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Evolving technology, shifting expectations: cultivating pedagogy for a rapidly changing GIS landscape

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ABSTRACT
As humans and natural processes continuously reshape the surface of the Earth, there is an unceasing need to document and analyze them through the use of Geographic Information Systems (GIS). The public is gaining more access to spatial technologies that were once only available to highly trained professionals. With technological evolution comes a requirement to transition traditional GIS training for the next generation of GIS professionals. Traditional GIS combined with non-traditional GIS (i.e. mobile and location media) and CyberGIS educational materials could attract new and diverse students into Geography departments while informing the next generation of geospatial tool builders and users. Here we pose an applied pedagogical framework for teaching cutting-edge GIS material to diverse student populations with varying levels of technological experience and professional goals. The framework was developed as part of the National Science Foundation (NSF) CyberGIS Fellows program and was applied as a course template at the University of Washington Tacoma's Master's of Science in Geospatial Technologies. We chart how the framework developed into a cyclical structure from our original conceptualization as a hierarchy. This changed the epistemological orientation accommodating the shifting technological terrain of the GIS landscape to improve the skills of those driving the machines.

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Introduction

The recent explosion in ownership and use of mobile technology has created vast new opportunities for the creation, collection, and analysis of digital spatial data. With upwards of 60% of all digital data containing a spatial component (Hahmann & Burghardt, 2013), the upsurge in the amount and breadth of locational data being produced has generated interest in geospatial analysis from diverse fields outside of traditional geospatial knowledge domains (Crampton, 2009; Haklay, Singleton, & Parker, 2008; Rickles & Ellul, 2014; Sui & Goodchild, 2011). As such, these new sources of data have brought about an opportunity for increased public, academic, and corporate engagement with spatial data, which has been reflected by a growth in interest in Geographic Information Systems (GIS), Geographic Information Science (GIScience) and particularly geovisualization from diverse audiences.

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Simultaneously, data collected via mobile phones, desktop computers, credit cards, transit cards and other digital mediums are often disorganized, heterogeneous, and unwieldy for traditional geospatial analysis.

At the same time, governments, industry, educators, and researchers are recognizing the utility of incorporating geographic information technologies into their workflows and classrooms. The knowledge and politics behind the production of geospatial analysis and information remain tightly coupled due to a higher valuation of knowledge when expressed quantitatively and in cartographic forms (Elwood & Leszczynski, 2013; Gerlach, 2015; Leszczynski & Elwood, 2015; Pickles, 1995; Wood, 1992) Traditional GISystems and Sciences have a long history of critique leveled against them as tools for the economically privileged and technically savvy, posing a risk of reproducing existing inequalities in the produced representations of the world (Curry, 1995a, 1995b, 1998; Obermeyer, 1995; Schuurman, 2006; Schuurman & Pratt, 2002).

Educators must grapple with counter-veiling pressures: one that insists on the application of new technologies upon heterogeneous, large data sets using new techniques; and one that cautions against reifying existing inequalities through naïve quantification and visualization. While addressing GIS curricula for a variety of industry and governmental needs remains a well-documented challenge (Dibiase et al., 2006; Kemp & Goodchild, 1992; Kemp, Goodchild, & Dodson, 1992), the degree to which spatial technologies have become ubiquitous aspects of the everyday presents new challenges and concerns relating to data access, equality, and privacy (Elwood & Leszczynski, 2011; Leszczynski & Wilson, 2013; Sui, Goodchild, & Elwood, 2013). In this article, following Elwood and Leszczynski's calls for the active use of modern forms of mapping as means of directly engaging societal inequalities (Elwood & Leszczynski, 2013; Leszczynski & Elwood, 2015), we present an intentional, reflexive pedagogy that embraces the emerging sub-domain of CyberGIS as a means of addressing the shifting terrain of GIScience education *and* the need for inclusivity in education and geovisualization. This framework was developed with support from the National Science Foundation (NSF) CyberGIS Fellowship program and implemented in the curricula of a new one-year Master of Science program in Geospatial Technologies at the University of Washington Tacoma.

To make this argument, the article proceeds as follows: first, we define CyberGIS as it relates to existing GISystems and GIScience. We then situate CyberGIS pedagogy in relation to existing GISystems and GIScience pedagogical literature, before presenting the new CyberGIS framework we developed. Finally, we conclude by reflecting on how our original pedagogical framing evolved over the duration of the one-year CyberGIS Fellowship. Ultimately, we suggest a shift away from an ordinal, scaffold-building approach to CyberGIS pedagogy and a move towards nominal categories of students defined by their existing skills, interests, and educational goals.

What is CyberGIS and why does it matter pedagogically?

In many accounts, GISystems refer specifically to the software and associated tools used to aggregate, inventory, and visualize spatial data (Longley, Goodchild, Maguire, & Rhind, 2015), while GIScience is the field of research related to these tools including "the development and use of theories, methods, technology, and data for understanding geographic processes, relationships, and patterns" (Mark, 2003, p. 2).[1] Geovisualization then becomes is a subset thereof which involves the interactive display of spatial information (Dykes, MacEachren, & Kraak, 2005; MacEachren & Kraak, 2001).

In turn, CyberGIS addresses big datasets associated with GISystems and GIScience. Jacobs (2009) defines big data as those sets of data whose size forces us to look beyond the traditional data analysis methods currently available. Big data emerges when existing methods for data analysis may not be appropriate due to data size and distribution. As such, while very powerful, traditional desktop GIS may not have the capabilities to analyse the extremely large, heterogeneous datasets now available (Wang et al., 2013), new cyber-infrastructures – networked systems of computation and data storage linked together through high performance hardware and software (Wang & Armstrong, 2009; Wang et al., 2013) – do. CyberGIS, then, refers to the utilization of these systems for geospatial analysis and visualization. Additionally, CyberGIS integrates spatial analysis and modeling (SAM), cyber infrastructure, and GIS (Wang & Armstrong, 2009; Wang et al., 2013). If big data are always necessarily a shifting target beyond the means of traditional methods, CyberGIS is an attempt to move geospatial analysis and visualization beyond the traditional desktop environment and into the realm of big data (Wang et al., 2013). Defined in this way, CyberGIS becomes a technological cutting-edge for GISystems, a set of highly dependent tools that allow for previously impossible analysis. These complex, ever-evolving systems require trained individuals to maintain, organize, and develop them.

Yet, GIS – both as a set of tools and as a research field – has been historically critiqued for being positivistic and representing the interest of the privileged and elite (see, for a review of these debates, Schuurman, 2000). Traditionally, the hardware, software, and sensors required for spatial analysis and geovisualization have been both expensive to acquire and difficult to use which have dissuaded some disciplines from quickly embracing their use (Ellul, 2015; Rickles & Ellul, 2014). With the lessening of the computational and equipment costs of spatial data visualization and analysis which occurred alongside the rise in smartphones offering location-based services and sensors capable of recording location data (Meier, 2015; Roche, 2014; Sieber, 2007; Sieber & Johnson, 2015), some scholars suggested that popular tools like Google Earth would presage a democratization of GIS (Crampton, 2009; Sui, 2008a, 2008b; Whalley, Saunders, Lewis, Buenemann, & Sutton, 2011).

At present, claims of democratization appear to have been overstated, instead existing technological, social and political hierarchies continue to limit possibilities for accessible web GIS to truly empower the masses (Haklay, 2013). However, this shift in increasing access to technology does present a valuable opportunity to foster an inclusive environment by attracting students that may not have otherwise considered GIScience. Students are encountering spatial data through the quotidian uses of their smartphone and may, subsequently, become interested in the function, analysis, and representation of spatial data. This creates both more opportunities for spatial data generation and data collection and an opportunity to encourage students with little or no programming experience to engage with spatial analysis and visualization.

When read as the leveraging of cyberinfrastructure to analyze geospatial data, CyberGIS becomes a critical asset in this process. CyberGIS research seeks to address critical technical and societal challenges such as: access to spatial data, improved data privacy, quality, aggregation, and integration from multiple sources, and implementing seamless interoperability among heterogeneous datasets associated with big data (Wang et al., 2013). We suggest that instructing the next generation of students in the methods and tools of CyberGIS offers the opportunity for a more inclusive environment for the next generation of GIS researchers and practitioners. To date CyberGIS has seen little curriculum and pedagogical development; however, we argue that the existing, extensive, and rigorously developed pedagogy for GIS (*inter alia* Dibiase et al., 2006; Goodchild & Kemp, 1992; Kemp & Goodchild, 1992; Kemp et al., 1992) can and must be leveraged to continue to address these deficiencies and inform ongoing CyberGIS praxis.

The CyberGIS Fellows program was established to commission creative and motivated faculty members across the country to collaboratively develop educational materials to address these challenges from multiple perspectives. In the following sections, we summarize current approaches to GIS pedagogy and how they might be applied to CyberGIS, before presenting the pedagogical framework that was developed and deployed in a one-year Master of Science program in Geospatial Technologies.

Towards a critical CyberGIS pedagogy

GIS pedagogy literature is both extensive and well debated. GIS in general has historically been harshly critiqued by for a seemingly empiricist agenda (Curry, 1995a, 1995b; Dobson, 1993; Pickles, 1995; Schuurman, 2000; Schuurman & Pratt, 2002). More recently, researchers have examined how specific epistemological commitments can influence the resulting GIS output (Dalton & Thatcher, 2014; Leszczynski, 2012; Rundstrom, 1995; Schuurman, 2006). One way to incorporate more epistemologies, more ways of knowing and understanding the world, is to encourage more and diverse ways of using GIS. Starting in the classroom, this requires the use of effective and inclusive pedagogical approaches (i.e. Summerby-Murray, 2001).

Here we situate GIS pedagogy within a constructivist frame which emphasizes a specific pedagogical framework that includes recommendations on how philosophy, strategies, tactics and tasks can be intertwined (Goodyear & Jones, 2004). Current approaches to pedagogy from GIScience subsequently inform our proposed and enacted CyberGIS pedagogical framework. We begin with an examination of pedagogical philosophy and strategies, and then discuss how the Geographic Information Science & Technology Body of Knowledge addresses tactics and tasks associated with GIS pedagogy.

Existing scholarship suggests that GIS education is most effective when utilizing a constructivist approach to knowledge acquisition, meaning one which builds on "principles already familiar to the student, in a structured manner, ensure[s] materials facilitate engagement in different ways and take[s] account of different skills to allow students to work at their own pace" (Rickles & Ellul, 2014, p. 8). The constructivist approach to learning accepts that existing knowledge both predicates and influences what new knowledge can be acquired (Schuurman, 2002; Summerby-Murray, 2001; Takacs, 2003). Existing knowledge acts as scaffolding to build new knowledge (Schultz, 2011). Constructivist theory of learning suggests that the learners will construct their own personal view of the world based on their individual experiences (Keiper, 1999; MacEachren, 2004). Social constructivism emphasizes that people learn through interaction and the students' feelings, attitudes, perceptions and ideas, greatly influence what is learned (Rickles & Ellul, 2014; Smith, 1999).

Experiential learning is the process of learning through direct experience, observation, and reflection (Kolb, 1984; Ormond, 2007; Steffes, 2004; Whitton, 2010; Zandvliet, 2006; Zandvliet & Fisher, 2007). These experiences in turn form part of an individual's epistemology. Constructivists recommend learning should focus on the use of authentic tasks, those everyday practices of a particular group, similar to on the job training (Greeno, Collins, & Resnick, 1996; Keiper, 1999). In line with the constructivist approach and experiential learning, many GIS curricula are developed around problem-based learning, activity based learning and understanding threshold concepts (Keiper, 1999; Sinton, 2009; Summerby-Murray, 2001; Whalley et al., 2011). These types of active learning have been shown to provide high level engagement and foster metacognition and deep learning (Schultz, 2011).

Sui (2005) noted that a distinction between teaching with GIS and teaching about GIS was necessary for course planning and content development (Sui, 2005). Students have been shown to struggle when tools and concepts are taught in isolation (Rickles & Ellul, 2014; Wright, Goodchild, & Proctor, 1997). When teaching concepts, it is required to describe why each button is pressed and what it does as opposed to a technical focus that simply shows students which buttons produce the desired results (Unwin, 2011). However, GISystems change quickly so it is necessary that students understand GIScience principles and concepts that can be applied regardless of which buttons are available at a given time (Dibiase et al., 2006; Longley et al., 2015; Şeremet & Chalkley, 2015; Tate & Unwin, 2009). For CyberGIS, the developer is not clicking buttons but writing the algorithms to process the data, which make these concepts even more important in this context.

What and how to teach GISystems and GIScience has been a long-standing challenge for domain educators. Over time, various attempts have been made to establish an appropriate corpus of knowledge for GISystems users. For example, in 1998, Marble (1998) created a pyramid of the concepts necessary to work with and build GISystems. The Geographic Information Science and Technology (GIS&T) Body of Knowledge (BoK) is a more recent attempt to coherently summarize a comprehensive set of knowledge and concepts that should be obtained at the undergraduate level, representing the core concepts and materials pertinent to GIScience (Dibiase et al., 2006). The BoK recognizes a need for standardized GIS in industry and curriculum while acknowledging the challenge of developing and maintaining teaching material for a constantly evolving technology is not new (Dibiase et al., 2006). Developed and agreed upon by over 70 educators, researchers and practitioners from the field of GIScience, the BoK has been considered by the GIS and technology community to be a representative sample of concepts to be included in GIS (DeMers, 2009; Dibiase et al., 2006, 2010).

However, neither Marble's pyramid nor the original version of the BoK are pedagogical in nature. They focus on what concepts must be known, but not how said concepts might be taught. Further, both these examples and many others fail to engage directly with many of the underlying critiques of GIScience as an austere, positivist science that reflects only those with the privilege and skills to utilize GISystems (Curry, 1998; Obermeyer, 1995; Rocheleau, 1995). Both traditional GIS and CyberGIS confront the processes associated with tool making, tool use, and the associated scientific endeavors (Pickles, 1995; Wang et al., 2013; Wright et al., 1997); therefore, given the role of CyberGIS in the emerging space of GISystems and GIScience, it is a natural space in which to take up the challenges facing GIS education. Big data are evolving and full of complex challenges, CyberGIS is well posed to address the ever-evolving challenges associated with them. In the following section, we outline a pedagogical framework for CyberGIS that is informed by the knowledges and skills necessary for GISystems users and builders while being mindful of the unique needs of diverse learning populations.

A CyberGIS conceptual pedagogical framework

Students pursue higher education with aims to find employment in a wide range of industries post-graduation. Students studying human and physical geography, earth science, political science, public health, criminology, biology, and a host of other disciplines are now finding careers where the ability to collect, organize, and analyze spatial data plays a critical role (Coetzee & Eksteen, 2012). At the same time, these individuals from disciplines outside the core domain of GIScience broadly and CyberGIS specifically often struggle to keep up with changing technology and to identify which combinations of new software and hardware will best meet their specific needs. People in industries outside of GIS may not work with spatial data on a regular basis; however, they may still make use of a variety of cutting-edge tools that offer spatial analysis to make informed, data driven decisions.

Existing GISystem and GIScience pedagogies and curriculums have an opportunity to evolve and incorporate CyberGIS concepts and techniques. Considerations particular to CyberGIS and big data include issues related to data heterogeneity, variety, size and cost to both store and process large data sets, the set of issues that has commonly come to be known as the volume, variety and velocity known as the "Three V's" of Big Data (Laney, 2001). As stated before, the tools of CyberGIS are different from those of traditional GIS in that there are fewer buttons to click and often more code to write. In the previous section, we situated GIS pedagogy and knowledge concepts in relation to the desire for experiential and inclusive learning outcomes. Here, guided by critiques of GIS as a tool for the privileged and technically savvy, we present a theoretically informed CyberGIS pedagogical framework to assist course designers in identifying effective solutions to teaching CyberGIS to meet their students' technical literacy and professional goals. In line with a social constructive approach which postulates that feelings the student hold and the social situation will influence what is learned, we accept that if material is too difficult for the student based on their existing technological skill level, frustration may overwhelm the student and then they may miss the learning opportunity. We describe CyberGIS educational tactics and tasks at a granular class level to meet student needs.

The reflexive, constructivist framework we present is a heuristic to guide the development of educational material in the field of CyberGIS and useful to other technical cognate disciplines. Digital tools will change and those listed are examples of tools for specific technological literacy skill levels.[2] In line with a constructivist approach, the tools and analytical methods selected by the instructor should be influenced by the concept being presented in class each week rather than the tool itself. It is pivotal that regardless of technological skill level, underlying GIScience concepts, particularly those found in the BoK, are well understood to ensure that new spatial tools are built and used appropriately.

As the theory and praxis of CyberGIS develop, they could reshape discourses within GIScience; for that to occur, we must lay the groundwork for their integration throughout a diverse set of disciplines associated with student learning as it relates to CyberGIS. The framework we present was conceptualized before and during the first year of a new Master of Science in Geospatial Technologies during which the authors were simultaneously NSF CyberGIS Fellows. The framework is designed as a guide for the process of developing new teaching material. In this section, we present three over-arching levels for student learners (see Figure 1) as this reflects the initial conceptualization of our framework. Each level of our pedagogical framework is aimed at a different target audience within higher

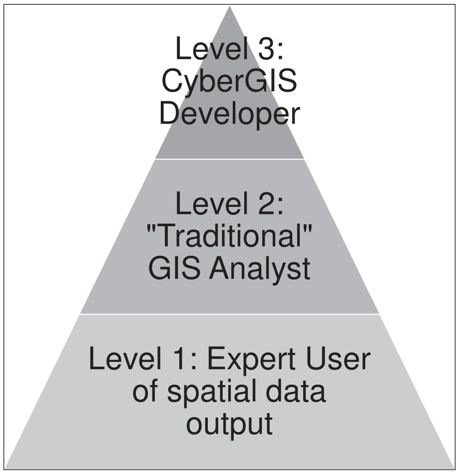

Figure 1. Original pedagogical levels related to technological background of the student.

education, and is meant to provide an understanding of the workflows, basic skills, and necessary concepts associated with GIS education that will benefit a new generation of students, especially as they relate to CyberGIS. Since unfamiliarity with core spatial concepts becomes a barrier to geospatial technology uptake and development (Rickles & Ellul, 2014), the concepts provided by the BoK (Dibiase et al., 2006) are recommended at each level and do not change based on technological skill level. Additionally, challenges associated with CyberGIS including critical technical and societal challenges such as spatial data access, privacy, quality, aggregation, information integration from multiple sources, and implementing seamless interoperability among heterogeneous datasets associated with big data (Evans, Oliver, Yang, Zhou, & Shekhar, 2014; Wang, Wilkins-Diehr, & Nyerges, 2012; Wang et al., 2013) are to be introduced at each level.

In this section, each level is presented and demonstrated to be unique according to student technological background. We additionally provide recommended tools and lab material appropriate for each level; these are meant as suggestions and not definitive requirements, a focus on lab work was chosen to emphasize the desired constructivist, experiential learning environment. Further, the term "level" is not meant in a hierarchical sense, as will be discussed in detail in Section "Discussion".

Level 1: expert user of spatial data outputs

Student description

This level of instruction is oriented towards students with a specific domain concentration or with specific local knowledge. For example, those interested in a particular topic within human geography, criminology, land use, ecology, or public health. For these students, knowledge and understanding of geospatial outputs and analyses are more critical than the ability to produce complex analyses themselves. These students are end users of traditional GISystems, like ArcGIS Desktop, and will rarely do more than interact with a GISystem Graphical User Interface (GUI).

Technological background

Students at this level will have experience with Microsoft Office have had interaction with web-based mapping platforms such as Google Maps or Apple Maps and will have done so in mobile and desktop computing environments.

Tactics and tasks associated with lab material

Students will gain the ability to harness basic functionality of a GIS, for example, the use of Google Maps and Google Fusion tables to convert a spreadsheet to a map, such as taking openly available crime or health data and creating a point map. Other examples include: an introduction to ESRI Online, 3D Maps for Microsoft Excel 2016, Google Earth Tours, and Tableau. For example, mapping with Socrata, a browser based online platform increasingly being used by governments where end users can view, download and interact with open data on a map or in tabular form. At this level, any relatively user-friendly mapping tool that offers a GUI would be appropriate.

Additionally, at this level students must develop an awareness of the issues and challenges associated with CyberGIS including spatial data access, privacy, quality, aggregation, information integration from multiple sources, implementing seamless interoperability among heterogeneous datasets associated with big data (Wang et al., 2013). These concepts may be integrated with the above suggested technologies, for example, students can explore the limitations of current open government data access through engagement with the Socrata platform.

Level 2: the "traditional" GIS student

Student description

This level is aimed at students who have experience with and interest in working directly with traditional desktop GIS software, like QGIS or ArcGIS. Students at this level build upon their existing GIS knowledge to gain an ability to interact and collaborate with front and back end developers[3] as well as the end-users of data and subsequent geovisualizations described in the first level. This is the "traditional" middle-actor that has stood between spatial data and data structures and processed spatial analyses and geovisualizations. Local government GISystems analysts and spatial business analytics are examples of this "traditional" role.

As technology shifts and spatial data increases in both volume and heterogeneity, familiarity with CyberGIS tools and concepts become necessary for the employment opportunities these students seek. In particular, at this level students develop an understanding and comfort level with CyberGIS tools and basic programming techniques, such as those found in the CyberGIS Toolkit for parallel cartographic computing (Shook et al., 2016; Wang, 2014) and the automated retrieval and processing of web-hosted spatial data using Python. Students at this level develop an understanding of various file formats and open-source and proprietary technologies, including but not limited to PostGIS, Web Mapping Services and JavaScript and Python libraries associated with the use of Application Programming Interfaces (API) to acquire, process, and display geospatial data.

Tactics and tasks associated with example of lab materials

Students in this level should be exposed to, but not expected to master, the concepts associated with a full stack development process associated with the design of a complete CyberGIS project: such as the acquisition, manipulation, analysis, processing, and visualization of spatial data hosted in the cloud. At this level, students should be challenged to think of creative solutions to tackle issues and challenges that could be solved with CyberGIS, for example the monitoring, analysis, and visualization of social media mentions of "election fraud" during an United States Presidential election or the aggregation and analysis of running data from run-tracking applications (like Strava) to reveal potential discrepancies between popular exercise routes and the locations of crosswalks. At this level, the instructor has a responsibility to push students to incorporate social justice and equity issues alongside the burgeoning technical ability of their students.

Level 3: CyberGIS developer

Student description

Students at this level come to the discipline with extensive programming background, but not necessarily any geography or traditional GIS experience. Already engaged in software or web development, these students are interested in becoming CyberGIS tool developers. At this level, the focus is to prepare students capable of creating new front and back end deployments of spatial information systems, in other words, students must be capable of *building* CyberGIS-capable GISystems. At this level, core spatial concepts are particularly important because students gain the ability to create bespoke geospatial tools. In other words, they are developing the code which powers the buttons that will then be pushed.

In order to do so, students must join programming knowledge with the fundamental spatial models that structure GIScience. Further, as their decisions influence what buttons do, what actions are possible in a given software application, students must not simply master the technical and theoretical concepts as distinct from society, but must reflexively consider the role of their decisions and resulting creations upon society. Tool builders have a responsibility to use their knowledge and skills to reduce the likelihood of reproducing inequalities through the use of their tools. This level is often comprised of students that have not yet been exposed to the challenges and critiques of GIS that have been highlighted in this paper. The tools being built need to provide the end user with the ability to conduct appropriate spatial analysis and geovisualizations, but to do so within as inclusive an environment as possible.

Tactics and tasks associated with lab material

At this level lab material should include skills associated with setting up servers and database management (i.e. Arc Server, GeoServer) that handle a diverse set of spatial data and information to users. Additionally, courses at this level will introduce tools required for the analysis of big data, such as Hadoop, Cassandra, Spark, and web based visualization software, like Leaflet, OpenLayers, or Carto. These specific tools will change over time.

Linking advanced conceptual skills, technical programming ability, and reflexive consideration of societal positionality and influence is a difficult task. One effective technique is to encourage students to identify a situation they wish to improve and then brainstorm how geospatial information and CyberGIS techniques might illuminate to better alleviate the existing condition. For example, a student interested in inequitable access to healthy food (Wang et al., 2012) could develop a tool that matched in-need families with their closest urban garden, while simultaneously allowing for the analysis and visualization of the distribution of food through a city via urban gardens.

Discussion

Structuring classes around these "levels" was constructive and helpful both during initial course design and when reviewing course material created through the CyberGIS Fellows program. However, we now suggest a break with the hierarchical nature implied by referring to the student groups as "levels." The ordinal nature of this stratification is problematic as one level is not more valuable than the others. For example, those who know how to build, maintain spatial data infrastructures and databases may not know the topic being scrutinized and analysed, and therefore may not be able to identify the most appropriate analysis method or represent the data stored in their databases. While, at the same time, a domain expert in the area being scrutinized might be able to make sense of the existing data within the infrastructure. Another reason discomfort arose is because not everyone will pass through each of these levels for individual reasons as originally conceptualized. Some students come to the field of CyberGIS via level 3 and may never encounter the same training that occurs at level 1 with a GIS GUI. For example, someone from an engineering background may already know how to technically build databases, but might not be familiar with the unique characteristics of spatial data and require training in these concepts.

Therefore, we see the relationship as cyclical, the levels are nominal categories rather than ordinal (See Figure 2). Each category is valuable, and being aware of each category is equally important for developing and using CyberGIS tools. The goal is to prepare students to engage at the level of their interest and intentions, while also training them in the necessary underlying concepts (technical, theoretical, and social). Doing so prepares them to be able to talk across "levels" or "categories" to perform the collaboration necessary for successful CyberGIS implementation. The categories are simply not ordinal, they are nominal.

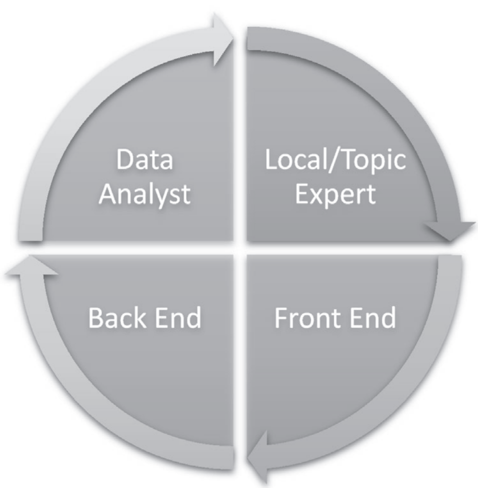

Figure 2. Updated CyberGIS pedagogical framework to reflect the cyclical relationship among the levels.

Despite differing levels of digital literacy level and technological capacity, multiple, varied individuals contribute to CyberGIS. The basic computer user may be the local or topical expert of the phenomena (originally thought of as level 1) for which data are being collected and analysed. A front-end developer creates the interface for this user (originally thought of as level 2), while the back-end developer creates the architecture through which the data passes (originally conceptualized as level 3). More complex projects involve multiple individuals in related roles, for example an analyst may decide which model is most appropriate for the existing data, while a project manager may set over-arching goals. Incorporating individuals from each level described is important for a functional and productive CyberGIS system, the levels should not be considered hierarchical and individuals must be trained to communicate across categories. Not everyone has all the skills required to create accurate, representative maps populated with data from large data stores, multiple perspectives and different skill sets are required, and this is particularly true when working with big datasets associated with CyberGIS. If an individual only interacts with those within the same technological experience level, the tools produced may not reflect the needs of someone at another level.

Considering this, while the categories for students and coursework organization remain distinct, data can be thought of passing through each category in a cyclical way. Data moves through people and tools in each category as it is captured, stored, analysed, and visualized. Potential students are able to contribute to CyberGIS in a variety of ways; they need not pass through each "level". These levels presented are now thought of as nominal categories.

Conclusion

As the amount of spatial data continues to grow, there is an evolving need for advanced GIS training. In turn pedagogy and curriculum must evolve and incorporate the new techniques, tools, and infrastructures for spatial data found in CyberGIS. This evolution could increase the likelihood for creative and diverse voices to generate new ideas that address the many challenges associated with CyberGIS. These challenges include but are not limited to: spatial data access, privacy, quality, aggregation, data integration from multiple sources, and implementing seamless interoperability among heterogeneous datasets associated with big data (Wang et al., 2013).

Here, we presented a framework for the pedagogical organization of CyberGIS students and coursework informed by traditional GIS pedagogy and constructivist-learning principles. The framework was inspired by the need to leverage both cutting-edge technologies and diverse populations to address complex challenges facing CyberGIS. The original pedagogical framework was conceived as hierarchical, it became increasingly clear that the "levels" are actually types of students with diverse epistemological positions, each category of student has knowledge valuable to contribute to the life cycle of a CyberGIS project. The "levels" are in fact organizational tools that reflect nominal, rather than ordinal, categories. Not everyone can or will pass through each technological level described in the framework. For example, a domain and regional expert is useful to input accurate data into a CyberGIS, the back end developer to build a functional and logical database, while a front end developer can help data analyst, streamline the data entry and data visualization process in an effort to communicate information effectively. All roles are valuable and necessary and it is imperative to recognize each other's strengths to best build and maintained CyberGIS tools to effectively to meet the needs of the end user and the supporting teams.

By incorporating this constructivist, reflexive pedagogical approach, it is hoped that students will feel encouraged by the learning process and in turn be attracted, and prepared to contribute to the field of CyberGIS. The aim is to create an inclusive environment that values new ideas. By bringing more and diverse voices to the field, it is hoped that more diverse solutions will be introduced to address the complex challenges facing CyberGIS.

Notes

1. Colloquially, GIS may refer to either a specific GISystem (the software and hardware) or the field of study that constitutes GIScience; in this article, GIS will refer to a GISystem unless otherwise noted.
2. For a more robust discussion of the specific tools that could be taught (see Roth, Donohue, Wallace, Sack, & Buckingham, 2014; Shook et al., 2016).
3. Front-end developers work with the parts of an application end-users interact with directly, while back-end developers focus on those parts end-users are unlikely to ever directly encounter, such as database structures.

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References

Coetzee, S., & Eksteen, S. (2012). Tertiary education institutions in Africa: Cloudy with a chance of GISc education in some countries. *South African Journal of Geomatics, 1*, 119–132.

Crampton, J. (2009). Cartography: Maps 2.0. *Progress in Human Geography, 33*, 91–100.

Curry, M. (1995a). GIS and the inevitability of ethical inconsistency. In J. Pickles (Ed.), *Ground truth: The social implications of geographic information systems* (pp. 68–87). New York, NY: Guilford Press.

Curry, M. (1995b). Rethinking rights and responsibilities in geographic information systems: Beyond the power of the image. *Cartography and Geographic Information Systems, 22*, 58–69. doi:10.1559/152304095782540573

Curry, M. (1998). *Digital places: Living with geographic information technologies*. London: Routledge.

Dalton, C., & Thatcher, J. (2014). What does a critical data studies look like, and why do we care? Seven points for a critical approach to "Big Data". *Surveillance & Society, 12*(2). Retrieved from http://societyandspace.com/material/commentaries/craig-dalton-and-jim-thatcher-what-does-a-critical-data-studies-look-like-and-why-do-we-care-seven-points-for-a-critical-approach-to-big-data/

DeMers, M. N. (2009). Using intended learning objectives to assess curriculum materials: The UCGIS body of knowledge. *Journal of Geography in Higher Education, 33*(S1), S70–S77. doi:10.1080/03098260903033980

Dibiase, D., Corbin, T., Fox, T., Francica, J., Green, K., Jackson, J., … Smith, C. (2010). The new geospatial technology competency model: Bringing workforce needs into focus. *URISA, 22*, 55–72.

Dibiase, D., Demers, M., Johnson, A., Kemp, K., Luck, A. T., Plewe, B., & Wentz, E. (2006). *Geographic information science and technology body of knowledge* (First.). Washington, DC: Association of American Geographers.

Dobson, J. (1993). The geographic revolution: A retrospective on the age of automated geography. *The Professional Geographer, 45*, 431–439.
Dykes, J., MacEachren, A. M., & Kraak, M. J. (2005). *Exploring geovisualization* (1st ed.). Amsterdam: Elsevier.
Ellul, C. (2015). Geography and geographical information science: Interdisciplinary integrators. *Journal of Geography in Higher Education, 39*, 191–194. doi:10.1080/03098265.2015.1039797
Elwood, S., & Leszczynski, A. (2011). Privacy, reconsidered: New representations, data practices, and the geoweb. *Geoforum, 42*, 6–15.
Elwood, S., & Leszczynski, A. (2013). New spatial media, new knowledge politics. *Transactions of the Institute of British Geographers, 38*, 544–559.
Evans, M. R., Oliver, D., Yang, K., Zhou, X., & Shekhar, S. (2014). Enabling spatial big data via CyberGIS: Challenges and opportunities. In S. Wang & M. F. Goodchild (Eds.), *CyberGIS: Fostering a new wave of geospatial innovation and discovery*. Springer. Retrieved from http://www.spatial.cs.umn.edu/CyberGIS/cyberGISNew.pdf
Gerlach, J. (2015). Editing worlds: Participatory mapping and a minor geopolitics. *Transactions of the Institute of British Geographers, 40*, 273–286. doi:10.1111/tran.12075
Goodchild, M., & Kemp, K. (1992). NCGIA education activities: The core curriculum and beyond. *International Journal of Geographical Information Systems, 6*, 309–320. doi:10.1080/02693799208901915
Goodyear, P., & Jones, C. (2004). *Pedagogical frameworks for DNER (the Distributed National Electronic Resource)*. Retrieved from http://unchange.pbworks.com/w/page/21352248/PedagogicalFrameworks
Greeno, J., Collins, A., & Resnick, L. (1996). Cognition and learning. In D. Berliner & R. Calfee (Eds.), *Handbook of educational psychology* (pp. 15–46). New York, NY: Macmillan.
Hahmann, S., & Burghardt, D. (2013). How much information is geospatially referenced? Networks and cognition. *International Journal of Geographical Information Science, 27*, 1171–1189. doi:10.1080/13658816.2012.743664
Haklay, M. (2013). Neogeography and the delusion of democratisation. *Environment and Planning A, 45*, 55–69. Retrieved from http://www.envplan.com/abstract.cgi?id=a45184
Haklay, M., Singleton, A., & Parker, C. (2008). Web mapping 2.0: The neogeography of the GeoWeb. *Geography Compass, 2*, 2011–2039.
Jacobs, A. (2009). The pathologies of big data. *Communications of the ACM, 52*, 36–44.
Keiper, T. A. (1999). GIS for elementary students: An inquiry into a new approach to learning geography. *Journal of Geography, 98*, 47–59. doi:10.1080/00221349908978860
Kemp, K. K., & Goodchild, F. M. (1992). Evaluating a major innovation in higher education: The NCGIA core curriculum in GIS. *Journal of Geography in Higher Education, 16*, 21–35. doi:10.1080/03098269208709163
Kemp, K. K., Goodchild, M. F., & Dodson, R. F. (1992). Teaching GIS in geography. *The Professional Geographer, 44*, 181–191. doi:10.1111/j.0033-0124.1992.00181.x
Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Englewood Cliffs, NJ: Prentice-Hall.
Laney, D. (2001). *3D data management: Controlling data volume, velocity, and variety*. Retrieved September 30, 2016, from https://blogs.gartner.com/doug-laney/files/2012/01/ad949-3D-Data-Management-Controlling-Data-Volume-Velocity-and-Variety.pdf
Leszczynski, A. (2012). Situating the geoweb in political economy. *Progress in Human Geography, 36*, 72–89.
Leszczynski, A., & Elwood, S. (2015). Feminist geographies of new spatial media. *The Canadian Geographer/Le Géographe canadien, 59*, 12–28. doi:10.1111/cag.12093
Leszczynski, A., & Wilson, M. W. (2013). Theorizing the geoweb. *GeoJournal, 78*, 915–919. Retrieved from http://link.springer.com/article/10.1007/s10708-013-9489-7
Longley, P., Goodchild, M., Maguire, D., & Rhind, D. (2015). *Geographic information science and systems* (Forth.). Hoboken, NJ: Wiley.
MacEachren, A. M. (2004). *How maps work: Representation, visualization, and design* (Paper Back.). New York, NY: Guilford Press.

MacEachren, A. M., & Kraak, M. J. (2001). Research challenges in geovisualization. *Cartography and Geographic Information Science, 28*, 3–12.

Marble, D. (1998). Rebuilding the top of the pyramid. *ArcNews,* pp. 28–29.

Mark, D. (2003). Geographic information science: Defining the field. In M. Duckman, M. Goodchild, & M. Worboys (Eds.), *Foundations of geographic information science* (pp. 1–18). London, New York: CRC Press Taylor & Francis Group.

Meier, P. (2015). *Digital humanitarians: How big data is changing the face of humanitarian response*. Boca Raton, FL: CRC Press Taylor & Francis Group.

Obermeyer, N. (1995). The hidden GIS technocracy. *Cartography and Geographic Information Systems, 22*, 78–83.

Ormond, C. (2007). *Environmental learning and higher education: A study of learning environments using place-based and constructive pedagogies*. Burnaby: Simon Fraser University. Retrieved from http://ir.lib.sfu.ca.proxy.lib.sfu.ca/handle/1892/9725

Pickles, J. (1995). *Ground truth: The social implications of geographic information systems*. New York, NY: Guilford Press.

Rickles, P., & Ellul, C. (2014). A preliminary investigation into the challenges of learning GIS in interdisciplinary research. *Journal of Geography in Higher Education,* (January 2015), 1–11. doi:10.1080/03098265.2014.956297

Roche, S. (2014). Geographic information science I: Why does a smart city need to be spatially enabled? *Progress in Human Geography, 38*, 703–711. doi:10.1177/0309132513517365

Rocheleau, D. (1995). Maps, numbers, text, and context: Mixing methods in feminist political ecology. *Professional Geographer, 47*, 458–466. doi:10.1111/j.0033-0124.1995.458_h.x

Roth, R. E., Donohue, R. G., Wallace, T. R., Sack, C. M., & Buckingham, T. M. A. (2014). A process for keeping pace with evolving web mapping technologies. *Cartographic Perspectives, 78*, 25–52. doi:10.14714/CP78.1273

Rundstrom, R. (1995). GIS, indigenous peoples, and epistemological diversity. *Cartography and Geographic Information Systems, 22*, 45–57.

Schultz, R. B. (2011). Active pedagogy leading to deeper learning: Fostering metacognition and infusing active learning into the GIS&T classroom. In D. J. Unwin, K. E. Foote, N. J. Tate, & D. DiBiase (Eds.), *Teaching geographic information science and technology in higher education* (pp. 133–143). Chichester: Wiley. doi:10.1002/9781119950592.ch9

Schuurman, N. (2000). Trouble in the Heartland: GIS and its critics in the 1990's. *Progress in Human Geography, 24*(4), 569–590.

Schuurman, N. (2002). Reconciling social constructivism and realism in GIS. *Acme, 1*, 73–90.

Schuurman, N. (2006). Formalization matters: Critical GIS and ontology research. *Annals of the Association of American Geographers, 96*, 726–739. Retrieved from http://www.jstor.org/stable/4124454

Schuurman, N., & Pratt, G. (2002). Care of the subject: Feminism and critiques of GIS. *Gender, Place and Culture, 9*, 291–299.

Şeremet, M., & Chalkley, B. (2015). Student perspectives on the teaching of geographical information systems (GIS) in geography degrees. *Journal of Geography in Higher Education, 39*, 18–36. doi:10.1080/03098265.2014.963795

Shook, E., Hodgson, M., Wang, S., Behzad, B., Soltani, K., Hiscox, A., & Ajayakumar, J. (2016). Parallel cartographic modeling: A methodology for parallelizing spatial data processing. *International Journal of Geographical Information Science, 30*, 2355–2376. doi:10.1080/13658816.2016.1172714.

Sieber, R. E. (2007). Geoweb for social change. In *Workshop on volunteered geographic information*. December 13–14, 2007. Retrieved from http://escholarship.org/uc/item/1574r603

Sieber, R., & Johnson, P. (2015). Civic open data at a crossroads: Dominant models and current challenges. *Government Information Quarterly, 32*, 308–315. doi:10.1016/j.giq.2015.05.003

Sinton, D. S. (2009). Roles for GIS within higher education. *Journal of Geography in Higher Education, 33*(sup1), S7–S16. doi:10.1080/03098260903034046

Smith, S. (1999). Social constructivisms and European studies: A reflectivist critique. *Journal of European Public Policy, 6*, 682–691. doi:10.1080/135017699343540

Steffes, J. (2004). Creating powerful learning environments: Beyond the classroom. *Change: The Magazine of Higher Learning, 36*, 46–50.
Sui, D. (2005). Will ubicomp make GIS invisible? *Computers, Environment and Urban Systems, 29*, 361–367.
Sui, D. (2008a). Is neogeography hype or hope? *GeoWorld, 21*, 16–17.
Sui, D. (2008b). The wikification of GIS and its consequences: Or Angelina Jolie's new tattoo and the future of GIS. *Computers, Environment and Urban Systems, 32*(1), 1–5.
Sui, D., & Goodchild, M. F. (2011). The convergence of GIS and social media: Challenges for GIScience. *International Journal of Geographical Information Science, 25*, 1737–1748. doi:10.1080/13658816.2011.604636
Sui, D., Goodchild, M., & Elwood, S. (2013). Volunteered geographic information, and the growing digitial divide. In D. Sui, S. Elwood, & M. Goodchild (Eds.), *Crowdsourcing geographic knowledge: Volunteered Geographic Information (VGI) in theory and practice* (pp. 1–12). Dordrecht: Springer.
Summerby-Murray, R. (2001). Analysing heritage landscape with historical GIS: Contributions from problem-based inquiry and constructivist pedagogy. *Journal of Geography in Higher Education, 25*, 37–52.
Takacs, D. (2003). How does your positionality bias your Epistemology. *The Nea Higher Education Journal: Thought & Action,* (Summer), 27–38. Retrieved from http://ww.nhea.org/assets/img/PubThoughtAndAction/TAA_03_04.pdf
Tate, N. J., & Unwin, D. J. (2009). Teaching GIS&T. *Journal of Geography in Higher Education, 33*(sup1), S1–S6. doi:10.1080/03098260903165964
Unwin, D. J. (2011). Discussion and prospect. In D. J. Unwin, K. E. Foote, N. J. Tate, & D. DiBiase (Eds.), *Teaching geographic information science and technology in higher education* (pp. 247–253). Chichester: Wiley. doi:10.1002/9781119950592.ch17
Wang, S. (2014). *CyberGIS Toolkit*. Retrieved September 30, 2016, from http://cybergis.cigi.uiuc.edu/cyberGISwiki/doku.php/ct
Wang, S., Anselin, L., Bhaduri, B., Crosby, C., Goodchild, M. F., Liu, Y., & Nyerges, T. L. (2013). CyberGIS software: A synthetic review and integration roadmap. *International Journal of Geographical Information Science, 27*, 2122–2145.
Wang, S., & Armstrong, M. P. (2009). A theoretical approach to the use of cyberinfrastructure in geographical analysis. *International Journal of Geographical Information Science, 23*, 169–193. doi:10.1080/13658810801918509
Wang, S., Wilkins-Diehr, N. R., & Nyerges, T. L. (2012). CyberGIS – Toward synergistic advancement of cyberinfrastructure and GIScience: A workshop summary. *Journal of Spatial Information Science, 4*, 125–148. doi:10.5311/JOSIS.2012.4.83
Whalley, W. B., Saunders, A., Lewis, R. A., Buenemann, M., & Sutton, P. C. (2011). Curriculum development: Producing geographers for the 21st century. *Journal of Geography in Higher Education, 35*, 379–393. doi:10.1080/03098265.2011.589827
Whitton, N. (2010). *Learning with digital games: A practical guide to engaging students in higher education*. New York, NY: Routledge.
Wood, D. (1992). The power of maps. *Mappings: Society/Theory/Space Mappings Series A Guilford Series*. Retrieved from http://books.google.com/books?hl=en&lr=&id=2t3AwxI81pYC&oi=fnd&pg=PA1&dq=dennis+wood&ots=gESbIYwE2f&sig=wlUNsyTerpm74v2mAr9j_kzqkq4#v=onepage&q=&f=false
Wright, D. J., Goodchild, M. F., & Proctor, J. D. (1997). Demystifying the persistent ambiguity of GIS as "tool" versus "science". *Annals of the Association of American Geographers, 87*, 346–362. doi:10.1111/0004-5608.872057
Zandvliet, D. B. (2006). *Education is not rocket science: The case for deconstructing computer labs in schools*. Rotterdam: Sense Publishers.
Zandvliet, D. B., & Fisher, D. L. (2007). *Sustainable communities, sustainable environments: The contribution of science and technology education*. Rotterdam: Sense Publishers.