization served to enhance surge capacity models meant to predict, over time, the number of people who will require hospital care, intensive care, and respiratory assistance with ventilators. Running those models to test the impact of various levels of adherence to social distancing policies and comparing the results with local health-care infrastructure capacity offer insight to plan and prioritize for future capacity needs (Geraghty, 2020b). Spatial thinking and models, enabled by GIS, help societies to make informed choices and policy decisions in challenging circumstances. Geographic science proved to be an extremely effective means to integrate human knowledge, understand complexity, and chart a course forward.

The global visibility of the value of geographic science escalated hand-in-hand with the societal need to make decisions quickly. COVID-19 GIS-based visualizations were set up by the thousands within a matter of days of the pronouncement of the pandemic on 11 March 2020 (WHO, 2020). These visualizations were viewed on a scale as literally nothing before in history: The Johns Hopkins University coronavirus dashboard alone has been viewed over 4.2 billion times per day at its peak and hundreds of billions of times cumulatively. If the general public did not know of the power of interactive maps updated in near real-time before 2020, COVID-19 ensured that they certainly do now. This grave situation presents geography and GIS with an unprecedented opportunity to showcase its relevance to education and society. Pandemics are global events, not subject to political boundaries nor disciplinary boundaries. As never before, the COVID-19 situation illustrates that collaboration and cooperation are not just a collegial thing to do but are essential.

2. Impacts of COVID-19 on Instruction

Teaching Online. The most obvious immediate impact that COVID-19 had on instruction is that educators were forced, in many places around the world, even in the middle of the term, to suddenly switch to teaching their courses online (Figure 1) (Allen et al., 2020; Mishra et al., 2020; Rapanta et al., 2020; Dhawan, 2020). Lab-based courses such as physical geography and GIS were especially challenged since students could no longer access an institutional lab.

In a course such as GIS, this is a computer lab, and in physical geography, the lab may have included soil or water quality testing equipment. Educators responded by changing the means by which their courses would be offered, the tools and data used, and the content of those courses.

Figure 1. The most immediate impact of COVID-19 on education was to require courses and entire programs to online mechanisms. Source: Joseph Kerski.

Geography educators made adjustments to their courses in several ways. They took steps to ensure that their textbooks were accessible fully or partly online and made substitutions if they were not. They supplemented traditional paper maps and charts with digital ones, including those made with web GIS. They shifted activities to those that could be supported by Learning Management Systems (LMS), such as Canvas, Blackboard, or Schoology, and made extensive use of conferencing and webinar tools such as Zoom or GoToMeeting.

GIS educators also made adjustments. Some educators switched to completely SaaS-based tools and data services in their instruction. These included the use of tools such as ArcGIS Online, Business Analyst Web, and ArcGIS Insights, as well as web mapping apps and tools such as ArcGIS Story Maps, Web AppBuilder, and the ArcGIS Experience Builder. Rather than asking students to download and format all of their data, educators increasingly asked students to use streaming data services from IoT-fed sources, such as stream gauges, traffic counts, crime incidents, and wildfire perimeters. Other educators chose techniques that allowed them to continue teaching desktop GIS software such as ArcGIS Pro by virtualizing the lab environment with tools like Citrix VMWare, and Amazon Web Services. These virtualization techniques were not new but began to be used much more frequently when students no longer had access to on-campus labs or libraries.

The content taught in this new all-online environment was in large part similar to that which educators were originally scheduled to teach, though educators realized some changes were immediately needed. They needed to create and host all their lecture notes online as text, diagrams, or videos. If their text was not in digital form, or the students had no access to it, instructors needed to find a suitable replacement. Online bodies of content such as the University Consortium of Geographic Information Science (UCGIS) Body of Knowledge, began to be relied upon more heavily. To be sensitive to varying bandwidths that students were encountering in their home offices, some GIS instructors reduced the number of points to be geocoded or reduced the areal size of a study area.

Ways to teach with GIS. GIS has been used in three main ways in education (Kerski, 2019a).

First, GIS is used as a standalone subject to be studied in its own right. This takes shape as a body of content, manifested in learning a set of technology tools and understanding the theoretical application of spatial information. This typically occurs as part of a GIS or GIScience program in a university or, less commonly, a secondary school (Figure 2). Less commonly, it is housed in a social or natural science program. In community and technical colleges, it is often a standalone program focused on helping students develop key workforce skills that can be applied to solve problems.

Figure 2. GIS has been used in three main ways in education. Source: Joseph Kerski.

The second way in which GIS is used in education is as a set of research methodologies. In the past, researchers would typically consult a GIS expert on campus to accomplish this work, but as GIS has become more accessible, easier to use, and online, researchers began to do the work themselves, applying GIS tools to archaeology, climatology, and other fields from A to Z across a campus. The visibility of web maps and dashboards resulting from COVID-19 has further increased the interest in GIS as a research tool.

The third way in which GIS is used in education is as a tool to teach core content outside of GIS, such as in the disciplines of history, language arts, geography, sociology, mathematics, biology, geology, and other subjects. This method is most common at the primary and secondary school level. For example, story maps are used to teach about population change, 3D scenes are used to teach about landforms, and interactive web GIS maps are used to teach about river and coastal access impacted by a historical event.

This “third way” of teaching with GIS saw an uptick resulting from the COVID-19 pandemic. An increased number of educators outside of geography, earth science, environmental science, and GIS began to investigate GIS as an instructional tool. Health instructors were logically attracted to GIS given COVID-19, but so too were faculty in business, civil engineering, environmental science, history, and mathematics. Some faculty in these disciplines were already using GIS, but as maps were on most everyone’s minds with the pandemic, some began to investigate how they could create maps and visualizations about other topics. Furthermore, those in emerging fields such as data science and geodesign began to look at the cloud-based infrastructure of modern GIS and use it to teach their own content.

Curricular content. Instructors have long had a choice of either creating their own lessons or, increasingly, using growing online libraries of existing lessons. The health crisis caused many educators to look afresh at the wide variety of online graphic-laden lessons, tutorials and help documentation at their fingertips. The disruption removed some of the stigma (manifested in musings like “Is it lazy of me as an instructor to use existing lessons that others have created?”) formerly attached to such materials. The libraries of GIS lessons range from the ArcGIS Learn library (https://learn.arcgis.com), to creative commons (such as Open Geography Education), and to shared higher education resources such as those from the GeoTech Center and iGETT. Some instructors made content from Massive Open Online Courses (MOOCs) offered by universities and Esri a requirement.

For a number of instructors, the disruption served as impetus to reinvent their existing lessons. In GIS instruction, a shift away from strictly tool-based approaches has occurred, such as how to geocode or georeference. Instead the focus is geared toward how to solve problems using GIS. In fact, the disruption caused many instructors to look anew at the ultimate goal, helping students “learn how to learn”, emulating the kind of resource gathering, networking, and problem solving that students will assuredly use in the workplace. The process considered the entire workflow for asking and addressing geographic questions (Figure 3) from gathering and analyzing data, to planning, making decisions, taking action and assessing outcomes, while always considering how to effectively communicate the results of their work. Instructors in many disciplines continued to make increased use of multimedia story maps as means whereby students could communicate the results of their research as submitted URLs and/or as part of video or synchronous online presentations to their classmates and instructors. Instructors also used these web mapping applications to assess student work. Student-developed maps and apps increasingly became viewed as a part of a portfolio that students could “take with them” once they graduated and present to potential future employers.

As GIS continues to evolve, some instructors found that hands-on lesson instructions could be shorter, for several reasons. First, the workflows in ArcGIS Pro and other tools are more logical and straightforward than in older versions of software, negating lengthy explanation. In modern GIS, for example, a student is placed into wizard-driven “Step 1- do this, make these choices, satisfied? If not, here are some adjustments you can make. OK - on to Step 2...”.

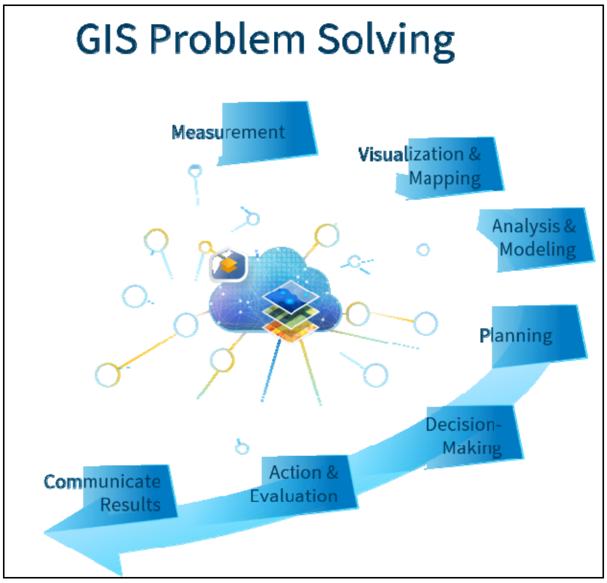

Figure 3. Workflow for GIS includes steps of observing, understanding, responding and communicating. Source: Esri.

This is the case for hundreds of other tools and processes that are easy-to-follow and yet offer options for customization. Second, instructors began to realize that they no longer needed to screen shot every procedure. In fact, if they do, they will be caught in a never-ending curation task as GIS tools continue to evolve. In the past, instructors had to create their own graphics and screenshots because these were by and large the only resource that students had access to. Nowadays, if a student gets stuck on a certain section, they can get help from online videos and tutorials, or the community of GIS users. Furthermore, resourceful students no longer read screen shots very much, if at all: They know that other resources exist and will find them if they have difficulty. Thus, instructors began to realize that they should spend less time updating procedures, and spend more time implementing new curricular ideas and teaching techniques.

Some educators also used the current situation to teach about the geographic implications of COVID-19, as described in section 4 below. For many, COVID-19 was too suitable a geographic problem to ignore, given its dynamism over space and time.

Collaboration and cooperation. More than just the educators themselves, the entire geospatial community responded to the crisis: Conferences and events shifted to online formats. Many of these events were vibrant, keeping the community connected, featuring discussions, demonstrations, papers, virtual exhibit booths, and even social hours.

Geography and GIS educators increased the depth and breadth of their networking in which they sought best practices for online teaching from their colleagues. Professional development not only went digital but increased in the number and variety of offerings. Private industry, professional societies, and educational institutions stepped up to support the education community. This included series of "global GIScience education conversations," panels offered by UCGIS (UCGIS, 2020) which focused on teaching GIScience online, theory, methods, practice, and student and faculty expectations.

One set of resources created for parents teaching at home and instructors teaching online has been a set of hour-long videos on how to teach with GIS entitled, The Mapping Hour. The videos are accompanied by lessons and data that are designed to scaffold concepts and skills for using ArcGIS Online for primary and secondary instruction. The videos take instructors and students from an initial introductory experience with GIS to integrating tools for an investigation about their own community or about a global issue. Another example of newly produced resources due to COVID-19 was a twice-weekly series of "online office hours" for the higher education community using Esri tools, that evolved later into a monthly lunchtime learn and chat session.

The annual Esri User Conference grew from 20,000 face-to-face attendees in past years to 83,000 when hosted online in 2020. Other events such as the Geo Ed conference, aimed at community and technical college GIS instructors, similarly increased attendance two to four-fold when they transitioned to an online format. Views of online discussions such as in the Esri GeoNet community, LinkedIn GIS and geography groups, geography and GIS-related YouTube videos, and Facebook geo-and-GIS groups, spiked. These pieces of evidence seemed to indicate that the GIS and geography education community became even more engaged and vibrant than before. A great deal of individual work still occurs, but many educators are beginning to realize that they do not have to author every single activity themselves, in a silo.

Through such networking opportunities, these educators became what could be called "resilient educators" those who are flexible and not only adapt but continue to innovate in challenging circumstances.

Field Experiences. Another impact of COVID-19 on education has been on field experiences. On the positive side, modern GIS includes a rich set of field applications, such as QuickCapture, Survey123, and iNaturalist, accessible to any student or faculty with a smartphone. These tools allow data to be collected, such as locations of trash or presence of invasive species, number of vehicles at intersections, cloud cover, or other information, and mapped. The data becomes a map service containing points, lines, or polygons. This mapped data can then be spatially analyzed, brought into 2D and 3D visualizations, or exported to statistics or other packages to be studied further. One challenge regularly encountered with the use of field data collection tools is internet connectivity. Notably, some tools can be used in an offline environment, in which the collected field data can be uploaded once the researcher is online again.

For many field experiences, students rely on a configured water quality, soils, glaciology, or other lab outfitted with relevant tools. These tools are often specialized and expensive. While a few typical lab tests can be run in a student's residence, such as a test for pH and dissolved oxygen in a water sample, most cannot, nor would a student be able to purchase or have room for most standard lab equipment.

Another characteristic that has long enriched field courses and programs is the experience of learning in a group. What will be the impact on learning if students are collecting field data alone rather than in a group? There is also an associated safety consideration for doing solo data collection. Time will tell if these courses, and the programs and universities that depend on them, will be able to survive the current disruption. This will have long-term impacts on the quality and quantity of scientific data collected in the field, with ensuing implications for research and policy.

Data Considerations. Another impact of COVID-19 and subsequent reliance on cloud-based GIS tools is increased awareness of data quality. Maps have long been relied upon as authoritative sources of data. The advent of open data platforms has made anyone a potential data producer, not just a data consumer. Thus, it is no longer solely the national mapping agencies of the world who produce maps: Today, millions of maps are created by the hour, in large part by non-scientists. Citizen science and crowdsourced apps have vastly increased the quantity of data at the fingertips of instructors and students. Web mapping platforms such as ArcGIS Online enable anyone in just a few minutes to easily create, symbolize, and classify a map, even one containing multiple layers. Thus, increasingly critical to teaching GIS, particularly web-based GIS, is paying close attention to the data, data quality and metadata (Kerski, 2015).

In this environment, it is important to ask the following questions: Who created the data? When? At what scale? How? What themes and fields are included? How often is it updated? Do I have permission to use it? Can it be trusted for my application? While some web mapping layers are well populated with metadata, many are not. Many appear to be authoritative but may not be. Helping students to be critical consumers of data, particularly mapped data, is more important now than ever.

Web-based GIS brings a new data concern to the fore. A student can easily make a copy of an existing map, modify it, and save it in one's own organizational web mapping account. If this is done, is the student carrying forward all proper attribution and citing the original source? What constitutes original work? What is the balance between leveraging existing resources and creating unique work products?

Further, in this online map-enabled environment, location privacy, personally identifiable information, and protected health information have become ever more important concerns. Since these issues are complex, founded in local legal statutes, and have the potential to put students, teachers and schools into a negative spotlight, additional instructional materials may be needed to support proper use of sensitive data.

Given the rapid pace of change in geography and GIS, educators are turning to data resources that are continuously updated, such as the Spatial Reserves book and data blog (https://spatialre-serves.wordpress.com) and Ethical Geo (https://ethicalgeo.org/). These guide educators in teaching strategies and guide students in becoming critical thinkers about data, methods, and map symbolization.

3. Returning to and Reconfiguring Campuses

GIS has been used in education for years as an administrative tool to manage campus facilities. From trees to light poles to fiber optic cable, the electrical grid, and water systems, this effort is aimed at ensuring campus efficiency and safety, and to build resilience. This is done chiefly at institutions of higher education, but is also used at primary and secondary schools, including the routing of school buses and decisions on where and when to open new schools based on changing demographics.

COVID-19 obviously impacted education's administration side. Every decision related to how, when, where, and at what scale a campus will reopen during and after the COVID-19 situation is a spatial one. A campus may include from one to dozens of buildings, but whether small or large, it is a dynamic place where flows of people, products, services and utilities change over space and over time, even by the minute (Figure 4).

The spatial decisions necessary during COVID-19 include understanding layouts and spaces to choose sections of dormitories and classroom buildings to reopen, optimal temperature screening locations, placing and restocking sanitizer stations, personal protective equipment stations, isolation areas, room capacities, distancing options, estimating crowd capacities, cleaning regimens at cafeterias and gymnasiums, reporting COVID-19 related problems and status, and many more.

Figure 4. A typical educational campus contains numerous buildings and thousands of flows that continually change. Source: Joseph Kerski.

Increasingly, spatial data, GIS tools, and workflows are in "solutions" form that delivers these tools together in a package, so that decision-makers can more easily implement them. This is of particular importance as decision-makers who have little or no background in GIS seek to take advantage of its utility. The Coronavirus Site Safety solution is a collection of maps and apps that can be used by schools and universities to create health safety plans for their campuses and monitor these plans as locations reopen. The solution includes tools such as a crowd counter app, a site safety dashboard that could be used by the health safety officer, and a spreadsheet that can be used to review the safety solution design. The site safety dashboard supports an executive view into all cleanings, disinfections, and restocking activities for a given location.

Another example of a packaged solution is one tailored for Coronavirus Health Screenings that could be conducted before employees, students and visitors are permitted to enter a building or campus. Many educational institutions are asking all employees and visitors to attest each day that they are symptom-free, have not had recent contact with anyone who has tested positive for coronavirus, and these institutions require a temperature check before people are permitted to enter a building or a campus. Map layers that are derived from this solution include those that are used to store the results of the screenings, those that contain the capacities of each room and building on campus, and one that records a survey filled out by visitors who self-report about their health status. Should a new COVID-19 infection arise, collected data could assist in contact tracing efforts to quickly break transmission chains on campus.

These solutions allow educational institutions (and others such as museums, libraries, office parks), to generate a dynamic set of maps and apps, rather than relying on static maps, paper forms, and time-consuming multi-step workflows. Real-time GIS-based solutions support agility in modifying policies and procedures when campuses are able to monitor the dynamic health situation that COVID-19 presents. Because each school and university has different needs, different history, different geography, these solutions are easily customized by those implementing them. See how two universities created "return to campus" resources that aid students such as that from Vanderbilt University and the University of Hamburg, and more importantly, they keep those resources updated in a rapidly changing environment.

A key development that is enriching the capabilities of educational administrators and facility managers is the blurring of the lines in recent years between GIS, Computer Aided Drafting or Design (CAD), and Building Information Modeling (BIM). As much of the decisions about campuses has to do with buildings, combining outside data layers such as parking spaces, bicycle racks, recycling bins, and so on, with interior data layers such as fiber optic cable, key-card enabled doors, emergency shelters, water lines, and the like, enables educational administrators and facility managers to create a "smart campus". As the name implies, a "smart campus" focuses on providing data and tools for decision-making. This includes a system containing interconnected databases that organize building and floorplan data that allow staff to create a "common operating picture" in which staff manage buildings and equipment as assets (Chiappinelli, 2020). It can include built objects such as electrical outlets and wi-fi routers, but also objects that can change, such as class schedules, furniture, and lab equipment. These capabilities can be used in ArcGIS Indoors, a 2D and 3D interior space management system. They can also be used in ArcGIS Urban, a planning and design tool that allows users to collaborate with a web-based 3D application that supports scenario planning and impact assessment. These tools aid in managing present campus infrastructure, assessing current and planned construction, and planning future campus growth. Germane to COVID-19, they can help make the campus safer. Moreover, they can help make the campus more sustainable, more walkable, energy efficient, and other elements that are increasingly part of university mission statements, long-range plans, and even serve as a recruitment mechanism to attract students to enroll in the first place.

Indoor maps are being used in direct response to the crisis, planning for the return to the physical spaces, and a response plan in the event of someone contracting the virus. But these maps do not magically appear; they have to be built and managed. For ArcGIS Indoors to provide information, for example, the following components have to be created: A floor plan map of each of the facilities (stadiums, classroom buildings, athletic centers, student commons, labs, and so on), an indoor-positioning system to locate people within each of the facilities, and a management dashboard to display key metrics associated with employees in facilities (Tait, 2020). "Geofences" are digital lines in the system that can be created to help navigate people away from restricted areas when they enter such statements as "find the most efficient route from my location to location x across campus" on their smartphone.

Facilities managers are beginning to use these tools to de-densify campuses for faculty and classrooms for students. Some educational institutions are using the tools to create a phased reopening system. A facility at phase 2 might enforce certain rules, such as prohibiting seating in open spaces and no more than 40% of the workforce can be in the workplace, and social distancing is managed very strictly. A facility at phase 4 might allow: 75% of the workforce back on campus, visitors with special permission, and common spaces to be open but with limited seating in cafeterias. To accomplish this kind of work in complex areas, like a university campus, and be able to adjust in response to evolving policies and to the virus, would be time consuming and inefficient with paper maps and charts. A dynamic problem-solving environment is needed with GIS enabling good data that can lead to good decisions. And for the individual student and faculty member, it can enable everyday decisions such as knowing which areas are off-limits and finding the nearest hand sanitizer station.

The creation of such systems has training and funding implications. Some facility managers possess CAD and GIS skills, but some still rely on outdated or inefficient practices, often through no fault of their own, but because they face continued budgetary challenges that prohibit investment in digital mapping solutions. However, COVID-19 has made many educational institutions keenly aware of the need for a digital set of maps and tools to enable them to move forward. Whether the funding and support from campus administrators will follow the awareness remains to be seen.

When and where these solutions are implemented, the geotechnology-using faculty on campus can provide some GIS training for the facilities managers. GIS students can assist in customizing the solutions and building the layers. This "on-campus internship" work gives students a real customer, their own university staff and fellow students. They also gain many practical GIS skills that will increase their marketability upon graduation.

4. Teaching about COVID-19 Using Interactive Mapping Tools

The advantages to using GIS as an instructional tool have been well-documented, but include fostering critical thinking, spatial thinking, and problem-solving. Students using GIS use real-world information in real contexts, locations, and situations. They use the same tools in education that they will encounter in the workplace upon graduation. They use a wide variety of data: remotely sensed imagery from aircraft, satellites, and UAVs, shapefiles, tables, and geodatabases, raster grids, ground photographs, videos, and other types of data as they construct maps and apps. Media fluency is enhanced (Kerski, 2019b) as students become adept at different ways to use the data, from downloading and unzipping it to using it as a streaming data service. With the guidance of their instructor, students become critical consumers of data as they decide whether or not to use it, and how to symbolize, classify, and project it. In using spatial analytical tools, they consider how changes in the tools' configuration and the model they use affect the results. Using GIS fosters the aforementioned geographic inquiry process of asking a geographic question, gathering and assessing data, exploring data, analyzing data, communicating about the data, and acting on the results of their findings. This usually leads to asking additional questions and the process continues. Students develop communication skills as they create and present about their research with the web mapping applications, such as swipe and story maps, that they create. In these ways they use GIS, students become empowered decision-makers and change-makers.

One fast way that educators and students can engage with these tools, focusing on COVID-19 as a timely topic, is to use the existing dashboard set up by Johns Hopkins University. Educators can also use this video to visualize the changes that occurred during the first three months of the pandemic, from January to March 2020. Another way to teach, learn, and understand the situation is to start with ArcGIS Online (www.arcgis.com). Start a new map, modify it, add data, search for layers in ArcGIS Online, find the COVID-19 case data updated and shared by JHU, and add this data layer to the map. The data will look like that shown here (Figure 5).

Because this map exists in ArcGIS Online, educators and students can perform many tasks on it: They can open and examine the table, sort on specific attributes such as "cases", filter the data for specific criteria, change the base map, and add data to the map such as ecoregions, population density, airports, and more. All of this can be done without signing in to ArcGIS Online. But equipped with an ArcGIS Online account (via the learn.arcgis.com program, via the developer site at developers.arcgis.com, or via the school or university ArcGIS Online organizational account), the capabilities expand. Once signed in, powerful spatial analytical procedures can be performed on it. These include summarizing points within polygons, spatial joins, overlaying one layer on another to understand intersections, creating map data from geocoding locations from tabular data, and enriching data using cloud-based data such as demographics, environmental conditions, or consumer behaviors.

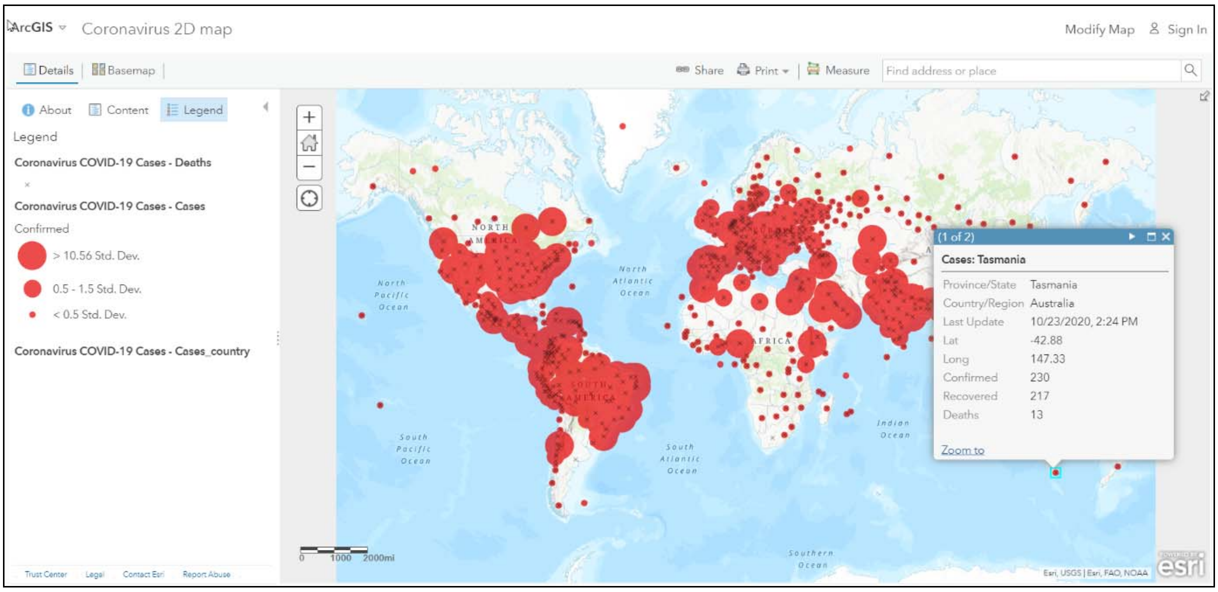

Figure 5. COVID-19 data mapped in ArcGIS Online. Source: Esri with data from Johns Hopkins University, the World Health Organization, and other sources.

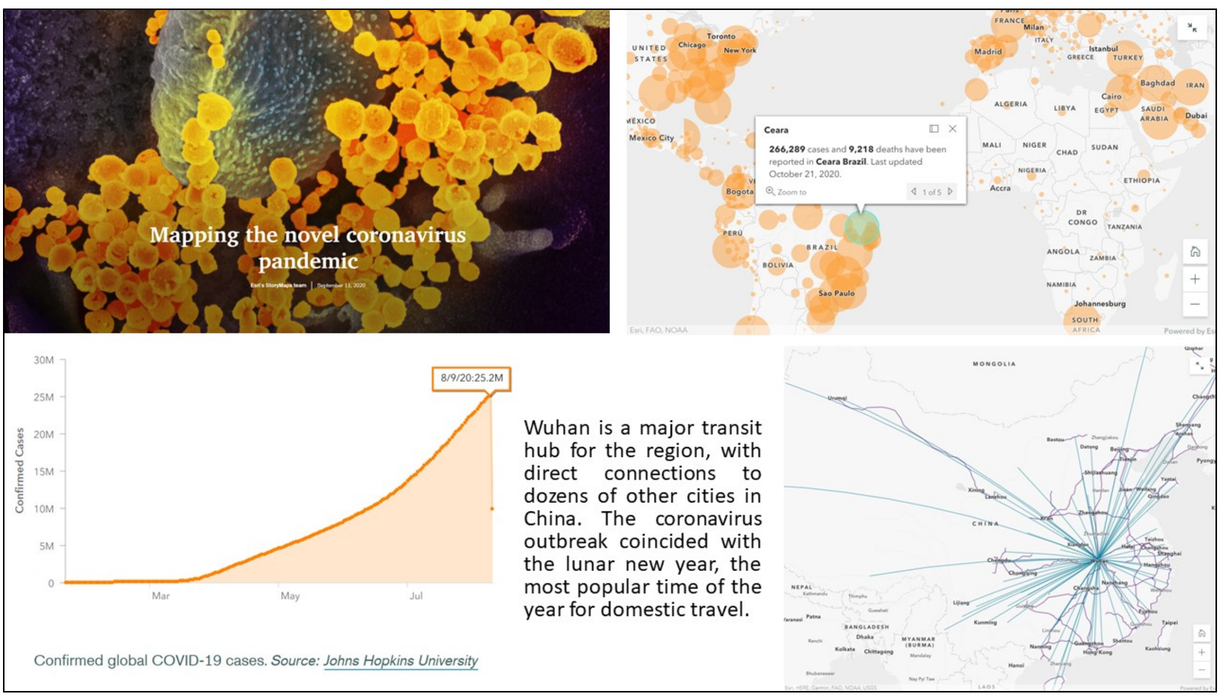

Figure 6. COVID-19 story map. Source: Esri with data from Johns Hopkins University, the World Health Organization, and other sources.

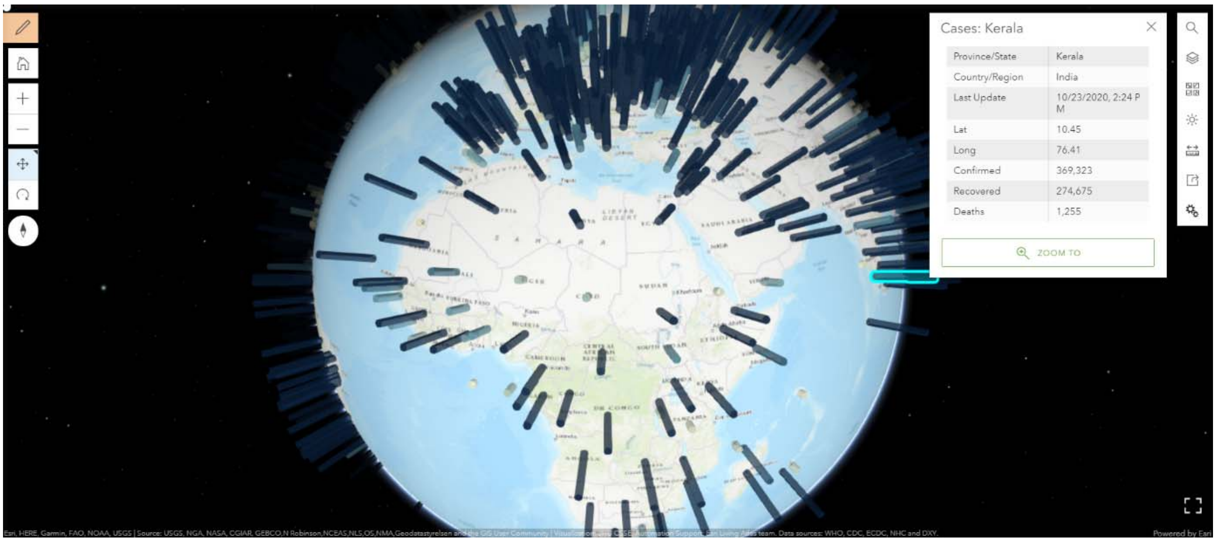

Figure 7. COVID-19 data displayed in a 3D scene. Source: Esri and Joseph Kerski with data from Johns Hopkins University, the World Health Organization, and other sources.

Educators and students can also share their maps with others. The “others” can be the entire world, their educational institution, or a small group of collaborators. Or, if the map or app is a work in progress, they may choose not to share it with anyone. They can also create a multimedia story map or another type of web mapping application, from it. The story map shown in Figure 6, for example, is updated daily, and is a powerful teaching tool that could serve as an idea for story maps students could create.

An instructor or student can also model the data in a 3D scene, with polygons extruding from the point data to illustrate a magnitude (Figure 7).

A student or instructor can also create a dashboard from these data sets. A dashboard is a dynamic set of content that can contain a map and key performance indicators in the form of gauges, images, and graphs, giving a “one screen” view of any phenomenon. This lesson shows how to create an interconnected dashboard, a survey, maps, and a story map. Spatial analysis tools such as proximity, enrichment, and standard deviational ellipse can be run on the data in ArcGIS Online, or for further study, in ArcGIS Pro. Another way of understanding COVID-19 and to foster skills in spatial thinking and analysis is to create infographics from the data as explained here for small geographic areas. As a response to the crisis, the Esri Coronavirus landing page was set up in March 2020 and continues to be updated, providing data sets, maps, solutions and applications.

5. Conclusions

The story of COVID-19 and education is still being written, and this article should be viewed as one composed in the early days of the impact. However, four things are already clear: Education will never be the same, educators have been resilient and innovative, modern GIS was well poised to be used in the face of disruption, and the attention on interactive maps and spatial thinking has never been greater.

Educators, by necessity, have broadened their thinking and their toolsets to help them succeed in these unusual circumstances. There is no doubt that COVID-19 is requiring innovation as a means to cope with the changing world. The future implications could be very positive given the emphasis on mass modernization toward web GIS and its many advantages.

Historically there have been too few studies at the intersection of GIS and education (Kerski, 2015) but those about teaching geography and GIS online during COVID are emerging (Bagoly-Simó et al., 2020; Hazen, 2020).

However, the current disruption in education suggests a natural experiment of sorts and provides an opportunity for future studies to examine the successes and failures of online learning, borrowed curricula, and collaborative problem solving. Continued and expanded teaching about GIS and with GIS will prepare students to take on the challenges of tomorrow with greater skill.

Acknowledgements

The authors would like to thank Esri for its longstanding support particularly in the fields of health and education.

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