That Thing in Your Pocket: Cultivating a Geo-Sustainable Mindset in High School Chemistry Students Using GIS to Study Smartphone Components

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Smartphones are ubiquitous in high schools across the US, but students rarely learn about the complex world of elements and materials beneath their shiny exteriors. Educators can bridge the gap between the abstract concept of smartphone elements and the real-world geography of their origin and impact by integrating ArcGIS geospatial software into their curriculum. A team of researchers has been working with high school teachers to infuse geospatial concepts and technologies into their teaching. One project involved a teacher using GIS to revisit his approach to teaching the periodic table: he would have his students investigate the global origins of smartphone components. This approach equipped students with essential knowledge about the materials that power their daily lives and nurtured critical thinking skills and an awareness of the environmental and ethical dimensions of technology consumption. This paper includes a description of the project and how geospatial technology was utilized, as well as a discussion on the implications and future research in this area.

Keywords: chemistry education, high school, GIS, geospatial technology integration

Across the diverse landscape of high schools in the United States, one object stands as ubiquitous across all contexts: smartphones (Sutisna et al., 2020). These pocket-sized computers have revolutionized communication, information access, and entertainment, while concealing a complex world of elements and materials beneath their shiny exteriors. Despite, or perhaps because of this impact, teachers have struggled to accommodate smartphones in their classrooms (see, for example, Dinsmore, 2019). Innovative science teachers have found ways to integrate smartphones into instruction, often via inquiry learning (Gordan et al., 2019; Kali et al., 2018). One opportunity to integrate smartphones into science instruction is to investigate it as a physical object – what substances go into that thing in your pocket?

Smartphones contain a wide variety of metallic elements (Bookhagen et al., 2020), many of which are mined in conflict zones (Lezhnev & Predergast, 2009). Given that many smartphone users are not aware of this aspect of the supply chain, a lesson on smartphone components provides an opportunity for teachers to engage students about the origins and effects of the technology many of them take for granted (Aggarwal & Zhan, 2016).Contemporary students are today's adopters and users of a variety of digital devices; in the future they will be the decision-makers confronted with the reality of developing, manufacturing, distributing, and disposing of digital devices in a way that is sustainable for the planet and its people. The challenge is how to connect students' conceptions of the familiar object, the smartphone, with the distant geographic and human contexts of the conflict minerals it contains. One reflective chemistry teacher employed geospatial tools (ArcGIS Online and its related software) to make these connections visible and cultivate a geo-sustainable mindset among his students. By harnessing the capabilities of ArcGIS, educators can bridge the gap between the abstract concept of smartphone elements and the real-world geography of their origin and impact on individuals, society and the environment (Kerski, 2008).

ArcGIS is currently the standard for companies, organizations, and governments who conduct geospatial analysis for everything from detecting flood zones to analyzing supply chains. The use of ArcGIS as a pedagogical tool to engage students in hands-on, exploratory learning experiences has yet to gain wide-spread adoption in many schools. A team of researchers across three universities has been working with high school teachers on seven campuses on a curriculum innovation project where they infuse geospatial concepts, strategies, and tools into their teaching in order to help students develop their spatial reasoning and awareness across a variety of disciplines (see, for example, Popejoy et al., 2023). One project that has emerged from this project entailed a teacher using GIS to support his students' understanding of the global impact hiding in their smartphones (Aggarwal, 2011). This approach not only equipped students with essential knowledge about the materials that power their daily, social, and entertainment lives, but also nurtured critical thinking skills and an awareness of the environmental and ethical dimensions of technology consumption.

CASE CONTEXT

This project addresses the importance of smartphone element analysis, discusses the capabilities of ArcGIS software, outlines the proposed strategy for classroom integration, and explores the implications of this approach for both educators and students. This journey into the unseen world behind our digital screens provides students with a deeper understanding of technology, geospatial awareness, and environmental stewardship.

The central enactor in this case is a high school chemistry teacher employed at a STEM (Science, Technology, Engineering, and Mathematics) academy situated in a large metropolitan area in the Southwest region of the United States. Prior to developing and implementing the lessons described here, the teacher had participated in professional development about using ArcGIS Online, Survey123, and StoryMaps. Other participating teachers at his school had brought these activities into their classrooms and implemented geospatial lessons such as water sampling at a nearby river, observing local bird populations, or exploring drone-based mapping and logistics. For this chemistry teacher, however, this would be his first time bringing this toolset into his classroom for students to use as part of their learning process.

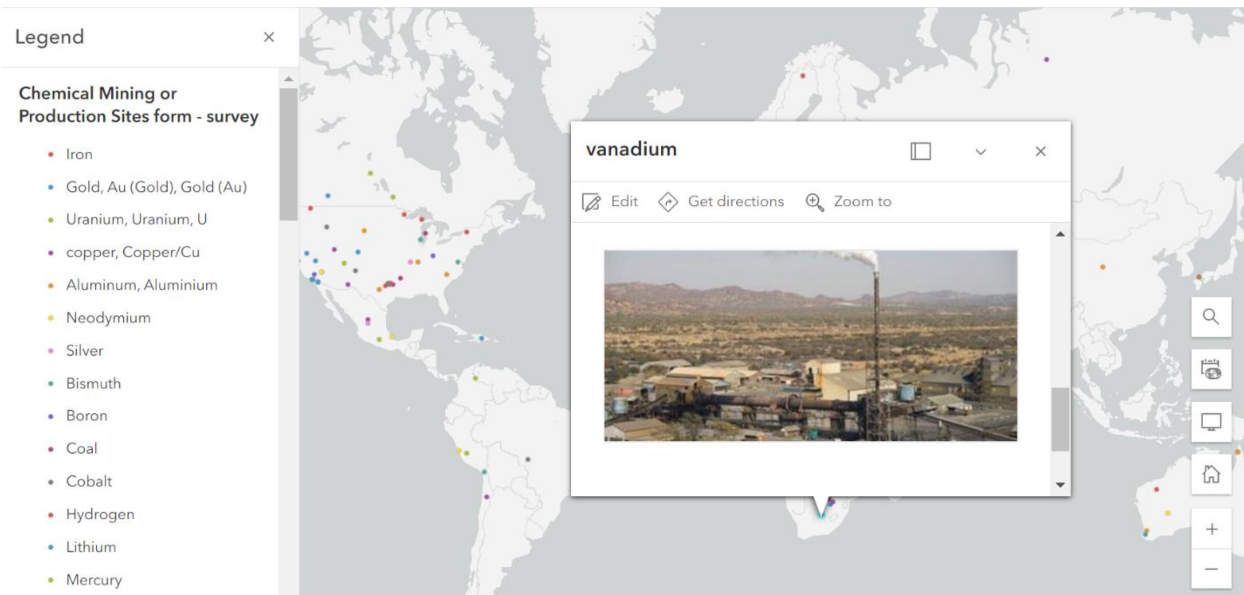
The starting point for this plan was a revisiting of the instruction that the teacher had previously done regarding the periodic table. In prior years, students would learn about elements and compounds through the periodic table, and chemical reactions were examined in an abstracted form, such as the properties of various metals, with some attention to their use in familiar, easily identified contexts, such as aluminum cans or aluminum foil. The context of producing these materials, both the extractive processes and the specific mining and/or refinement locations. By introducing the smartphone as a point of focus, students could both learn about many elements in the periodic table and learn about their contexts of production.

IMPLEMENTATION

This project utilized a variety of geospatial tools. Students used ArcGIS software for each phase of the project, and the result was an interactive digital map and StoryMaps where the students could reflect about their learning.

The initial step was for students to begin to think geographically about elements and chemicals. The teacher prepared a web map, populated by a Survey123 form input, in which the students would geolocate a production facility of an element (such as carbon) or chemical (such as styrene) or a substance (such as diamonds). After researching, the students generated 94 geographic locations. For each, they specified the element or chemical, explained why it is important, and briefly described its production process. They also provided an image for each production site. This information was automatically synced to the shared web map (see Figure 1, below).

FIGURE 1
ArcGIS MAP OF STUDENT RESEARCH ON CHEMICAL PRODUCTION & MINING SITES



Note: The selected student researched vanadium production in South Africa, describing its importance, its production process, and supplying an image of a production site.

Next, the teacher drew students' attention specifically to the elements used in producing smartphones: the battery (lithium, cobalt, and others), the casing (carbon, nickel, and others), the screen (aluminum, oxygen, silicon, indium, and many others), and the interior circuitry (copper, silver, tantalum, silicon, and many, many others). (For a highly effective, student-friendly infographic and supporting explanation, see https://www.compoundchem.com/2014/02/19/the-chemical-elements-of-a-smartphone.) Smartphones provided both a familiar and motivating point of focus for students, and as a category they also consume a wide range of elements.

The next step in the lesson sequence was for students to re-engage with their research, this time to produce a StoryMap that included multiple elements:

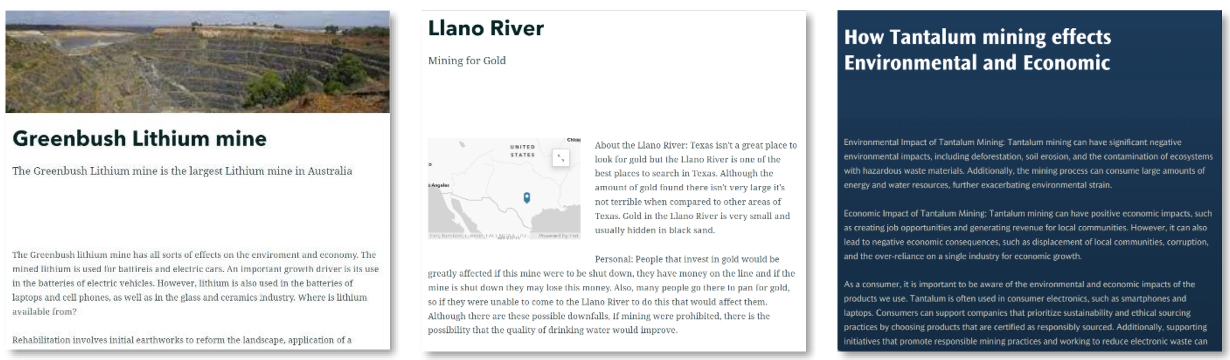
1. A map marked with a polygon showing the specific production site
2. A photograph of the production site
3. A paragraph or more describing
    a. The ways the element is present in students' daily lives.
    b. The economic significance of the element's production.

c. The environmental impact of the element's production and/or use.

To model this process for students, the teacher produced a partially-worked sample of a StoryMap, both illustrating the process (how to launch the StoryMap tools in ArcGIS Online; how to add text and other features) and demonstrating the expectations (for example, embedding and annotating a map to show the specific geographic context).

Students worked individually or in groups for approximately one week of classtime. Their final products were then presented and shared within class, allowing for peer learning. In total, they produced 56 complete StoryMaps. (See Figure 2, below, for selected examples of StoryMaps.) Thirty-six of these discussed elements used in smartphone production, with seven of these specifically mentioning the element's use in smartphones, computers, or other electronic components. Excluded from this count were two StoryMaps that discussed oil extraction. Petroleum is of course highly relevant for producing many, many objects of modern life, including the plastic parts used in smartphones. However, the students researching oil production focused their attention on energy policy and ecological issues; "plastics" was mentioned once in a list—"oil is a valuable resource used in a wide range of products, including plastics, chemicals, medicine, and cosmetics" (StoryMap JR 05-12-23)—without connecting to its role in manufacturing end-user technological products.

FIGURE 2
SELECTED EXAMPLES OF STUDENT-PRODUCED STORYMAPS



Following this initial sorting, the researchers created a coding frame to organize the analysis: each StoryMap would be analyzed for geographic references (including mapping), personal connection, economic and environmental impacts, and use of ArcGIS features. The researchers then individually analyzed and coded the StoryMaps, expanding the code list as needed. They then conferenced to discuss and resolve coding discrepancies, identify themes, and formulate findings.

RESULTS

Across the 36 StoryMaps that either directly discussed smartphones or their component elements, the most consistent theme was *geographic contextualization*. Students specifically identified sites across all human-occupied continents: cobalt mines in Africa, silver and gold mines in South America, bromine processing plants in Asia, lithium mines in Australia, iron mines in Europe, cerium mines in North America, and so on. More than 90% of the StoryMaps established a geographic context for the element discussed, using a mix of map annotation, location-specific photos, and text descriptions. While some descriptions were highly generic (for example, locating boron production "in California" – StoryMap OP 05-15-23), most StoryMaps named specific locations (such as Surat, India or Kolwezi, DRC) or even specific production sites (Mountain Pass Mine on the California-Nevada border, Benson Mines in upstate New York). Several StoryMaps identified multiple production sites around the world, such as titanium mines in Russia and Mozambique.

Our next most consistent theme across the StoryMaps was attention to *production processes*. In their text, students described various mining methods (open-pit mining, underground mining, surface mining, dredging, and so on) and specific steps involved in mining different minerals (crushing, grinding, flotation, smelting, etc.). Many StoryMaps discussed the dangers associated with mining, including cave-ins, exposure to hazardous materials, and physical labor. These discussions often connected to negative social impacts, such as concerns about child labor and unfair working conditions in some mining operations. Several discussions of production processes and their negative impacts also engaged with the chemistry of mining, such as mercury's use in isolating silver and gold or the use of chlorine and magnesium in processing titanium ores into useable forms.

Another consistent theme was the *relative attention to environmental and societal impacts*, as opposed to the economic impacts, of mining these resources. While all StoryMaps addressed economic impacts, such as common uses for metals, these topics were addressed in very broad statements, such as "If we didn't mine aluminum, we would have these products [foil wrap, fluorescent light bulbs, cookware, polishing compounds, siding, etc.]" (StoryMap GM 05-17-23). Many of these statements appeared to be copied or paraphrased from Internet sources. For example, one StoryMap states that "Arizona copper accounts for 74% of U.S mining production" (StoryMap SN 05-16-23); this appears to be an erroneous paraphrase from the Arizona Game and Fish Department: "Copper is the most abundant and valuable of Arizona's metallic minerals and accounts for almost 74% of the domestic copper production in the United States" (see https://awcs.azgfd.com/conservation-challenges/energy-production-and-mining). In contrast to these seemingly shallow statements about economic impacts, the StoryMaps offered more detailed and more authentic statements about the environmental and social impacts of the production process. One StoryMap expressed this sentiment directly in its title ("Mercury, and why it kinda sucks for the ecosystem"). For the other StoryMaps, this relative emphasis came through in the text and images. All StoryMaps contained at least one sentence, and often multiple paragraphs, that identified multiple ecological impacts (carbon emissions, deforestation, erosion, air pollution) and in often vivid terms (fish die-offs, heavy metal poisoning symptoms, Antarctic ozone depletion). Several StoryMaps providedaccompanying images to illustrate the environmental impacts, such as a photograph of acidic drainage from an abandoned Australian iron mine (StoryMap IFG 05-16-23). One StoryMap presented a unique inversion of this trend, however, presenting paragraphs of text about the environmental protections being put in place by a specific lithium mining company, all seemingly copy-pasted from the company's "Sustainability" pages (see https://www.talisonlithium.com/environment).

Our final theme is formed from an absence: across all 36 StoryMaps, only one addressed *personal agency* when discussing the social and economic issues raised by element production. Following the prompt from the teacher, almost all StoryMaps identified personal use cases of the elements identified, whether by presenting photos of familiar objects (such as aluminum cans) or by naming items containing the element (such as rechargeable batteries). The StoryMaps clearly expressed how the mining and extraction operations were relevant to students' lives. However, only one StoryMap brought the same personal connection to its discussion of the environmental and social that come with these activities:

> As a consumer, it is important to be aware of the environmental and economic impacts of the products we use. Tantalum is often used in consumer electronics, such as smartphones and laptops. Consumers can support companies that prioritize sustainability and ethical sourcing practices by choosing products that are certified as responsibly sourced. Additionally, supporting initiatives that promote responsible mining practices and working to reduce electronic waste can help mitigate the negative impact of tantalum mining on the environment and local communities (StoryMap WK 05-12-23).

This statement inspired us to go back and re-examine the human context (if any) brought to the presentation of the negative impacts of mining and extraction. This re-examination affirmed that, as presented in the StoryMaps, the human impacts of these challenges were borne by the miners, processors, or local residents; the consumers were not involved. For example, a StoryMap about silver stated that, "in

Peru with huge mining companies, children are dying because of heavy metal poisoning. …[T]he local residents have taken it upon themselves and went to protest to the Health Ministry" (StoryMap SJ 05-16-23). The following text discusses uses of silver and even its role in manufacturing electronics, but without making a connection to any responsibility or opportunity for the consumer to consider the people impacted by the circumstances of production. The students seemingly viewed themselves as being on the outside of these negative impacts rather than being part of a causal chain that triggered both the benefits and the downsides of these activities.

DISCUSSION AND IMPLICATIONS

This novel chemistry education activity brought a new perspective to both the curricular context and our research focus. Our project sought to bring geospatial tools into curriculum-aligned instruction (Hammond et al., 2019), which initiated a new frame for the teacher's chemistry education: georeferencing topics within the chemistry curriculum. The fact that 90% of the student products referenced specific geographic locations was an expected and welcome outcome of this work. The unanticipated outcome was the engagement with issues of sustainability and social justice. While the teacher provided the opening frame for this investigation, by prompting students to examine the environmental impact of the production process, it was the students themselves who brought these issues to the forefront through their engagement, as demonstrated by the relative focus they brought to their StoryMaps. The selection of the smartphone as a point of focus was perhaps pivotal, since it provided the link of a familiar object—even an object of fascination—that connected students to these often-distant places, people, and concerns.

In reflecting on this case, we anticipate that there is potential for even greater engagement with sustainability and its politics. One student, as noted above, presented a lithium company's "greenwashing" (Zharfpeykan, 2021) uncritically, highlighting the environmental protections and even improvements introduced by the company while minimizing the negative impacts of their extraction operations. This outlier in our data set raises the possibility of engaging in the political and social forces around mining and other environmentally high-impact activities—why did this company feel compelled to document its mitigation activities? How does, for example, a Dutch company obtain permission to operate a copper mine in Libya? When workers or local residents protest, to what authorities can they turn and what influence can they hope to have? Another student provided an outlier in the opposite direction, raising the issue of consumer's responsibility to think about the source of an element (tantalum)—is it produced in a conflict zone? Is it produced at the cost of releasing hazardous byproducts? If this lesson is to be repeated in a subsequent chemistry class, the work of these two students suggests that teachers could add a third step in the instructional sequence, reflecting on the final StoryMaps to engage more deeply with the politics and personal agency that can make element mining and extraction more sustainable.

CONCLUSION

The learning experience that is the focus of this study was immersive and interdisciplinary, combining chemistry, geography, environmental science, and social studies. By exploring the intricacies of smartphone production, from the periodic table to global supply chains and social responsibility, the students gained a more well-rounded understanding of the technology that defines their generation and the broader global context in which it operates. The model created by the participating chemistry teacher only enriches curriculum-aligned learning but also cultivates critical thinking, environmental consciousness, and ethical awareness in the next generation of STEM scholars and practitioners, all by turning a critical lens on that thing in your pocket.

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