Research Highlights in Technology and Teacher Education

Todd Cherner & Rebecca Blankenship
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Research Highlights in Technology and Teacher Education

Edited by

Todd Cherner
Rebecca Blankenship

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We would also like to recognize the many individuals who served as research participants for the studies included in this volume. Being part of a research study as a participant is an investment of time, energy, and intellect, and we are grateful they invested.

Finally, we would like to recognize the educators, technologists, students, and larger educational community. Our collective effort helps drives the purposeful use of extended reality technologies for teaching and learning. Thank you for your dedication.

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FOREWORD

It is my pleasure to present to the technology and teacher education community the fifteenth edition of *Research Highlights in Technology and Teacher Education*. This volume contains some of the most important research happening in our field as presented at the 35th annual SITE Conference. To no one's surprise, issues related to artificial intelligence permeated much of the work presented at the conference. As we have with major technological innovations in the past, the researchers and practitioners in the SITE community are embracing the possibilities and interrogating the challenges this new technology presents at all levels and from multiple perspectives, and the quality of that scholarship is on display in this volume.

This edition of *Research Highlights in Technology and Teacher Education* is particularly special, as we welcome two new editors, Todd Cherner and Rebecca Blankenship. Drs. Cherner and Blankenship follow in the footsteps of David Gibson and Marilyn N. Ochoa, who for years ably stewarded this publication, ensuring that the important work of the SITE community is communicated as widely as possible. The SITE community is tremendously grateful for their service, and are equally excited by the energy with which Drs. Cherner and Blankenship are approaching their editorship.

SITE is the premiere place for scholars of technology and teacher education to connect, share ideas, and work together to address the most pressing issues in our field. As readers engage with the scholarship in this volume, I encourage them to consider building off the questions posed within it by submitting their own proposals to future SITE conferences, so that they might be featured in a future edition of *Research Highlights in Technology and Teacher Education*.

Jonathan D. Cohen

President, Society for Information Technology and Teacher Education

INTRODUCTION

It is an honor to serve as an editor for *Research Highlights in Technology and Teacher Education* (RHTTE), an annual publication that disseminates high-quality research presented at *the Society of Information and Technology in Teacher Education's* conference. I am extremely proud of this year's volume because of the wide swath of research topics and authors represented in it. I also want to acknowledge the chairs of all the different special-interest groups who provided recommendations of works to be included in this edition. Having their recommendations guided the selection process of articles, and I am grateful to them. Next, I'd like to provide a preview of the articles included in this edition.

- **Article 1.** Kwon, Kim, Seo, Kim, and Brush examine how embodied learning experiences in a mixed-reality setting enhance first-grade students' understanding of computational thinking concepts, revealing both beneficial congruent movements and instances of incongruence that inform the dynamics of embodied learning.
- **Article 2.** Curby, Weinburgh, and Brown explore how educators can use geospatial tools like ArcGIS to enhance students' understanding of the global impact and material composition of smartphones, fostering critical thinking and environmental awareness through location-based learning projects.
- **Article 3.** Saubern and Urbach (2024) explain how item response theory, particularly Rasch analysis, can be applied to TPACK research to provide meaningful qualitative descriptions of teachers' quantitative TPACK proficiency scores, offering a novel approach to interpreting survey results in this field.
- **Article 4.** Trevisan (2024) investigates the effectiveness of internships in initial teacher education programs, revealing an expectation gap and vulnerability to contextual pressures among pre-service teachers, particularly regarding technology integration, and recommends closer collaboration between ITE programs and internship settings to better support teachers' professional identity development.
- **Article 5.** Baumann, Tiede, Latoschik, and Grafe explore pre-service teachers' experiences with a social mixed reality environment for transcultural education, identifying opportunities and challenges to inform future practices in developing media pedagogical competence within initial teacher education programs.
- **Article 6.** Clausen, Rutledge, Borthwick, Driscoll, Jin, Sprague, Warr, and Williams use Q methodology and factor analysis to examine how teacher education candidates from seven U.S. institutions perceive their preparation to use technology, evaluating their experiences against Foulger's four pillars of technology infusion in teacher preparation programs.
- **Article 7.** Kidd, Pazos, Gutierrez, Rhemer, Ringleb, Kaipa, Kumi, Ayala, and Cima compare two instructional models for developing preservice teachers' competence in engineering education, finding that both cross-disciplinary collaboration with engineering students and education student-only teams using prepared lessons led to increased engineering knowledge and pedagogical skills, with each approach offering unique benefits.
- **Article 8.** Mishnick, McLemore, and Wise conducted a qualitative case study that reveals how an educational technology course significantly enhanced alternative teaching certification students' understanding and potential application of ISTE Standards, addressing the critical need for technology skills in teacher preparation programs.
- **Article 9.** Ozen, Cayton, McCulloch, Fye, Muthitu, Fletcher, and Bailey examine how a framework introduced in a methods course helped secondary preservice teachers develop their ability to anticipate student thinking on technology-enhanced mathematics tasks, showing a shift from self-focused thinking to student-focused anticipation.
- **Article 10.** Williams and Kell detail how rural teachers and university facilitators co-created state competencies to inform the development of accessible, adaptive online professional

learning opportunities, using human-centered approaches to address teacher retention issues in rural communities.

- **Article 11.** Von Gillern, Obubo, Lannin, and Hutchison analyze two teachers' perspectives on how engaging students in analyzing, creating, and sharing digital messages about cyberbullying enhanced students' digital citizenship skills, fostered creativity, and provided a versatile approach to addressing civic issues.

As you read across the articles, I challenge you to think about what is *next*. The next steps that can be taken to advance the line of inquiry. The next technologies that can scale the results reported in these findings, so all students prosper. The next research questions that continue to build upon these scholarly insights.

Finally, I want to express my gratitude to SITE President Jake Cohen for offering this editorship to myself, and Dr. Rebecca Blankenship for being a wonderful co-editor who took the lead on the second volume of this year's RHTTE edition. Lastly, I want to recognize the work of RHTTE's prior editors, Drs. Maddux, Gibson, Ochoa, Liu, Dodge, Koehler, Mishra, and Owens. I hope that Rebecca and I continue the tradition of this editorship.

~ Todd Cherner, Ph.D.
August, 22, 2024

CULTIVATING A GEO-SUSTAINABLE MINDSET IN HIGH SCHOOL CHEMISTRY STUDENTS USING GEOGRAPHIC INFORMATION SYSTEMS

Curby Alexander, PhD
Texas Christian University, USA
curby.alexander@tcu.edu

Molly Weinburgh, PhD
Texas Christian University, USA

Kristen Brown, PhD
Texas Christian University, USA

Abstract. While smartphones are familiar in high schools, their intricate material composition and far-reaching geographical footprint remain largely unexplored. This research explores how educators can leverage ArcGIS, a geospatial software tool, to bridge the gap between theoretical understanding and real-world consequences. The paper details a collaborative project between researchers and teachers to integrate location-based learning into the curriculum. One such project involved a teacher using geographic information systems to guide students in exploring the global impact of smartphones. This approach fostered critical thinking and environmental awareness, equipping students with vital knowledge about the materials behind everyday technology. By harnessing the power of geospatial tools, educators can cultivate a generation of "geo-sustainable" thinkers prepared to navigate the complex life cycle of digital devices – from extraction to disposal – in an environmentally responsible manner. This paper delves into the project methodology, the application of geospatial technology, and the broader implications for future research in this domain.

Keywords. Geographic Information Systems (GIS), Geo-Sustainable education, High school Chemistry, ArcGIS, Smartphone Materials

Introduction

Across the tapestry of American high schools, one ubiquitous object reigns supreme: the smartphone (Sutisna et al., 2020). These compact computers have revolutionized communication, information access, and entertainment. However, beneath their sleek exteriors lies a hidden world of materials and elements, extracted from across the globe. To grasp the true impact of smartphones on society and the environment, we must delve deeper and explore the building blocks that bring these devices to life (Bookhagen et al., 2020).

In our globalized world, educators face the challenge of fostering critical thinking about technologies deeply integrated into our lives (Chalup, 2024). This paper proposes ArcGIS, a geospatial software tool, as a key to unlocking a deeper understanding of smartphones – devices students use daily yet often take for granted. By integrating geographic information systems (GIS), educators can cultivate a "geo-sustainable" mindset. Students will not only explore the origins and impacts of these devices but also grapple with the future: how can we develop, manufacture, distribute, and dispose of them responsibly (Koppelaar et al., 2023)? This approach bridges the gap between the abstract concept of a smartphone's components and the real-world geography that shapes their impact on individuals, society, and the environment.

ArcGIS is a powerful software developed by Esri that enables users to analyze, visualize, and interpret spatial data. It plays a crucial role in various fields such as urban planning, environmental management, and public health by providing tools to create detailed maps, analyze spatial relationships, and model geographic phenomena. By integrating and analyzing diverse datasets, ArcGIS helps users in spatial analysis and data visualization. In education, ArcGIS holds immense potential for pedagogical tool, hands-on, and inquiry-based learning, but it remains limited in many schools. This paper demonstrates the technologies unique affordances for education.

This paper details a collaborative project involving researchers from three universities and teachers across seven high schools aimed to bridge this gap. The project focused on integrating geospatial concepts and strategies into the curriculum using the ArcGIS suite of tools, fostering students' spatial reasoning and awareness in various disciplines. One captivating example involved a teacher using GIS to guide students in exploring the hidden global impact of their smartphones. This approach not only equipped students with vital knowledge regarding the materials behind the everyday technology they use, but it also fostered critical thinking skills. Students gained a deeper understanding of the environmental and ethical considerations surrounding society’s consumption of technology. This case study also serves as a testament to the power of ArcGIS in cultivating a generation of responsible consumers who are aware of the geographical footprint hidden within their devices.

Review of Literature

In recent years, as society has focused more on environmental sustainability, some teachers and researchers have explored the intersection of technology and its environmental impact, examining how these two domains both impact the environment and can be used to promote an environmentally sustainable mindset among students.

Becker and Dreesmann (2023) investigated the potential of computer simulations in German high school biology classes for helping students understand environment issues. Their research findings indicated computer simulations as a student-centered method can be profitable for students, increasing their understanding of environmental issues and combating their lack of botanical knowledge. Buchanan, Pressick-Kilborn, and Maher (2018) critically explored innovative, formal and informal learning practices with technology in environmental education initiatives among schools, families and communities. Their study included the use of digital technologies, including videoconferencing, mobile apps and virtual and augmented realities, to provide new ways of engaging students in environmental stewardship. Similarly, Napal, Mendióroz-Lacambra and Peñalva (2020) researched the application of information technology to help students develop environmental sustainability competency. The findings of these two studies suggest the potential of geospatial technologies to pique student interest, enable learners to capture experiences of local and distal environments, to collect data, and share findings with broader audiences.

Several additional studies have explored the use of GIS technology for teaching environmental sustainability. As early as 2004, Bednarz was discussing the affordances and constraints of GIS for teaching about the environment, environmental issues, and sustainability. Aguilar et al. (2022) developed a curriculum using GIS-driven visualizations to teach sustainability concepts to students at various levels. Landenberger et al. (2006) employed the remote sensing capabilities of GIS to develop land-cover biology and hydrology investigations, and their findings suggest that GIS was an effective tool for helping students understand how terrestrial and aquatic systems interact, and it strengthened their knowledge about the link between science and land use policy. More recently, Carrigan et al. (2019) employed the field-based data collection capabilities of ArcGIS to facilitate student investigations of the intersection between ground temperature, surface type, tree cover, and urban heat. Students used infrared thermometers to collect and map data about ground temperatures around their school. The GIS technology enabled them to create visualizations showing the campus “hot spots,” and they presented their findings to the school community to advocate for planting trees in critical areas around the school campus.

Theoretical Framework

The Technological Pedagogical Content Knowledge (TPACK) framework serves as the guiding theoretical model for this study, underpinning the integration of geospatial technology in high school curricula. TPACK is a comprehensive framework that articulates the interrelationship between three primary forms of knowledge: technological, pedagogical, and content knowledge (Koehler & Mishra, 2009). This model is instrumental in understanding how teachers can effectively leverage the affordances of technology in their teaching practices to enhance both content learning and pedagogical strategies (Mishra & Koehler, 2006).

Technological Knowledge (TK) refers to the educators' proficiency with technology tools such as geospatial, immersive, or media production technologies. Proficiency with technology can include understanding the features of the software and hardware, knowing how to troubleshoot issues, and using the technology effectively. Pedagogical Knowledge (PK) involves the strategies and methods employed by the teacher to facilitate learning. This knowledge domain includes developing a repertoire of teaching strategies (e.g., direct instruction, project-based learning, concept teaching, inquiry-based learning, etc.), understanding developmentally appropriate practices, and classroom management strategies. Content Knowledge (CK) pertains to knowledge about the subject matter being taught. Teachers with well-developed content knowledge understand the nature of their discipline, the structure of the knowledge base, learning progressions, and common misconceptions particular to a certain area of content knowledge. Having a solid grasp on content knowledge allows teachers to plan instruction in an effective and meaningful way.

Context

This project tackles the critical issue of smartphone element composition and its environmental impact. By exploring the potential of ArcGIS software as a tool for educators and proposing a novel strategy for integrating it into high school classrooms, this instructional unit invited students into the hidden world masked by digital devices, fostering both geospatial awareness and responsible environmental practices (Fairfield, 2018).

The project was implemented within a Science, Technology, Engineering, and Mathematics (STEM) academy located in a large metropolitan area of the Southwestern United States. The researchers' central aim was to empower students to connect the elements found in their smartphones to the broader geographical and environmental implications of the digital device production process. The following sections detail the project itself and the steps undertaken for its implementation.

This project, designed by a high school chemistry teacher, aimed to cultivate student comprehension of the chemical composition of their personal digital devices and their broader societal and environmental impact. The participants included 93 first-year high school students enrolled in the STEM academy (Table 1). Students did their own research to identify the geographical origins of the raw materials vital to smartphone production. This investigation delved into the global nature of the technology manufacturing industry, specifically focusing on the locations of mining and extraction for elements like rare earth metals, lithium, and cobalt.

Table 1

Demographic Characteristics of Participants

Sample Characteristics	**n**	**%**
Gender		
Male	38	40.9
Female	55	59.1
Race/Ethnicity		
American Indian or Alaska Native	0	0.0
Asian	2	2.2
Black or African American	14	15.0
Hispanic or Latino	40	43.0
Middle Eastern or North African	2	2.2
Native Hawaiian or Pacific Islander	0	0.0
White	35	37.6

Note: N = 93 for Gender; N = 93 for Race/Ethnicity. Percentages may not sum to 100 due to rounding.

The initial phase of the research tasked students with investigating the processes behind element extraction, refinement, and distribution of smartphones. This encompassed exploration of mining techniques employed to acquire the materials, the refinement processes required to render them suitable for technological applications, and the distribution networks responsible for transporting these resources to global manufacturing centers. Furthermore, the study expanded its scope to encompass the environmental ramifications associated with the entire life cycle of smartphones, from the initial extraction of raw materials to the manufacturing process, product use, and eventual disposal. This holistic approach ensured students gained a comprehensive understanding of the environmental consequences associated with these digital devices.

To complement their investigation into mining and extraction techniques for individual elements, students were tasked with analyzing how technology companies address the environmental damage caused by production and disposal waste due to the production of smartphones. This analysis centered on understanding the recycling, reuse, and responsible disposal practices implemented by manufacturers.

The project culminated in an exploration of labor laws and practices within the countries responsible for element production or device manufacturing. This final phase involved a critical examination of issues such as working conditions, worker rights, and the broader social implications associated with element extraction and processing. This multifaceted approach ensured students gained a nuanced understanding of the ethical dimensions embedded within the entire smartphone life cycle.

Methodology

The study employed thematic analysis as its primary methodological approach to explore and understand the nuanced perceptions and experiences of high school students and educators regarding the integration of geospatial technology in the curriculum.

Data Collection

The data for this study consisted of 93 student-generated narratives about the production practices and environmental impacts of smartphone manufacturing taken from the ArcGIS StoryMaps. These narratives were collected as part of an integrated physics and chemistry high school course. Students researched their assigned chemical element found in smartphones, and they entered their findings in a Survey123 form integrated with ArcGIS. Each student response was geocoded and associated with that particular geographic location on a map. In addition to the name and geolocation of their chemical element, students were asked to include an image of the mining facility. They researched the following prompts and entered their data in the form:

1. *Discuss why this production or mine is important*
2. *Briefly explain the steps required to mine/produce this chemical?*

All the student responses were aggregated on the same map, and the researchers were able to access their responses directly through the map and by exporting them into a spreadsheet. The aggregated student responses and map can be viewed at https://t.ly/1CrV9.

Data Analysis

The researchers employed a thematic analysis approach to investigate the student narratives (Braun & Clarke, 2012). This qualitative research method focuses on identifying, analyzing, and reporting patterns or themes within a dataset. The analysis unfolded in a series of steps. First, familiarization involved the researchers meticulously reading through all 93 narratives. This deep immersion allowed them to identify initial patterns and ideas within the data. Next, the researchers generated initial codes and systematically coded emerging themes from the data, essentially organizing the narratives into meaningful groups. Subsequently, the researchers shifted their focus to searching for themes. They collated the various codes into potential overarching themes, aiming to capture significant elements of the data concerning smartphone production practices and environmental impacts. Finally, the analysis culminated in defining and naming themes. Analysis of these data has revealed the following themes.

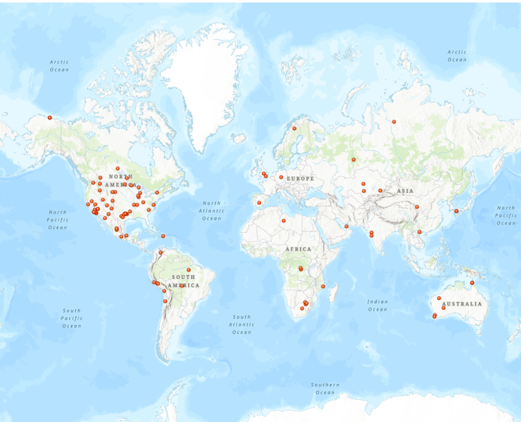
Implementation

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 along with StoryMaps where students could reflect about their learning.

For the learning process, students first conducted comprehensive research to identify the metals and minerals used in the manufacturing of smartphones. They sought information regarding the name of the element, its global sources, the methods employed for its extraction, and the significance of its geographical location. To streamline the data collection process, students utilized a Survey123 form, which integrates seamlessly with ArcGIS Online. Within this form, they recorded the details they had gathered about each element. This information was automatically synced to the class map, as depicted in Figure 1.

Figure 1

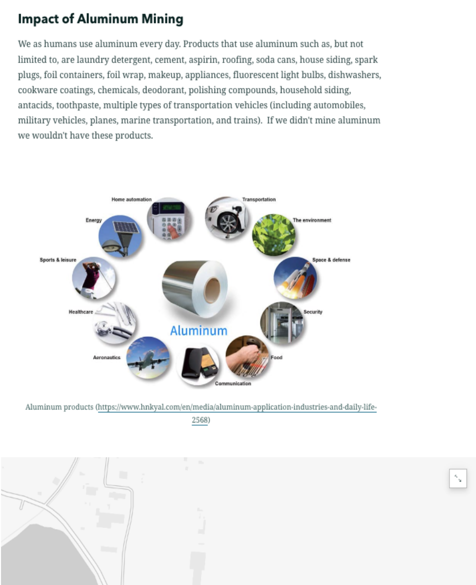
ArcGIS map of Student Research on Elements Found in Smartphones



Leveraging the capabilities of the ArcGIS platform, students next created interactive and informative ArcGIS StoryMaps (Figure 2). These StoryMaps served as a platform for the thoughtful integration of geographical data pinpointing the mining locations of each element. Functioning as a multimedia narrative, the StoryMaps allowed students to present a holistic analysis encompassing the multifaceted impact of each element. This analysis balanced both the positive and negative repercussions on the local economy, environment, technological advancement, and labor practices within the region of focus.

Figure 2

StoryMap with Student Reflections



The project's implementation phase proved to be a dynamic and engaging learning experience, fostering active student participation in the exploration of smartphone components. By harnessing the power of geospatial technology and fostering reflective storytelling, the project facilitated a deeper understanding of individual elements and equipped students with the critical skills necessary to analyze the broader global impact associated with smartphone production. This multifaceted approach fostered a deeper appreciation for the complexities of the technology industry and its associated environmental and societal considerations.

Results and Findings

In the following section, the results of the study are presented, highlighting the key findings that emerged from the data analysis. These findings provide insights into the relationship between student knowledge and understanding of the elements used to build a smartphone and the geospatial implications of extracting and refining those elements for consumer use.

First, through their research, students identified the importance of specific resources. Their responses highlighted the economic benefits, historical significance, and unique properties of these resources. Students emphasized the role of mined minerals in various aspects of their lives, from technology and infrastructure to everyday products. For example, one student identified the importance of uranium because “it is crucial for powering nuclear reactors, which provide electricity to communities in countries like Japan and the USA.” Another student stated, “Aluminum is widely used in the construction of aircraft, vehicles, and buildings. It is also used in everyday items like kitchen utensils and appliances,” and a third student made the following observation, “Boron is used in a variety of products, including glass, ceramics, and detergents. It is also essential in agriculture and as a fire retardant.”

Second, students were able to articulate the global impact of mining. Students discussed how mining activities have a global reach, impacting economies, trade, and even political power. They also mentioned specific countries and regions as major producers of certain resources. The responses highlighted the global nature of the mining industry, with minerals being transported and traded across continents. Regarding economic impact, one student stated, “The Escondida Mine in Chile is the largest copper mine globally. Copper is essential for wiring, motors, plumbing, and electrical industries, making it a critical component of modern infrastructure and technology. The mine's production supports both local and global economies by providing essential materials for various industries.” Similarly, another student wrote, “The boron mine in California is the largest in the world, providing nearly half of the world's borates. This mine supports global agricultural, industrial, and household applications, demonstrating the extensive reach of boron mining on daily life and industry,” and a final stated, “The largest gold mine in Latin America, located in the Dominican Republic, significantly impacts the local and regional economy. It contributes to economic growth, employment, and sustainable development, benefiting neighboring countries through mutual prosperity.”

The third theme to emerge from this analysis was the environmental and societal impacts of mining these resources. Several responses acknowledged the environmental consequences of mining, such as the release of harmful chemicals or the depletion of natural resources (e.g., “Open-pit mining methods, such as those used in gold mining in the Dominican Republic, can lead to significant land disturbance and habitat destruction.”), and some responses extended to the social impacts, like job creation or cultural preservation (e.g., “The Eagle Mining Co. in California was restored to its 1870s condition to share the state's history, demonstrating efforts to preserve mining heritage.”). The responses also touched upon the environmental consequences of mining, such as deforestation, land degradation, and pollution. Some students express concern about sustainable mining practices. For example, one student made the following observation, “The petroleum refinery in California, with its large crude oil refining capacity of 363,000 barrels per day, likely contributes to air and water pollution.”

Fourth, student responses addressed the technological advancements shaping the mining industry, making it more efficient and allowing for the extraction of previously inaccessible resources. For example, students mentioned that advancements in mining equipment over the last several years have made the extraction of bauxite more efficient for mining companies worldwide. The Bayer Process, developed for aluminum mining, has made the process more expeditious. Students described various mining methods, including open-pit mining, underground mining, surface mining, and dredging, used for different minerals and depending on their depth and location. Students outlined detailed specific steps involved in mining different minerals, such as crushing, grinding, flotation, smelting, and refining. These responses also included discussions of the dangers associated with mining, including cave-ins, exposure to hazardous materials, and physical labor. As one student stated, “Uranium mining involves exposure to radioactive materials, which can pose significant health risks to miners. The process includes strip mining and underground mining, both of which can be hazardous due to the potential for cave-ins and the handling of radioactive ore,” and another wrote, “The mining of nickel sulfide involves crushing ores and using selective flotation, which can expose workers to hazardous chemicals and dust. The physical labor involved in mining and processing nickel sulfide can also be strenuous.” They mentioned protective equipment and safety precautions miners need to take. Students also voiced their concerns about child labor and unfair working conditions in some mining operations. They highlighted the use of machinery, explosives, and chemicals in these processes, and they raised concerns about the environmental and ethical implications of mining practices. Regarding the mining of iron in Australia, a student wrote, “The mining of iron ore contributes a large amount to air pollution, and the mining of iron ore also causes water pollution of heavy metals and acid that drains from the mines. This can affect the life of nearby animals and plant life. The pollution caused by these mines also lasts for a long after the mine is stopped. In the long run, this will severely damage the environment.”

A fifth theme was the historical context of mining in different regions of the world, discussing their role in ancient civilizations or major historical events. One student reported, “The Eagle Mining Co was part of the California Gold Rush in the 1800s, a major historical event that attracted thousands of people to the region in search of fortune. This gold rush significantly contributed to the economic development of California and the western United States.” Another student referenced the historical significance of coal mining near Chicago, “Coal mining in Chicago began in 1865 and lasted about a century. It played a crucial role in the city's development, providing essential resources for building and industrial activities.” Some responses mentioned the evolution of mining techniques over time, contrasting traditional methods with modern approaches (e.g., “Early gold mining relied on methods such as panning, sluicing, and placer mining, which involved manually separating gold from other materials in riverbeds and streams. Modern gold mining involves more sophisticated processes such as crushing, flotation, oxidation, and the use of cyanide for extraction.”). Some responses addressed the economic dependence of certain communities on mining activities. For instance, “The Karatau Mine in the Budenovskoye Uranium ore field in Kazakhstan is important for local jobs. Uranium mining supports the local economy by providing employment opportunities and contributing to the energy sector.”

Finally, students made personal connections to the mining industry by mentioning their own connections to mining, either through family members who work in the industry or their experiences visiting mines. For example, one student mentioned visiting the Eagle Mining Company in California, and another talked about having relatives who work in the oil and gas industry. This included students referencing steps they could take as consumers or advocates that demonstrate environmentally friendly practices and attitudes. One student referenced a refinery that, “manufactures cleaner-burning California Air Resources Board (CARB) gasoline and diesel fuel, as well as other conventional gasolines and petroleum products. This demonstrates a commitment to producing cleaner fuels and reducing environmental impact.”

Discussion and Implications

In today's world, characterized by rapid technological advancement and increasing environmental concerns, cultivating a geo-sustainable mindset among the next generation of students is paramount. This mindset goes beyond simply understanding environmental issues; it fosters a holistic perspective that considers the geographical, social, and economic implications of human activity on a global scale.

The learning experience explored in this study serves as a powerful example of how to cultivate critical thinking by leveraging TPACK. By integrating chemistry, geography, environmental science, and social studies, the project offered students an immersive and interdisciplinary exploration of smartphone production.

Technological Knowledge (TK) in the context of this study was identified in the educators' and students’ proficiency with ArcGIS, a sophisticated geospatial software tool. By leveraging ArcGIS, students were able to map the geographical and material journeys of smartphones. This enhanced students' understanding of the global impact of these devices, fostering a deeper engagement with the content. Pedagogical Knowledge (PK) involved the strategies and methods employed by the teacher to facilitate learning. In this project, the inquiry-based pedagogical approach encourages critical thinking, research and information literacy, and aggregating all the data into one map. Students were then able to combine geospatial data with other media into StoryMaps, such as text, video, and images, to communicate the journey of these various elements from the earth to the smartphone. Content Knowledge (CK) pertained to the subject matter being taught, which in this study included the material composition and geographical footprint of smartphones. The integration of this content with geospatial tools provided a rich, interdisciplinary learning experience that connected science, technology, and environmental education. This approach not only enhanced students' content knowledge but also their ability to apply this knowledge in practical, meaningful ways.

Using TPACK, educators effectively combined technological tools with pedagogical strategies to deepen their students' content knowledge. It was not just about the elements on the periodic table, but rather, it was about where those elements are mined, the environmental impact of extraction, the complex global supply chains involved, and the ethical considerations surrounding labor practices. This multifaceted approach, facilitated by TPACK, allowed students to move beyond the sleek device in their pocket and delve into the intricate web of factors that contribute to its existence, thereby enhancing their critical thinking and understanding of the interconnected world.

Equipping students with a well-rounded understanding of the technology that defines their generation is crucial. Smartphones are ubiquitous, yet the hidden complexities behind their production often remain unexplored. Through the application of TPACK, this project enriched classroom learning and fostered a deeper appreciation for the broader global context in which technology operates. For example, teachers used interactive digital maps (technology) to help students visualize and understand the geographical origins of raw materials (content) used in smartphones, which facilitated their inquiry-based learning to be aggregated into a common map (pedagogy). Additionally, the StoryMaps platform allowed students to communicate their findings using a variety of media (technology and content) in a collaborative environment (pedagogy). Furthermore, by examining the human element in smartphone production through multimedia resources and real-world case studies (technology), the project fostered ethical awareness, encouraging students to consider the social implications of technological advancement.

Conclusion

In conclusion, this research paves the way for a more holistic approach to STEM education, one that cultivates not just technical skills, but also a generation of responsible and informed citizens who understand the interconnectedness of the planet and the impact of human actions on a global scale. This geo-sustainable mindset will be instrumental in navigating the challenges of the future and ensuring a more sustainable and equitable world for all.

Limitations

This study has several limitations that should be acknowledged. First, the data were collected from a single school, which limits the generalizability of the findings. The unique context and characteristics of this school may not reflect those of other schools, making it difficult to apply the results broadly. Additionally, all the students in the study were taught by the same teacher. This introduces a potential bias, as the teacher's specific instructional methods, personality, and interaction style could have influenced the students' responses and the quality of their work.

Furthermore, the study involved only one teacher and 93 students. While this sample size is relatively large for a qualitative study, the lack of diversity in the teaching staff means that the findings are based on a singular pedagogical approach. This limits the ability to explore how different teaching styles might impact student outcomes and thematic patterns.

Another limitation is the variability in the quality of student products. The wide range of quality in the student work could affect the reliability of the thematic analysis. High variability might lead to an uneven representation of themes, as some themes might emerge more prominently due to the presence of high-quality submissions, while others could be underrepresented due to lower-quality work.

Lastly, qualitative thematic analysis inherently involves a degree of subjectivity in identifying and interpreting themes. While efforts were made to ensure rigorous and systematic coding, the findings are still influenced by the researchers' perspectives and biases. Future research could benefit from including multiple schools and teachers, employing a more diverse sample, and incorporating additional methods to triangulate the data and validate the themes identified.

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