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Rethinking GIScience Education in an Age of Disruptions

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ABSTRACT

GIS and GIScience education have continually evolved over the past three decades, responding to technological advances and societal issues. Today, the content and context in which GIScience is taught continue to be impacted by these disruptions, notably from technology through artificial intelligence (AI) and society through the myriad environmental and social challenges facing the planet. These disruptions create a new landscape for training within the discipline that is affecting not only *what* is taught in GIScience courses but also *who* is taught, *why* it is being taught, and *how* it is taught. The aim of this paper is to structure a direction for developing and delivering GIScience education that, amid these disruptions, can generate a capable workforce and the next generation of leaders for the discipline. We present a framework for understanding the various emphases of GIScience education and use it to discuss how the content, audience, and purpose are changing. We then discuss how pedagogical strategies and practices can change how GIScience concepts and skills are taught to train more creative, inclusive, and empathetic learners. Specifically, we focus on how GIScience pedagogy should (1) center on problem-based learning, (2) be open and accelerate open science, and (3) cultivate ethical reasoning and practices. We conclude with remarks on how the principles of GIScience education can extend beyond disciplinary boundaries for holistic spatial training across academia.

1 | Introduction

GIScience education has evolved over the past four decades, in part by continually responding to disruptive forces inside and outside the discipline (Frazier et al. 2018). The rapid development of GIScience in the 1980s and 1990s was itself a response to the maturing of computational technologies and the emergence of the Internet, which revolutionized the storage, processing, analysis, and visualization of spatial data. As GIScience emerged as a field, the need for a curriculum teaching its principles and technologies became clear. Spearheaded by the National Center for Geographic Information and Analysis (NCGIA), a core curriculum of educational materials and rich case studies emphasizing the scientific fundamentals of the field was developed before geographic information systems (GIS) textbooks were widespread (Goodchild and Kemp 1992). Debates about whether GIS was a tool or a science (Goodchild 1992; Wright et al. 1997a) gradually gave way to a synthesis of the "systems" and "science" dimensions of the field, creating space for interactions between GIScientists, social theorists, and human and physical geographers, which created a broad awareness of the social and environmental implications of GIS (Pickles 1995). GIScience education, particularly in the United States, similarly evolved to encompass a wider spectrum of knowledge. Educators blended technical proficiency with theoretical underpinnings to propel scientific understanding and practical application within a diversifying community of users that came to include scientists, engineers, managers, and practitioners (Forer and Unwin 2005).

Today, the content and context in which GIScience is taught continue to be impacted by technological and societal disruptions. Disruptions break or interrupt the normal course or continuation of activities or processes, and in doing so, often spark process change or even complete reimagination. Technological disruptions bifurcate from established norms and alter the ways in which people study, work, and perform their jobs. Artificial intelligence (AI), including large language models, is currently a major disruptive force that will likely irrevocably change the ways in which GIScience is practiced and taught (Hutson et al. 2022; Nelson et al. 2024). Furthermore, technology has created massive streams of spatial data with wide-ranging applications, while advances in high-performance and cloud computing are transforming the analytical landscape for GIScience (Shook et al. 2019). These disruptions to the data, methods, and science of GIS necessitate new thinking on how GIScience is taught and what skills should be included in GIScience education.

Societal disruptions are also affecting GIScience education through the grand challenges impacting the planet, including climate change, biodiversity loss, global conflicts, migration, rising inequality, political tensions, and sustainability. Such disruptions require geographic responses and geographic solutions (Nelson et al. 2022) and warrant a curriculum that emphasizes geographic and systems thinking for complex problem-solving. A strength of GIScience is its embeddedness in applications, enabling decision-making and monitoring change over space and time. Geographic information and geospatial technologies courses provide opportunities for students to learn about new methods and data that can help them address a range of challenges facing societies, both locally and globally. Importantly, GIScience can be a gateway through which students explore impacts and find solutions for challenges that cross social and ecological systems while also enabling the integration of different types of information with visualizations (Winkler 2016). Since many of the major challenges facing our planet, including climate change and social inequities, are inherently spatial, responses to them that do not consider geography are unlikely to succeed. It is critical that students receive analytical training that recognizes the spatial and temporal dimensions of these challenges while also learning to design solutions that are contextualized by local geography. Meanwhile, society is facing the tension between a growing focus on data-driven and evidence-based decision making, while at the same time, confidence in higher education is waning (Brady and Kent 2022). Educators in all technology and information science fields are grappling with these tensions, and GIScience is particularly well suited to lead these discussions given the connections to geography and local contexts.

The goal of this paper is to establish a direction for developing and delivering GIScience education that, amid disruption, can generate a capable workforce and the next generation of leaders for the discipline. We begin by presenting a framework for understanding the various emphases of GIScience education and use it to discuss how the content, audience, and purpose are changing amid disruptions. We then shift to discussing how pedagogical strategies and practices can change the teaching of GIScience concepts and skills to train more creative, inclusive, and empathetic learners. We end with some concluding remarks on how the principles of GIScience education can extend beyond disciplinary boundaries for holistic spatial training across academia. This approach requires recognition of the geographically varied nature of the development of GIScience and the localized nature of disruptive impacts. While the authors of this article represent a wide range of institutions, they are primarily located in North American and European institutions and situated in an Anglo-American GIScience context. The discussion presented in this paper is therefore informed by that history and experience, but this approach should not marginalize the rich and varied development of GIScience education or the disruptive force experienced in non-Anglo-American contexts. Indeed, a parallel examination of these issues from other perspectives is not only warranted but would enrich the discussion presented here.

2 | A Framework for Evolving GIScience Education Amid Disruptions

GIScience teaching and learning have taken many forms over the years, with debates playing out in the literature over which approaches best serve different learners and create the greatest impact (Schulze 2021). To frame the forthcoming discussion, we distill these different course approaches into a GIS Skills Ternary Chart (Figure 1) whereby the emphasis of a class or curriculum can be mapped according to the focus on GIS as a tool, as a science, or for an application (Figure 1). A course that equally balances all three of these approaches would be positioned near the center of the triangle. Courses merging two of these foci would be positioned along the edges of the triangle, and courses strongly focused on just one of these emphases would be represented at the corners. For instance, a graduate-level course on GIScience theory may lean heavily toward the concept foci, with less emphasis on GIS as a tool or application.

There has historically been considerable overlap in the skills and competencies taught across introductory and advanced GIS courses (Kedron et al. 2016), so Figure 1 can represent both introductory and advanced (or undergraduate and graduate) levels. It is also flexible for integrating emerging courses in a curriculum, such as spatial data science. Importantly, Figure 1 provides a framework for understanding what is being taught, for what purpose, and what types of students might be enrolling in different courses and provides a foundation on which to understand how the pedagogical landscape is

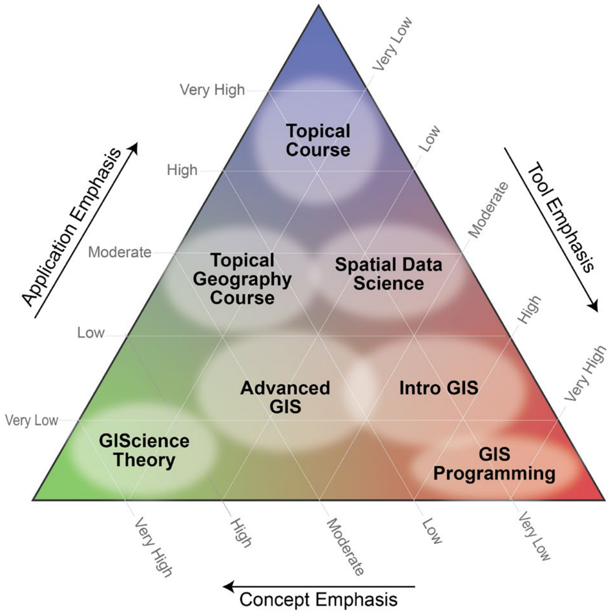

FIGURE 1 | Ternary chart of the general foci of GIS/GIScience courses with varying emphasis on GIS as a tool, GIScience concepts, or topics and applications. Courses near the middle blend all three foci, while those on the edges focus on two, and those at the points focus on one. Note: Exact placement of courses on the chart varies according to how instructors design and teach their courses. Therefore, placement is intended to be for general and illustrative purposes only.

changing. The remainder of this section walks through how disruptions are changing *who* is being taught, *what* is being taught, and *why* it is being taught, followed by a discussion on *how* GIScience education and pedagogy can evolve in response.

2.1 | *WHO* is Learning GIScience is Evolving

GIScience learners have arguably become more varied over time. While early GIS courses were offered primarily in geography departments and were designed for majors, classes today are taught in many different departments or programs (Fagin and Wikle 2011; Mathews and Wikle 2019) and involve students from a much broader range of disciplines with diverse motivations for enrolling (Westerholt 2023). For instance, some participants may be eager to build their spatial data science skills to increase competitiveness in the job market, while others may be interested in supplementing their disciplinary expertise with mapping and geovisualization, and still, others may enroll to fulfill general education requirements or satisfy degree needs.

Historically, a distinction has been drawn between GIScience "makers" and GIS "users" (Wright et al. 1997b), with the former generally occupying the lower parts of the ternary diagram in Figure 1, and the latter occupying the upper parts. Certainly, students aiming to be "makers" will continue to need deep conceptual knowledge and a wide range of skills from the basics of coordinate systems and projections to advanced theory, programming, data carpentry, and high-performance computing. However, the technological disruptions occurring around AI and machine learning are shifting the skill set needed by "users," even at the introductory level, to include a stronger emphasis on working with data as well as familiarity with web- and cloud-based platforms and higher proficiency in coding. It is in the context of these disruptions that GIScience educators must rethink which critical skills and competencies to include in introductory and topical courses, and what content can potentially be shifted to more specialized courses. Streamlining content that is often duplicated in introductory and advanced courses (Kedron et al. 2016) is one way to "make space" for new topics. Another way educators can respond to these disruptions is to start small when introducing students to new data or coding concepts. For example, having students write just a few lines of code to enhance a map symbol or label can allow them to experience success before moving on to more substantial technical skills. Initiatives such as "Hour of Code," which has developed bite-sized coding activities suitable for all grade-school levels, are a way for educators at the primary and secondary levels to gently introduce coding concepts at an early age.

While a primary focus in GIScience education has been on capturing and serving an academically diverse group of learners, ongoing societal disruptions around diversity, equity, and inclusion have made it clear that the discipline has much work to do to increase representation (Lawson 2004; Nelson et al. 2022; Sheppard 2012), especially across racial and other minority groups. Diversifying STEM and the academy is a job for all sciences; however, GIScience is in a position to attract diverse participants because of the nature of the questions that can be addressed through spatial-based perspectives (Oyana et al. 2015). One way to attract new learners is by developing topical GIS courses that focus on diverse perspectives and viewpoints, such as "GIS for Equity and Social Justice" (Babinski 2021) or "Indigenous GIS," which could draw on the rich history of scholarly activity in these areas (Nyerges et al. 2011). These topical courses would be situated near the middle or top of the triangle (Figure 1), with less emphasis on science but serving an important role as a gateway for students into the discipline. Simply advertising these and other GIS courses on social media channels that reach diverse audiences (e.g., NorthStar of GIS, BlackInSTEM, Women in Earth Science, African Women in GIS, GeoChicas, and many others) is a first step any program can take to help attract more diverse learners, but resources also exist for building capacity at scale. For instance, the US National Science Foundation's INCLUDES program and the US National Aeronautics and Space Administration (NASA)'s MOSAICS program have supported infrastructure building to facilitate these types of transitions and help overcome the barriers and obstacles that historically marginalized groups might face in GIScience.

2.2 | *WHAT* is Taught in GIScience Courses is Evolving

There has been growing tension between GIScience education and the workforce demands around data science. The US National Academies of Sciences, Engineering, and Medicine recently hosted a meeting examining whether a crisis is emerging in the geospatial workforce (NASEM 2023). Concern centers on the fact that traditional GIS curricula underemphasize many of the technical skills that are in demand (e.g., database management, data visualization, and full-stack development), prompting the need for fundamental innovations. While there are substantial overlaps between data science and GIScience, many students are attracted to the former due to demand and prestige. As updates are made to improve the technical and data science aspects of "doing GIS," it is natural for other GIScience skills and competencies to be deemphasized, especially in introductory courses. Yet, it is also necessary to ensure that fundamental geographic concepts and spatial approaches are still part of curricula, particularly for students majoring in GIS/GIScience. Striking this balance can be difficult, but a coordinated review by faculty of the comprehensive GIScience curriculum can help identify content overlap as well as areas to emphasize new technologies versus traditional geographic concepts.

GIScience is unique from other fields that intersect with data science because of the explicit consideration of spatial attributes in data and spatial processes in models (Singleton and Arribas-Bel 2021). Moving forward, GIScience education should therefore continue to emphasize spatial thinking and core GIScience concepts (National Research Council 2005) but adjust these as needed to meet modern demands. GeoAI is a good example of where spatial thinking can be further promoted and emphasized (Nelson 2024). Presently, most GeoAI approaches apply state-of-the-art, nonspatial AI and deep learning techniques to spatial data. However, this focus has the potential to change based on emerging approaches that include geometry (Miolane et al. 2020) and spatial autocorrelation (Li et al. 2021) explicitly in AI. In the next phase of development, GeoAI "makers" will need both data science expertise and expertise in spatial concepts, which requires students to receive the necessary training in two or more concentrations to think about problems and implement solutions spatially.

Disruptive technologies such as generative AI built on large language models (LLMs) are also impacting how spatial thinking can, and should, be taught in GIScience courses. One way to imagine integrating AI and GIS is that AI will act as a co-pilot for implementing spatial technology. While a fully autonomous GIS is still in development (Li and Ning 2023), the integration of LLMs into GIS software has already made advanced spatial analytical techniques more accessible through straightforward user interactions or prompts. For example, the QChatGPT plugin for QGIS software assists users in GIS data analysis tasks ranging from calculating statistics to performing spatial queries, generating Python code snippets for use in QGIS's Python console for automating tasks, debugging, and even optimizing GIS workflows. To use these tools effectively, however, students still need to understand the core spatial approaches being implemented and what is being produced by the prompt. Therefore, these key concepts should be taught alongside the effective use of AI-based GIS assistants, particularly around constructing prompts. A close integration of these skills can even provide critical thought opportunities for students to evaluate whether AI-based models are providing appropriate guidance for spatial decision making and how the training of the LLM or other foundation model may be influencing the response.

Another example is Esri's pretrained deep learning models that permit a user to extract features directly from imagery, such as trees or boats, with a simple text-based request. These processes, which previously took hours of specialized coding, are now implementable by all users. Esri is currently in the research and development phase of their "Mapping Assistant," which combines the power of GIS with the emerging field of generative AI to load data from online sources, create various types of maps for any attributes, filter and subset data values, and change symbology based on user text prompts. As integration of AI and GIS grows, it is essential to recognize that the ease of use provided by LLMs will increase the importance of a deep understanding of core spatial thinking and GIScience concepts. Without sufficient conceptual depth to interrogate results and suggestions from AI models for designing workflows for spatial analytics, students run the risk of introducing errors or bias into models.

Lastly, GIScience educators are often all too familiar with the constant need to update course materials based on new software versions, changing platform functionality, and even entirely new technologies to ensure students have a smooth learning experience. However, even this bedrock is changing as the next generation of GIS users must be able to navigate these complex and ever-changing software environments themselves. The new challenge for educators is to develop students who are equipped with the technical skills to respond to broken code, error messages, and system crashes across platforms as well as the critical thinking and perseverance mindset to work through these issues. Using open platforms (discussed below) is one way that educators can build these dual skill sets as students must work to overcome technical barriers while simultaneously working through an applied or societal problem.

2.3 | The *PURPOSE* of GIScience Courses is Evolving

With the myriad societal disruptions occurring, there is an increasing need to balance the value of producing fundamental scientific knowledge (i.e., "science for the sake of science") with the need to produce tangible outcomes that address pressing social challenges like climate change, biodiversity loss, and social inequalities. This tension is not new; for many years, the US National Science Foundation and other funding agencies have required researchers to consider the intellectual merit of a project's basic science alongside the benefits to society when researchers apply for funding. However, for students, it can be discouraging to work on fundamental research problems that may not have immediate direct applications. As educators, it is important to continue to instill in students a curiosity for scientific investigation, not simply as the means to an outcome but as a valuable contribution in itself. As courses and curricula shift to include a heavier emphasis on the technological and data science aspects of GIScience, it is also important for educators to ensure students receive robust training in fundamental GIScience principles, particularly at the graduate level. Otherwise, future theoretical and scientific advances in the field may be inadvertently stymied, and it is possible this shift is already underway. However, if basic advances in the field have slowed, the full extent of those implications might not be known for many years. This is an area where a metascience approach (Scheider et al. 2020) could prove useful to understand the right balance between technical skills and fundamentals.

3 | Evolving *HOW* GIScience is Taught Amid Technological and Societal Disruptions

Geographic education is a key way to advance basic science and accelerate solutions relevant to pressing challenges facing society. However, effectively advancing education in the midst of disruptions requires evolution in *how* concepts and skills are taught, not just because the *who*, *what*, and *why* of GIScience education are changing but also because pedagogical strategies and practices are evolving. It is critical for students to grow into creative, inclusive, and empathetic learners. We suggest the following three priorities as focal areas for updating GIScience education and pedagogy (Figure 2). First, GIScience education should be linked to real problems through project-based learning so students develop systems thinking and workforce process skills. Second, GIScience education should cultivate a representative and inclusive community, which should accelerate open spatial science. Third, GIScience education should foster ethical reasoning and practices so students are prepared to grapple with the social and technological disruptions they are encountering. These priorities are detailed in the sections below.

3.1 | GIScience Education Should Center on Problem-Based Learning

Centering GIScience courses on project- or problem-based learning (hereafter, PBL) (Gallagher and Savage 2023; Johnson et al. 2009; M. Nichols 2016; M. H. Nichols and Cator 2008; Prince and Felder 2007) is a proven way to deliver GIS educational experiences that are engaging and relevant (Bowlick et al. 2016). In the PBL model, students learn fundamental GIScience methods through the process of designing solutions to real-world problems in a manner that integrates theoretical knowledge and promotes learning by doing. Students are able to develop critical thinking skills and dive deeper into topics through hands-on experiences (Krajcik et al. 2018) while also fostering academic and workplace skills by collaborating with peers, thinking across disciplines, and sharing knowledge through communication (Prince and Felder 2007). Challenge-based learning (CBL) (Dadrass Javan et al. 2023; Ettema et al. 2020) builds on PBL by having students work in collaborative teams, including groups that are interdisciplinary and diverse (Myers 2017).

FIGURE 2 | In a time of technological and societal disruptions, GIScience education should maintain a focus on who, what, and why courses and content are being taught, while GIScience pedagogy should center on problem-based learning, be open and accelerate open science, and cultivate ethical reasoning and practices.

PBL and CBL can be incorporated into GIScience classrooms in many ways (Dadrass Javan et al. 2023; Ettema et al. 2020). Students can be tasked with developing individual solutions to hypothetical spatial problems, ultimately comparing their solutions with their peers. This approach can help students engage with the conceptual foundations of GIScience (e.g., defining entities or spatial relations) as they develop a research design that addresses a spatial problem. The combined use of PBL and GIS creates an opportunity for students to understand how different groups conceptualize, approach, and design activities to address spatial problems. In other cases, students might work closely with community actors to design solutions to a range of real-world problems (University of Twente 2023) that are presented to stakeholders at the conclusion of the course. For example, spatial engineering students at the University of Twente worked to design solutions to actual community spatial challenges, including urban flooding in the Netherlands and Uganda, and food and water insecurity (University of Twente 2021, 2024). In another example, GIScience students used volunteer geographic information (VGI) on bicycling to support a "20-min city" concept for the City of Tempe, Arizona, USA (Nelson et al. 2015; Da Capasso Silva et al. 2019). In both cases, students gained valuable professional skills while gaining real-world project experience.

PBL also connects well with other pedagogical trends such as flipped classrooms, where students are provided materials to learn core concepts in advance of attending classes. The classroom time can then be dedicated to discussions centered around problem solving (Howarth 2015). One challenge for PBL that can emerge in flipped GIScience classrooms is when instructional time is split between a concept-oriented lecture and a technically oriented lab. This division complicates PBL because it unnaturally separates the interdependent tasks of conceptualizing and designing workflows and testing those workflows, which can undermine the iterative review and revision that is the core of PBL. Additional resources and support for implementing PBL are available through the following links (https://www.iaspbl.aau.dk, https://www.ucpbl.net/).

The importance of including systems thinking in GIScience curricula, and specifically PBL approaches, deserves explicit mention. Finding solutions to disruptive problems often requires a systems-based approach (Sundstrom et al. 2023), and this type of thinking, which focuses on understanding the interconnected aspects of a problem and solution, is emphasized in PBL. The systems thinking that is inherent in GIScience may also represent a fundamental difference between GIScience and other fields linked to data science. Incorporating systems thinking into GIScience curricula, as mediated through PBL or otherwise, enables learners to increase their awareness of how, in an age of interconnectedness, alterations in one component might cascade through the entire system. Systems thinking also prepares learners to understand how communities and ecosystems respond, adapt to, or recover from disruptions. For example, the integration of network analysis into spatial analysis as a framework that embodies the systems thinking paradigm (Mitchell 2006) can provide GIScientists with the tools to unearth the vulnerabilities and strengths that shape a region's capacity to withstand human- and nature-driven disruptions.

3.2 | GIScience Education Should Be More Open and Accelerate Open Spatial Science

The adoption of openness and open-source practices in GIScience is essential for developing the next generation of spatial scientists (Rey and Anselin 2006). Since the term "open" can take on many different meanings and be applied to different aspects of the learning process, we first discuss the growing opportunities for openly accessible education in GIScience and then focus on open science as mediated through open-source software and materials. Throughout this section, we also discuss some of the challenges that these practices create.

An obvious mechanism by which GIScience education can be made more open is by delivering courses virtually and making learning materials publicly available. Sharing GIScience course materials enables more students to access education, which is particularly important for learners with multiple commitments (i.e., full-time work and caregiving), those who cannot physically attend courses, or even those at the primary and secondary grade-school levels where GIS may not be offered. The growing number of GIScience courses and degrees being offered online is evidence that online learning is serving a critical role in training the next-generation workforce (Blanford et al. 2020; Vos and Kamei 2024; Wikle 2010). Pedagogical approaches proven to be successful in face-to-face course modes (e.g., PBL) have also been demonstrated to work in online GIS courses (King 2008), and scaling up online learning through, for example, Massive Open Online Courses (MOOCs) can increase accessibility (Baturay 2015) by removing cost barriers. Open resources are also improving, including through the GIS&T Body of Knowledge (https://gistbok.ucgis.org/), the emerging I-GUIDE Convergence Curriculum, Esri open education materials including the Guide to the Geographic Approach, and the Open Educational Resources for Spatial Data Infrastructures (OER4SDI) project (Keßler et al. 2024).

As open and online modalities become more common, one aspect that educators must work to overcome is the lack of personal interaction, which can lead students to feel isolated. This limitation is particularly detrimental in GIS courses, as frustrations can arise when students become stuck on a technical aspect without immediate support, and instructors or assistants end up fielding an overabundance of technical questions. Effectively leveraging online discussion boards, providing credit for peers who assist in helping classmates, or gamifying engagement through third-party applications (e.g., Yellowdig) can help create positive interactions and learning outcomes. Effective use of LLM-powered chat boxes and autopilot technologies can also be taught as part of the curriculum to help students learn to troubleshoot issues themselves.

Integrating open-source software, data, and code into the classroom is another way to increase access to GIScience education. At the most basic level, teaching students to use computational notebooks can foster open practices (Arribas-Bel et al. 2021; Koster and Rowe 2020; Rowe et al. 2020) and improve transparency and reproducibility (Brunsdon and Comber 2021; Kedron et al. 2021; Páez 2021). Integrating these tools into the classroom can be a challenge, though (Páez 2021), as support documentation and resources are often lacking, and open systems are not always updated or maintained to the same degree as other software. The growing availability of open data products (e.g., IPUMS, OpenStreetMap, WorldPop, WorldClim, etc.) and other resources (*I-GUIDE platform*, n.d.; Keßler et al. 2024; Rey et al. 2023) are helping to overcome these challenges. However, the challenges themselves can offer a learning opportunity by requiring students to create and share comprehensive spatial metadata that conforms to existing International (ISO) standards and teaching them how those practices facilitate data reuse and the critical evaluation of problems. Together, these skills can advance data-driven discovery while also fostering Findable Accessible Interoperable and Reusable (FAIR) data practices (Holler and Kedron 2022; Wilkinson et al. 2016).

Open source software can also be a mode through which critical thinking skills are taught and students engage with critical epistemological aspects of GIS (Holler 2020). For example, coupling a domain topic with open-source GIS requires students to simultaneously develop fundamental knowledge of the skills and topic to address societal issues (Holler 2019). Furthermore, using open-source software allows students to interrogate the idea that GIS is authoritative and improve their problem-solving skills by identifying and fixing data errors and software bugs that might affect results. In this way, teaching the next generation how to build and use open GIS can help overcome some of the power inequities in access to GIS that contribute to the digital divide (Ghose and Welcenbach 2018).

Another pedagogically rich way to facilitate open GIScience is to integrate reproductions and replications of published research into coursework using open science tools. There are several pedagogical benefits to having students engage in replications of published research (Kedron et al. 2024). First, it requires them to deeply engage with GIS concepts, methods, and arguments, helping to make these often abstract elements more real. Second, students learn and practice open research design and management skills such as using an open version control system (e.g., GitHub) and responding to public comments. These types of skills are durable and robust to shortening competency cycles. Finally, replications allow students to work on meaningful questions that are unresolved by the scientific community. A template for guiding reproduction and replications of geographic studies is available (Kedron and Holler 2022) that can be implemented in GIScience courses. Openly published reproduction and replication reports demonstrate how to use the template in classes (Burt et al. 2022; Holler et al. 2023; Kedron et al. 2023).

It should be noted that simply making courses and software open will not automatically solve access issues or power inequities, and using open-source materials can, in some cases, add barriers to learning. For instance, with open software, students may need to piece together operations from many different systems, which can cause more challenges than working with a single application. It is not uncommon for open applications to rely on other open-source packages being active and up to date, which can lead to unexpected time spent debugging by both educators and students. This extra step can disrupt the learning process and create frustrations, particularly for students who are new to learning GIS (Holler 2019). The lack of documentation can also create roadblocks for educators and require extra time for tutorial preparation. For early career faculty who may also be balancing scholarship and service work, this additional time could exacerbate inequalities, while for those teaching primary or secondary school, it may detract from the intended learning outcomes.

3.3 | GIScience Education Should Cultivate Ethical Reasoning and Practices

Grappling with social and technological disruptions demands strong ethical reasoning and practice. Ethical reasoning involves not just judging right and wrong human behavior but assessing personal ethical values, understanding the social context around issues, applying various ethical viewpoints to complex dilemmas, and considering the consequences of alternative actions. Even the composition of a GIS project team can profoundly influence the nature of the questions that are asked and the interpretation of results. As such, ethical considerations must permeate every phase of a GIS project, underscoring the need for GIScience education to integrate ethical discussions at each stage of learning (Elwood and Wilson 2017; Nelson et al. 2022). A holistic approach to cultivating ethical reasoning and practices not only prompts students to engage with these issues throughout their education but also aids in the development of a strong ethical identity and refined decision-making capabilities.

First, students should be familiar with existing codes of ethics from organizations such as the GIS Certification Institute (GISCI), the American Society for Photogrammetry and Remote Sensing (ASPRS), and the Urban and Regional Information Systems Association (URISA). These codes encourage professionals to take on social responsibilities and enhance the social value of GIS projects. Next, ethics should be integrated fully into GIScience curricula in a way that is inclusive and comprehensive and takes into account the needs and interests of various life forms, species, and sentient beings, as well as the role of geospatial data in serving/influencing these interests (Zhao 2023). These lessons and discussions should be woven into the content each week through case studies, modules, and lab exercises from diverse cultural and social backgrounds that are suitable for different learning trajectories. For example, the GIS Professional Ethics Project (Dibiase et al. 2009) has produced open educational resources, including case studies, to help students recognize ethical problems and act with integrity. Ethical training can begin as early as the introduction of spatial data with discussions, for example, of known issues concerning the representativeness of spatial data from social media platforms (Mislove et al. 2011). Those discussions can extend to decisions or policies made based on biased or uncertain data and can highlight the potential disproportionate effects of those decisions on individuals or communities.

In parallel, to ensure that the next generation of geospatial experts represents a fuller range of backgrounds and perspectives, GIScience training programs must emphasize diversity and inclusion in the community. This approach echoes the early efforts of William Bunge in the Fitzgerald neighborhood of Detroit, where he trained Black community members in cartography to help them champion their own interests (Bergmann and Morrill 2018). Initiatives including NorthStar of GIS, the University Consortium of GIS (UCGIS) TRELIS-GS (Training and Retaining Leaders in STEM—GeoSpatial Sciences) program, Golden Compass, and GradWINGS (The Graduate Women+ in Geospatial Science) are exemplary mentoring programs continuing these efforts in academia and practice. Indeed, while GIScience has traditionally been a tool for those with power and resources, a reformed curriculum that emphasizes ethical considerations will empower marginalized communities to utilize GIS as a means to represent and advocate for themselves. Training programs and educational support should likewise extend beyond the North American and European contexts. While GIScience education has expanded around the world, many communities in the global south continue to have limited access to GIS technologies and training. Innovative projects such as YouthMappers have created important opportunities in many countries across the world, particularly in the Global South. However, much work remains to be done. Expanding who receives GIScience training can enrich the field and deepen the impact of discipline by integrating a multitude of voices and perspectives.

4 | Concluding Remarks

GIScience education prepares learners to think spatially about complex interconnected problems and teaches learners to build and use computational tools to understand those problems and implement solutions. Rethinking how GIScience education is developed and delivered amid technological and societal disruptions can help ensure the next generation of learners is prepared to tackle the growing number of grand challenges impacting our world. A GIScience workforce that has been trained in ethical reasoning will be better positioned to participate in civic debates and support civic processes concerning the collective response to disruptions. Because these responses will inevitably be geographically varied and implemented at multiple spatial scales, having a widely dispersed GIScience workforce with knowledge of local contexts will also be essential to understanding and shaping how communities and governments respond to disruptions. When possible and appropriate, teaching future GIScientists to adopt an open science approach can help accelerate positive outcomes.

However, achieving these outcomes requires a reflection on how GIScience curricula can be altered to meet the changing needs of technology and society. This paper frames that discussion by presenting how current technological and societal disruptions can be leveraged to improve *who* is being taught, *what* is being taught, and *why* it is being taught. The paper also offers a direction for *how* modern GIS should be taught based on advancing pedagogical and workforce needs. The directions and recommendations provided focus on GIScience courses and programs, but there are also more systemic actions that can be taken to improve training and build capacity. First and foremost, a geographic approach should be centered across degrees and course offerings, particularly when GIS is being taught outside of geography departments. A geographic approach emphasizes location and the important context that place and space encapsulate when organizing information and solving problems. Integrating this approach into general education courses and across disciplines can help to build a spatially literate society that is adept at identifying misinformation and debunking myths as they pervade social media and other popular news feeds.

While not the primary focus of this paper, an emphasis on spatial thinking and a geographic approach is also adaptable at the primary and secondary education levels. Many of the recommendations made here, such as the use of project-based learning and open resources, are already common in many precollegiate settings. What continues to be missing, though, are GIS materials tailored to these settings. Addressing this issue is essential because today's precollegiate students are tomorrow's collegiate students and geospatial workforce.

Progress on the precollegiate and collegiate front will depend simultaneously on the systematic efforts of the GIScience community and individual efforts. For example, a recent AAG initiative focused on bringing geographic concepts and coding into precollegiate education in the United States created a series of open lessons for the widely adopted Code.org platform. The cleverness of this approach rests in emphasizing a skill that educators are increasingly teaching (coding), using a platform they are already adopting (Code.org), but building lessons around geographic concepts and spatial thinking. Geography faculty at Middlebury College take a similar approach in their GIS curricula where all GIS courses are structured around teaching the theories and concepts of physical and human geography. For example, GIS labs teach students buffers and tessellation as means of understanding and applying central place theories to real-world settings, which roots GIScience in geographic theory and applied problem solving.

The need for spatial programming and infrastructure to support spatial problem-solving, inquiry, and exploration in colleges and universities is the central concept of "The Spatial University" first forwarded by Baker and DiBiase (Baker and DiBiase 2012) but quickly picked up by others (Janelle et al. 2014; Manson et al. 2022; Sui 2014). Many academic disciplines increasingly embrace core foci that include space, place, and human-environment dynamics. This development presents GIScience—especially during a time of scientific disruption—with an excellent opportunity to advance the idea in which spatial science and infrastructure become increasingly central to research, teaching, and service/outreach through the Spatial University. While infrastructure is often thought to be physical or technological, the Spatial University understands how people and training are also central to modern forms of infrastructure. Ideally, students see themselves as an integral part of a Spatial University that weaves spatial thinking throughout the curriculum and benefits from large-scale spatial infrastructure such as spatial@UCSB, U-Spatial at the University of Minnesota, the Geographic Data Science Lab at the University of Liverpool, the Center for Geographic Analysis at Harvard University, the Spatial Sciences Institute at the University of Southern California, or the Spatial Structures in Social Science (S4) and Earth Lab at Brown University, among others.

Importantly, spatial infrastructure in higher education can be relatively modest (e.g., one or two staff members that curate spatial data or support geospatial software), yet it can have disproportionate impacts on its reach. For example, hundreds of students, teachers, and researchers can be introduced through mechanisms like StoryMaps or GIS software on virtual machines. Additionally, these spatial infrastructures that form the foundation for the spatial university rarely come into existence overnight (Kne et al. 2022). The large infrastructure at the University of Minnesota, for example, began with only a few meetings per year among small and previously separated groups across colleges, libraries, IT, and facilities management. These conversations set the stage for an increasingly broad and inclusive community.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

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