[KE-01-025] GIS&T Education and Training

Abstract

GIS education and training have their roots both in formal educational settings and in professional development. Methods and approaches for teaching and learning about and with geospatial technologies have evolved in tight connection with the advances in the internet and personal computers. The adoption and integration of GIS and related geospatial technologies into dozens of academic disciplines has led to a high demand for instruction that is targeted and timely, a combination that is challenging to meet consistently with diverse audiences and in diverse settings. Academic degrees, concentrations, minors, certificates, and numerous other programs abound within formal and informal education.

Keywords: certificate, college, degree, education, GIS&T workforce, higher education, learning, professional development, teaching, training, university, workshop

Author & citation

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Explanation

1. Definitions

Education. Generally understood to be the systematic giving and receiving of instruction, often in school and university environments. Includes both the oft-used distinctions between teaching about GIS (a focus on GIS&T as the content) and teaching with GIS (a focus on disciplinary content such as geography, health, environmental studies, history, etc., learned via GIS&T as a support system).

Training. Generally understood to be focused more on delivery and acquisition of technical and software skills to accomplish specific tasks. Often takes place in professional development settings.

Credential. A qualification or level of achievement attained by an individual that documents his or her acquired knowledge and skills. Often measured via a combination of experience and/or formal assessments. In response to the question, “What credentials do you have for doing X?” a person could describe the degrees, certifications, or certificates that he or she has earned.

Micro-credentials. Micro-credentials document mastery of a discrete and well-defined set of skills, often associated with a competency-based format of education. Evidence of completed requirements can be recognized by earning badges, for example.

Degree. A degree is a qualification awarded by a secondary school or an institution of higher education after a person has successfully completed a course of study. In higher education, a person can hold a degree in a wide variety of academic disciplines (geography, health, business, biology, etc.) and also have acquired GIS skills or have completed a minor in GIS&T, without having a degree in GIS, or a person can hold a degree in GIS&T. Most GIS-focused degree programs are at the Associates, Bachelors, and Masters level, though a few exist at the Ph.D. level. GIS-focused degree programs also appear in other disciplines under different names, such as Location Analytics, Data Analytics, or Health Informatics.

Certificate. Certificates are non-degree academic programs offered by institutions of higher education or other professional programs. They are usually applied or technical in nature and include coursework that can be completed in 1-2 years. GIS&T Certificates have become very popular since the late 1990s as a desirable way to acquire GIS&T knowledge and skills without being overly time consuming. However, there is little or no consistency about what constitutes a Certificate; the expectations for the experience vary considerably across the programs and departments that offer these.

Certification. A certification is a type of credential most often associated with a profession or industry, designed with input from professionals in that field to establish minimum standards and expectations. Examples include the GIS Professional (GISP) certification offered by the Geographic Information Systems Certification Institute (GISCI), the Professional Certifications offered by the US Geospatial Intelligence Foundation (USGIF), and the diverse collection offered by the Imaging and Geospatial Information Society (aka ASPRS). These professional certifications are software-neutral and focus instead on work experience; each also requires the individual to pass an exam. Esri offers a set of software-specific technical certifications.

Accreditation. Accreditation is the process that an institution or organization undergoes, overseen by external evaluators, to validate its competency, authority, and overall control of quality. In the GIS&T context, the Council of Engineering & Scientific Specialty Board (CESB) accredits the Certification process that ASPRS oversees and the National Commission for Certifying Agencies (NCCA) accredits the Professional Certifications offered by USGIF. Currently the only GIS&T accredited curriculum is the GEOINT one that USGIF oversees under its Collegiate Accreditation program.

Knowledge, Skills, Abilities, and Competencies

- Knowledge is typically defined as theoretical understanding of facts, principles,

processes, and general concepts.
- Skills are capabilities or proficiencies that represent the application of knowledge. These can be acquired through training or practice. Skills can be cognitive or practical.
- Abilities are similar to skills but are considered traits that are innate rather than those acquired through training or practice. A person may have an inherent ability but it can also still be honed or improved.
- Generally, competencies are a combination of knowledge, skills, abilities, plus attitudes or behaviors that indicate how a person applies these. Competency-based education and competency-based learning are increasingly pursued as an approach that may improve student outcomes.

Body of Knowledge. A Body of Knowledge is a collection of the concepts, techniques, and theoretical foundations associated with and defined by a professional domain. It thus indicates what a professional in that discipline may be expected to know and be able to do, and has value for curricular planning and employment assessment. The Geographic Information Science & Technology Body of Knowledge (GIS&T BoK) was first published in 2006 (DiBiase et al. 2006) and is now updated quarterly in a digital version (which you are reading). In 2013, a European project, Geographic Information: Need to Know (GI-N2K), modified the original GIS&T BoK to one that more strongly reflected geospatial workforce needs (Vandenbroucke and Vancauwenberghe 2016), and this has continued development and expansion through the EO4GEO Project. USGIF maintains a GEOINT Essential Body of Knowledge.

2. Overview of GIS&T within Higher Education

Computer-supported geographic information systems had its beginnings in the field of land management, when Roger Tomlinson was experimenting with quantifying land cover in the Canadian provinces (Tomlinson 1967). At that same time, certain academic audiences were becoming familiar with the technologies, such as programs of landscape architecture and geography. Early adopters in those fields quickly appreciated how quantifying and qualifying the inputs within alternative scenarios could become part of their work-flows (Figure 1).

Figure 1. Professor Carl Steinitz discussing design and development scenarios to a class at Harvard’s Graduate School of Design, circa 1968. Source: authors.

Teaching and learning GIS during the 1970s and early- to mid-1980s was largely an ad hoc activity pursued informally and on a small scale by inquisitive practitioners, vanguard faculty, and determined students. In industry, government, and other professional settings, applications of GIS over these early decades developed in parallel with advances in computing infrastructure--from punch cards to command-line entry, from mainframe to minicomputers to PCs, from coarse to higher resolution data sets, and from line printers to early plotters. These same technological pathways and developments were taking place in academic settings, and this was affecting GIS (Dobson 1983) and cartography alike (Dymon 1996). Most early-adopting instructors and students were constrained to a small number of commercial GIS packages (Esri’s ArcINFO, MapInfo, SPANS, AtlasGIS) or academic-sponsored GIS software (Geodesy, and Idrisi) and the data sets that could be (with great effort) ingested into those packages. Processing time was slow, and the visualization of mapped results was underwhelming.

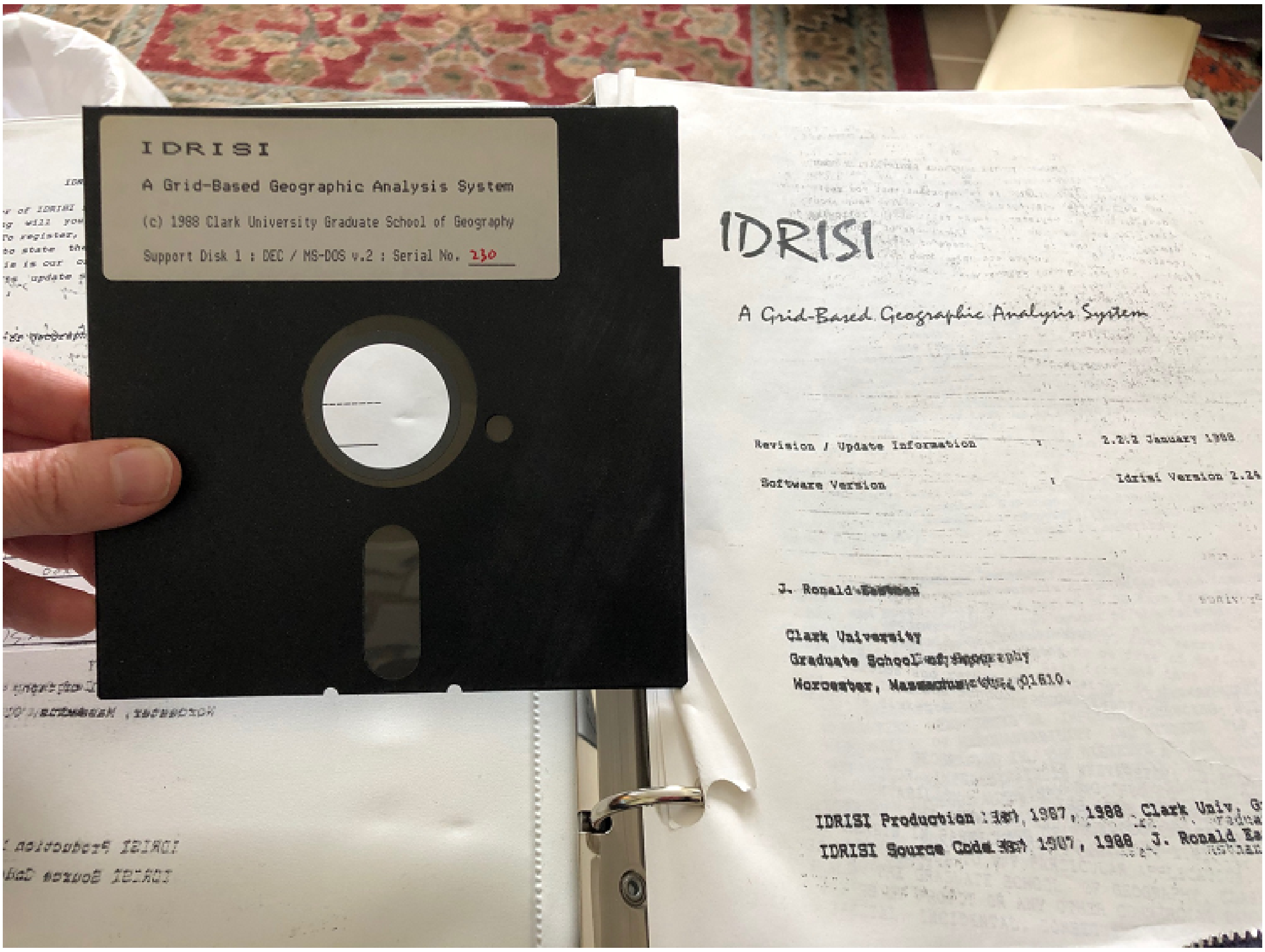

Figure 2. One of the five 5.5” floppy disks provided with the 300+ pages of instructions for using version 2.24 of IDRISI, the grid-based geographic analysis system produced by Clark University’s Graduate School of Geography. This binder of instructional materials was used by students in the first GIS course ever offered at Middlebury College (Vermont) by geography professor Robert Churchill in spring 1988. Source: authors.

At that time there was little community agreement about what could or should be covered within a single introductory GIS course, much less a full curriculum. In his 1983 ode to Automated Geography, Jerry Dobson warned that whatever we were to do, it should be done quickly.

“If geography is to compete with other disciplines, our college departments must offer computer instruction almost as enticing as video games by the late 1980s. This implies an immediate need for a training or retraining program for a significant contingent of our current geography faculty and a substantial developmental program to create new materials for automated instruction and for the practice of automated geography.” (Dobson 1983, 141).

Not until 1986 was Peter Burrough’s Principles of Geographical Information Systems for Land Resources Assessment published, considered the first textbook dedicated to GIS concepts and emerging theories. By the late 1980s the need to organize GIS education was recognized as essential to support and advance emerging research agendas; hence, coordinating educational efforts became part of the activities supported by the National

Center for Geographic Information and Analysis (NCGIA), first funded by the National Science Foundation in 1988. By 1990, a collection of 75 “topics” – designed for combining into different courses or modules - had been drafted by a network of scholars and practitioners. This collection comprised the “NCGIA GIS Core Curriculum” and it was made available (via paper copies and eventually on the World Wide Web) for instructors to review, adapt, or adopt (Goodchild and Kemp 1990; Kemp and Goodchild 1991).

Meanwhile, in the 1990s, advances in computational power, helpful graphical user interfaces, and the emerging capacity of the Internet rapidly fueled GIS instruction to spread to more and increasingly diverse learning environments, in the US and abroad (Kemp and Frank 1996). Penn State’s “World Campus” Certificate Program in GIS was the first national-scale program offered by a major higher education institution, and numerous other ones have followed. The European UNIGIS program was also a very early effort at distance learning in Geographical Information Systems and Science that continues today.

Short workshops and trainings were suitable for acquisition of software skills, but as a theoretical domain began to coalesce around geographic information science (Goodchild 1992), tensions between how and why to teach GIS as a tool or a discipline of its own became more wide-spread (Wright et al. 1997). The popular growth of software-focused training compelled some educators to aspire instead to a “model curriculum” for geographic information science (Marble 1999), one that could blend together the individual topics previously identified during the core curricular effort with prescribed learning pathways and suggested sequences to meet the needs of the increasingly diverse audiences interested. As O’Kelley recommended:

“A tightly integrated cumulative sequence of courses at the introductory, intermediate, and advanced levels with meaningful increments of technical demands, should be a reality in all serious instructional programs. … In recent years, in my opinion, methodological geographical course work was loosely arranged, so that instructors could waive prerequisites and allow (or even worse require) students to take courses without solid preparation, leading to the type of shallow exposure to methods that served no one particularly well.” (O’Kelley, 2000, 26).

However, the energy necessary to coordinate and create ambitious and very broad curricula, while accommodating increasingly diverse audiences, was unsustainable. An effort in the late 1990s to grow and transition the original topics into a NCGIA Core Curriculum in GIScience was never completed to its full extent, though portions are still available.

In 2003, a Strawman Report on Development of Model Undergraduate Curricula for Geographic Information Science & Technology was produced by Duane Marble and a UCGIS-affiliated Model Curricula Task Force, with an ambitious agenda to definitively and proudly establish an initial and full curriculum (Task Force on the Development of Model Undergraduate Curricula, 2003). The curricula would cover three components: 1) Geographic Information Science, 2) Geographic Information Technology, and 3) Applications of GI Science and Technology (Figure 3).

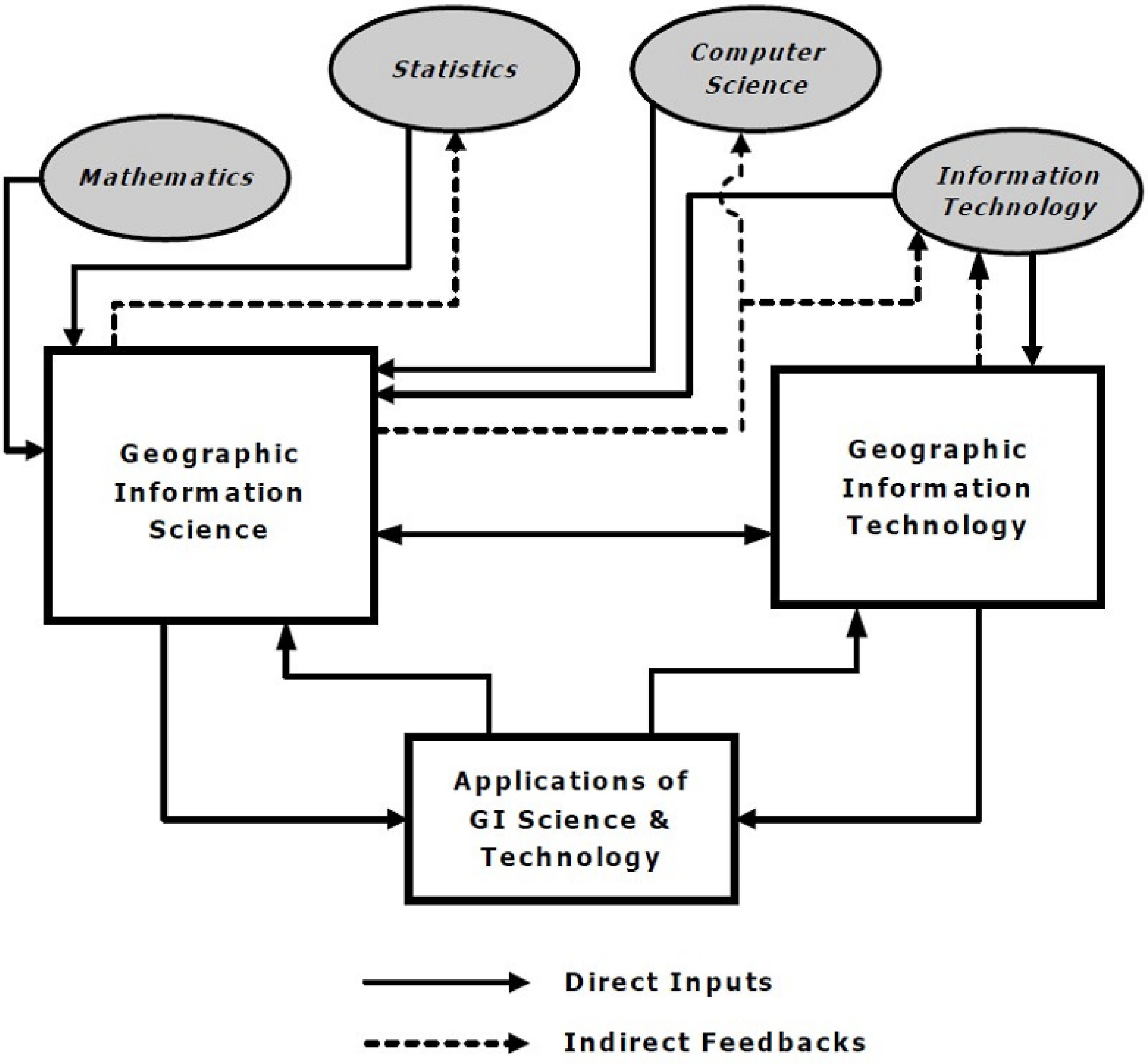

Figure 3. The three components of Geographic Information Science & Technology, as illustrated in the Strawman Report (2003). “The first of these [components] provides the 10 broad scientific basis for the other two; the second deals with the engineering creation and testing of tools based largely upon concepts drawn from GI Science, and the third involves the application of concepts and tools drawn from the first two areas to the identification and efficient solution of a variety of real–world spatial and spatial–temporal problems.” Task Force on the Development of Model Undergraduate Curricula, 2003, 9.

This curriculum was envisioned as a comprehensive whole: to include courses that focused both on the topics within a GIS&T Body of Knowledge (which was an item to be created as part of this curricular process) as well as other courses that would be supporting or application-area specific, plus integrative learning experiences such as internships or capstone projects. Another key element was the plan for suggested learning pathways, through which individuals with different interests would experience it.

Unfortunately, this Model Curricula was never realized as it was envisioned. As noted in the document itself,

“The primary resource required, is of course, the time donated by the volunteers who will be doing most of the work. While there are many individuals who have expressed a strong interest in the Model Curricula work, it has proven difficult to overcome the reluctance of organizations, academic units in particular, to recognize the time spent on this activity as something of value.” (Task Force on the Development of Model Undergraduate Curricula, 2003, 31).

One of the intended elements, however, was eventually produced. The foundational Geographic Information Science & Technology Body of Knowledge (GIS&T BoK) was finally published in its first edition in 2006 (DiBiase et al. 2006), and you are now reading its digital version.

Meanwhile, by the early 2000s, GIS&T was becoming well established as a subject of its own to study as well as being integrated into research work-flows (Wikle and Finchum 2003). University-based geographers had taken the lead in the original curricular development efforts in the 1990s, and departments of geography became the most frequent academic “home” for GIS&T (Kemp et al. 1992), but it was also increasingly common to find GIS-savvy faculty and their courses in schools and departments of planning, urban studies, environmental studies, geosciences, and other disciplines in the natural sciences, social sciences, and humanities (Sinton and Lund 2006). Moreover, academic libraries were also becoming instructional loci (Gabaldón and Repplinger 2006).

By 2010, nearly every major university in the USA had a set of GIS courses and/or a GIS degree program (Gould 2016), as did most major universities worldwide. Also during the decade, GIS had begun to appear in technical and community colleges with a focus on skill development, fueled by rising workforce demand and initiatives such as the NSF-funded GeoTech Center (Johnson and Sullivan 2010). A community of practice was developing around GIS education, supported in part by conferences such as Esri’s Education Users Conference, held annually since 2001.

One persistent topic of interest among the GIS&T community of practice are tips and strategies for effective instruction, yielding graduates of GIS&T classes (and whole degrees) who are competent and confident in their knowledge and skills. This seemingly simple outcome is undermined by both the uncertainties of both what to teach and how to teach it. Friction between education and training endures, though it is increasingly appreciated that these are not mutually exclusive (Hall-Beyer 2019; Mathews and Wikle 2019). Project- and problem-based learning is the most popular approach as it most closely mimics authentic, real-world experiences (Drennon 2005; Bowlick et al. 2016). A recent survey of the community found that active learning pedagogies are becoming more firmly established, supplementing or replacing traditional teaching approaches (Mathews and Wikle 2019). This is consistent with the idea that the learning process being experienced by students is a dynamic and active one, and approaches by instructors that are ineffective can be counter-productive (DiBiase 2018).

Today, the geospatial sciences, including GIS, cartography, remote sensing, and related geospatial technologies continue to serve numerous roles in multiple places in higher education (Sinton 2009; Sinton 2012). These can be generalized into three main categories of education, research, and administrative use (Kerski 2019).

1. As the focus of coursework on its own, with course titles such as Introduction to GIS, Advanced Applications of GIS, Cartography and Map Making, Remote Sensing of the Environment, Geospatial Programming and Web Services, and hundreds of others. The topic sometimes is its own body of content and/or it is applied as a toolset or a methodological approach. There are few academic disciplines within higher education – from biology to business to psychology to history to computer science -- which have not offered some type of GIS&T instruction at some point within the last decade. Thousands of individual classes and sequences of multiple courses are offered in traditional face-to-face settings as well as online and as MOOCs. Whole GIS degrees are more likely to be found in association with geography departments, and in addition, courses are bundled into concentrations, minors, and certificates.
2. As a set of methodologies used by researchers and students outside of instructional classrooms. This may take place through a GIS Center or independently by the individual scholars. Tools and methods from the geospatial sciences are applied to archaeology, climatology, and dozens of other fields from A to Z across a campus.
3. As a platform for administrative use or applied activity outside of instruction and research. GIS&T is supported and deployed in offices of admissions, alumni relations, buildings and grounds, libraries, fundraising and development, campus planning, athletics, offices of sustainability, offices of service learning & civic engagement, etc.

When vibrant activity exists across all three of these sectors on a campus (education, research, and administration), it can be considered a more integrated and mature situation that is likely to evolve only over time. This could be the educational counterpart to URISA's GIS Capability Maturity Model (GISCMM) that exists for organizations and agencies to self-assess how well they are reaping the efficiencies and benefits of enterprise GIS, to identify areas for improvement. Cowen (2019) has proposed an initial version of such a maturity model for universities to conduct their own self-assessment to evaluate, qualify, and quantify the ways in which their campus is involved with GIS. Universities such as the University of Minnesota, Clemson University, and the University of Redlands have been provided as examples of institutions that have achieved this level of integration.

By suggesting that a model towards this type of maturity exists, could be pursued, and may be desirable is open to debate. Ironically, many of the elements contained within the GIS maturity model are those identified in the 2003 Strawman Report (Task Force on the Development of Model Undergraduate Curricula, 2003) as desired components within the Model Curriculum. In any case, this idea might serve as one to market to universities whose administration may be largely unfamiliar with GIS&T and where poor coordination across campus is limiting to synergistic opportunities for faculty and students that might otherwise be possible.

3. Development of Instructional Resources

An interest in and demand for formal training and education in GIS&T preceded the existence of organized, vetted, and publicly available instructional materials. Conversations about what to teach and how to teach it were frequent and often anxiety-filled. Academic and software-specific publishers eventually filled these gaps with many options, but the role of user-generated content and community efforts were key from the beginning.

For example, The NCGIA GIS Core Curriculum (1990) and the GIS&T Body of Knowledge (first edition, 2006) were two valuable resources for faculty and instructors to consider as they designed new syllabi and plans for both formal and informal instruction. The learning objectives included for every topic in the GIS&T BoK were a useful first cut for building course syllabi and envisioning approaches to assessment (DeMers 2009; Prager and Plewe 2009). More recently, the GeoTech Center, funded by the National Science Foundation as the National Geospatial Technology Center of Excellence, has designed curricular pathways for workforce development that closely links to the Department of Labor's Geospatial Technology Competency Model (GTCM). These have also formed the basis of their Model Courses, built in part from structured, bottom-up activities known as a Developing a Curriculum (DACUM). A Meta-DACUM for the geospatial technologies also currently exists, produced by synthesizing across multiple DACUMs for the GIS and Remote Sensing Technicians, Specialists, Analysts, and Senior Analysts.

Before comprehensive GIS textbooks began to appear in the late 1980s and early 1990s, instructional resources such as books or tutorials were limited to manuals produced by GIS software companies (see Figure 2). But quickly thereafter, GIS textbooks became more plentiful and it became an annual process to query other instructors about what textbooks they would recommend. A wide and diverse set continues to exist today, including ones that focus broadly on geographic information science and spatial analysis (e.g., de Smith et al. 2018 or Bolstad 2016), ones that are designed as tutorials directly for use with specific software (e.g., Price 2016 or Graser 2013), and ones that aim to blend these two strategies (e.g., Shellito 2016).

The advent of the internet facilitated the distribution of individual lessons, such as Esri's collection of user-contributed ArcLessons (1998-2012), which has since morphed and expanded into Esri's LearnArcGIS Library. The Open Source Geospatial Foundation supports the Geo for All initiative, to connect educators world-wide who are committed to building their teaching, learning, and research platforms on open source platforms. Stand-alone geospatial lessons and instructional exercises continue to be developed and disseminated by entities such as Integrated Geospatial Educational and Technology Training (iGETT). Many of these are application-specific, and this trend continues with the preponderance of publications for particular domains and disciplines, such as GIS and Crime Mapping.

Apart from books designed to teach and learn about GIS, GIScience, and software directly, over the years books and articles have been published that have explored and critiqued the social context into which GIS has developed and in which it is deployed. Well-known examples include John Pickles' Ground Truth (1995) and articles or book chapters by Harley (1989) and Crampton (2009). An entire Journal of Location Based Services now exists for topics related to data privacy. Readings such as these are often assigned to students to support a more balanced understanding and awareness of the impacts and effects of geospatial technologies in the world.

The most significant trends in GIS instructional resources since the 2000s has been the shift to online activity and the growth of open educational resources. Printed textbooks are not used nearly as widely as in the past because of the proliferation of multimedia resources that an instructor can use or create independently, the frustrating challenge to keep developed materials aligned with changing software versions, and their cost. E-textbooks that are software-neutral (e.g., Campbell and Shin 2012; de Smith et al. 2018), as well as ones that have been designed to coordinate with software usage are increasingly adopted.

4. Geospatial Professional Development for Working Professionals

When conducted in the work-place or designed specifically for working professionals, GIS training is intended to help professionals in government agencies, non-profit organizations, industry, private companies, or any other work setting, acquire skills with software, data management and wrangling, and analysis. Desirable outcomes are to have confidence and competence at using geospatial technologies in their professional work-flows. This type of technical professional development was initiated during the 1980s by software companies in need of skilled workers for their expanding operations. The trainings offered by companies such as Esri has since expanded exponentially, through their extensive set of workshops available during their annual conference as well as through their own set of Massive Open Online Courses (MOOCs), published books, and webinars. Esri also now offers its own Technical Software **Certification**.

One way the demands for workforce training have been met has been the significant growth in GIS **Certificate** Programs offered by colleges and universities. In 1997, approximately 25-30 of these non-degree programs existed (Wikle 1998), while today there may be as many as 400 (Wikle and Sinton, in preparation). Often these are offered through a university's School of Professional and Continuing Education and designed for a local and regional workforce audience.

Meanwhile, the demand for targeted training is stronger than ever. Whole new programs exist for specific content such as GIS and Web Map Programming at the University of Wisconsin, or Mapping with Small Unmanned Aerial Systems at the University of Florida. Geospatial professional organizations such as URISA has begun to focus on GIS leadership skills, an area not typically covered in other more-general curricula. Trainings are also conducted by and for specific disciplinary audiences such as the Society for Conservation GIS, the National Institute of Justice, or the American Society of Civil Engineers.

In the early 2010s, massive open online courses (MOOCs) focusing on geospatial topics were extremely popular means to fulfill professional development demands, especially from global audiences. The Geospatial Revolution MOOC offered by Penn State University was reaching tens of thousands of students during its heyday (Robinson et al. 2015). Interest in these has waned somewhat since, though the University of California Davis offers a 4-course GIS specialization as a MOOC, as does the University of Toronto. Some MOOCs exist for specific audiences, such as this University of Texas one for journalists, and Esri's The Location Advantage is targeted towards business professionals.

Regardless of how one's knowledge, skills, and abilities are acquired, a Professional **Credential** is one option for individuals to document their expertise. The GIS Certification Institute offers a GIS Professional credential, and ASPRS has numerous certifications related to remote sensing, LiDAR, mapping, and GIS. The US Geospatial Intelligence Foundation has its own professional certification program, and is also the only entity that currently **accredits** any type of whole geospatial curricula: in their case, that which is focused on GEOINT. On the smaller scale, **micro-badges** have also gained popularity in GIS (Esri Insider 2014).

5. GIS in Schools and Professional Development for Educators

In the United States, cognizance of GIS continues to be limited at the primary and secondary school levels, much more so than in higher education, but awareness continues to grow incrementally. Even in the early days, a handful of K-12 educators were interested in exploring GIS as a learning tool. The very first Educational GIS Conference (EdGIS), convened by TERC (Technology Education Research Center), was held in 1994 in Cambridge, Massachusetts. Other such conferences followed, as noted in this timeline (National Research Council, 2006). Beginning in 2001, Esri began holding an annual three-day Education Users Conference (EdUC) in conjunction with its International User Conference in San Diego. This event, focused on building community, sharing best practices, and gaining hands-on training in new tools, approaches, and curricula, continues to attract around 600 educators annually. The participants represent a mix of levels and interests, including primary and secondary school teachers, curriculum designers, university faculty, librarians, and informal educators. Each year about half of the audience is new to the event, a reflection of how the awareness of and interest in GIS is continuing to slowly expand.

Over the years, the National Science Foundation has supported trainings and community-building initiatives such as the Virtual Immersion in Scientific Inquiry for Teachers (VISIT) program through Eastern Michigan University, and the Integrated Geospatial Education and Technology Training (iGETT) program, focused on remote sensing skills and curriculum for higher education. In the late 1990s and early 2000s, numerous universities had their GIS&T programs established and faculty trained with support from the NSF's old Course, Curriculum, and Laboratory Improvement (CCLI) program in the Division of Undergraduate Education (DUE). From 2003 to 2011, the National Institute for Technology & Liberal Education (NITLE), supported largely by the Mellon Foundation, offered numerous professional development GIS activities for faculty, librarians, instructional technologists, and other academic support staff at liberal arts colleges. During that same time frame, European initiatives such as HERODOT and iGUESS provided hands-on training and networking for educators (Kerski, Demirci and Milson 2013; Donert et al. 2016). These educationally-focused programs spanned multiple years, built communities of practice, and resulted in sets of reusable curricular modules. Increasingly, geospatial librarian positions have been funded and staffed in universities, and these librarians have been holding regular faculty professional development opportunities (Gabaldón and Repplinger 2006).

Throughout the years, significant effort and resources have been spent debating how (when, where, why, if) the "industrial-strength" GIS software was appropriate with school environments and aligned with objectives of digital tools to support teaching and learning. In response, educationally-focused alternatives such as MyWorld GIS, GEODESY (Kerski 2015), and company-sponsored tools such as Esri's ArcExplorer Java Edition for Education (AEJEE) were designed and created by educators, for educators. As GIS and the educational community itself have matured, it's become clear that the software itself is not the only barrier to successful integration of geospatial technology as learning tools or platforms. For the most part, the community has realized that creating, deploying, and maintaining GIS software specifically for educators has not been feasible or necessary. The focus has returned to commercial software, or to educationally-sensitive modifications of open-source software such as gvSIG Educa.

Professional development opportunities for teachers and instructors have responded to tightening budgets by shifting to online formats, co-locating with other events, or planning ways to reduce costs by focusing on regional – rather than national – audiences. The Dallas-area GeoTech conference and the Educators Day at the Northeast Arc User Conference are examples of this latter scenario. The Esri Teachers Teaching Teachers GIS (T3G) institute, which over 500 educators have attended, was held as a face-to-face event in Redlands, California from 2009 to 2016, and subsequently migrated to an online offering. Elsewhere in the world, teacher training opportunities are embedded into national programs such as Singapore's Ministry of Education's EduGIS program or Europe's GI Learner program.

6. Research in GIS-Supported Education

Unfortunately, research in GIS education has had limited uptake, reach, depth, and impact. A handful of dedicated scholars have focused in this area over time but it is uncommon to find an academic department that expects its incoming faculty to be pursuing this important topic. On-going challenges to current and future scholars in this field include the diversity of audiences and definitions, the difficulty in isolating variables and interventions, and the difficulties in undertaking school-based research (Baker et al. 2015).

While they are investigating the questions around GIS&T and learning, scholars must navigate the same types of educational and technical challenges that have affected the implementation and use of GIS&T in all formal and informal learning environments. Over the years, these have included hardware speed and capacity; the ability to install software in restricted-system environments; the complexity of desktop GIS software; shortages of GIS-based lessons with alignment, curricular fit, and adherence to national and state content standards; administrative and technical support; and time required to implement GIS-based methods (Bednarz 2004).

In many places and over time, the most limiting of these pedagogical factors have now been mitigated through such advances as internet-based GIS, wider access to online data coupled with an increased awareness and interest in citizen science, and publication of numerous educationally-focused exercises and activities that have been aligned with appropriate standards. Over 7,000 K-12 schools in the US will have active ArcGIS Online organizational accounts by 2020 (Kerski 2018a).

However, this has not translated into a significant uptake into research activity in this field. Many more worthwhile research questions exist than there are commitments by scholars to pursue them. In the United States, some GIS&T-based investigations have been supported by the National Center for Research in Geography Education, and in other countries, scattered research continues to be pursued as well. In Europe, for example, research questions have included how GIS education makes meaningful connections with critical spatial thinking (Bearman et al. 2016) or citizenship activities such as the SPACIT project.

7. Near and Long-Term Future

If we consider the late 1980s and the early 1990s as the time when GIS&T education and training became established, then we can consider that this area has had about 25-30 years to mature. During those decades, the "First Phase" saw tremendous expansion of

GIS instruction in both formal and informal settings, with much of it being fairly consistent and predictable. In United States universities, desktop GIS software, most often the Esri flavor, was used for an “Introduction to GIS” course and its most common sequel, “Advanced Applications of GIS.” The vast majority of instruction took place in departments of geography, environmental studies, geology, and planning. Elsewhere in the world, free and/or open source software was more likely to be the default available, including QGIS and GRASS. Growth of degrees focusing on GIS&T has been significant, though across formal educational settings there has been an inclination towards the technologies over the basic science, as predicted and anticipated by Marble (1998) and O’Kelley (2000). GIS&T course content within geography departments rarely demands that students acquire competence in programming and computational thinking (Bowlick et al. 2017). This is not surprising, especially because most students are introduced to GIS&T through only one class or module during one academic term, rather than a whole degree or curriculum. Students have learned to digitize (first with dedicated digitizing tables and then heads-up), to join tables, to perform types of overlays, and to write map algebra equations. Individual student and class projects became increasingly diverse and innovative, and in the meanwhile, many inventories of campus trees have been accomplished.

We have now entered the Second Phase, a transition that was triggered by the advent of web-based GIS and location-enabled technologies such as smart phones. GIS&T are present in countless academic instructional and research settings, including under the guise of Location Analytics, Digital Earth, Smart Planet, or Location Intelligence. As GIS increasingly becomes an enterprise-wide asset in organizations and businesses, coupled with and driven by trends such as the Internet of Things, Big Data, and crowdsourcing, new formats and instructional content are in demand, such as One-Hour Lessons in Geospatial CyberLiteracy (Shook et al. 2019). A stronger and more persistent role for spatial analysis and geospatial information science within the increasingly popular data science activity is warranted and this resonates with the GIS&T chorus (University Consortium for Geographic Information Science 2018), but as Arribas-Bel and Reades (2018, 6) note, “data science has not been engaging with space but ‘reinventing it.’”

In the primary and secondary educational system, bandwidth improvements and adoption of smartphones will continue to help advance web GIS as the platform of choice in schools around the world (Kerski and Baker 2019). In the US, the College Board had considered a possible Advance Placement GIS course, though the proposal has been furloughed following critical questions about capacity, sustainability, and articulation. The idea of a widely-adoptable and adaptable Model Curriculum continues to be enticing but as aspirational as ever as the potential audiences continue to diversify and the attention spans continue to shorten. A one-size-fits-all instructional model in GIS is not only futile but also outdated and unhelpful (DiBiase 2018). The future is both bright and uncertain.

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