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Editors and Review Board

Geospatial Education at U.S. Community Colleges: Background, Challenges, and Opportunities

Ann B. Johnson and Deidre Sullivan

Abstract: *Despite the fact that the enrollment of community colleges is composed of nearly 50 percent of U.S. undergraduate students, the role of these community colleges has been largely overlooked in the GIS education literature. This article describes their important role in preparing a diverse student population to meet the needs of the geospatial technology workforce. Challenges and opportunities confronting community college educators and programs are identified and discussed, including accountability, articulation, geospatial curriculum design and assessment, and general education. A timeline of national-scale initiatives in geospatial technology education is presented, with emphasis on community college contributions. In particular, the roles of community college initiatives in completing and promoting the U.S. Department of Labor's Geospatial Technology Competency Model, and in related workforce development initiatives, are highlighted.*

INTRODUCTION

Community colleges provide access to higher education and technical training to a diverse student population and are important resources for educating the U.S. workforce. More than 11.8 million people attend community colleges (AACC 2010). Of the approximately 1,200 community colleges in the United States, about 450 offer geospatial courses and programs. This paper focuses on the development of the community college education system as it relates to geospatial workforce needs. Particular attention is paid to the need to coordinate these programs and to strengthen their relationship to university geospatial education. Past initiatives to define geospatial core competencies and the industry are reviewed, culminating in the recently issued Geospatial Technology Competency Model (GTCM) of the U.S. Department of Labor (DOL). The GTCM was completed as a result of a collaboration between the DOL and the National Geospatial Technology Center of Excellence (GeoTech Center). Through its Advanced Technology Education Program, the National Science Foundation (NSF) established the GeoTech Center to support community college geospatial educators and programs by helping them align their geospatial curricula with national workforce competency standards.

COMMUNITY COLLEGE EDUCATION

American community colleges have been in existence since the early 20th century (American Association of Community Colleges 2006). The term *community college* includes two-year, lower-division educational programs providing credit and noncredit education and training usually limited to conferring academic Associate's degrees, lower division Certificate programs, and Career and Technical Education (CTE) terminal degrees. These institutions sometimes are called *junior, tribal,* or *technical* colleges, but we will refer to these institutions collectively as community colleges.

Among the factors that contributed to the rise of community colleges are the need for workers trained to operate the nation's expanding industries and the drive for social equality, the potential result of providing more people with access to higher education (Cohen and Brawer 2002). Community colleges continued to increase in importance throughout the 20th century as more students graduated from high school and the demand for additional education increased. In 1947, the President's Commission on Higher Education articulated the value of a population with free access to two years of study beyond high school and asserted that half the young people could benefit from formal studies through grade 14 (Cohen and Brawer 2002). In October of 2010, President Obama convened a Community College Summit to discuss ways to support community college programs by forming partnerships with business and aligning curriculum closely with the needs of the workforce (White House 2010).

The latest available data (2007 through 2009) from the American Association of Community Colleges (AACC) indicates that 43 percent of U.S. undergraduates attend community colleges with a total enrollment of 11.8 million students in credit and noncredit programs (AACC 2010). Of this student population, 56 percent are women. Forty percent are minorities. The average age of students is 28, with 46 percent under 21 and 40 percent between 22 to 39 years of age. Community colleges awarded more than 600,000 Associate's degrees and 325,000 Certificates in 2007. In a recent study of younger students (18 to 24 years old), the Pew Research Center (Pew 2009) determined that attendance at community colleges surged from 3.1 million in 2007 to 3.4 million students in 2009, while attendance at four-year colleges and universities remained flat. The Pew study suggested that the

increase was mainly because of economic conditions, but that increased high school graduation rates also may have contributed (84.9 percent in 2008 versus 75.5 percent in 1967).

The reasons students enroll in U.S. community colleges are as diverse as their personal backgrounds. These include:

- High school graduates completing lower-division courses before transferring to four-year institutions;
- High school students co-enrolling in courses at community colleges or taking courses at colleges as part of home-schooling programs;
- Students pursuing Career Technical Education (vocational) degrees or certificates;
- Adults working toward General Equivalency Diplomas (GEDs)[1] or entry-level workplace competencies (such as Welfare-to-Work[2]);
- Re-entry students who have been in the workforce for some time and are looking for new careers or skills;
- Students of all ages pursuing personal interests;
- Students who have already earned Bachelor's degrees or higher and want new skills or skill upgrades. The growing trend of these so-called "reverse transfer" students has led some to refer to community colleges as the new form of graduate school (Arnone 2001); and
- Long-term unemployed students and high school graduates who hope to acquire skills needed to enter or reenter the workforce.

Community college student populations tend to be more diverse in terms of age, ethnicity, socioeconomic status, and prior experience and objectives than those at four-year colleges and universities. The downside of this diversity is the difficulty in tailoring programs to meet the needs of such a heterogeneous audience.

Recognizing the potential of community colleges to strengthen the nation's workforce as well as to advance social equality, the NSF, DOL, and others have invested heavily in initiatives meant to expand access to community college education and training (Community College Research Center 2005). Investments include numerous grants over the past 15 years to support geospatial education at community colleges (Johnson in press).

GEOSPATIAL TECHNOLOGY AND THE ECONOMY

Geospatial technology (GST) is a rapidly evolving industry that crosscuts nearly every discipline and sector of the U.S. economy (Gewin 2004). GST encompasses geographical information systems (GIS), global positioning systems (GPS), remote sensing (RS), and emerging technologies that enable collection, analysis, and interpretation of spatial data (U.S. Department of Labor 2005a). A wide range of industries, including agriculture, emergency services, environmental technology, health, national security, resource management, and transportation, rely on GST to collect and analyze data about issues and occurrences that affect everyday life. Recent natural and man-made disasters from hurricanes to oil spills illustrate the need for coordination and sharing of geospatial data among all levels of government and the public. Applying the lessons learned from these events—and adapting to an Information Age that is increasingly tied to GST—requires a populace and workforce that can effectively understand and use the information derived from GST.

The DOL has done much to focus attention on geospatial workforce needs. One example is the President's High Growth Job Training Initiative, a strategic effort to prepare workers to take advantage of new and increasing job opportunities in high-growth, high-demand, and economically vital sectors of the American economy (U.S. Department of Labor 2005b). Another example is the six new geospatial Occupational Codes the DOL established in late 2009; after years of consultation with growth in these occupations between 2008 and 2018 (O*Net 2010), it is catalyzing interest in the capacity and effectiveness of the geospatial education infrastructure.

GST is not immune to general economic conditions. Consistent with many other industries, worldwide sales of geospatial data, software, and services flattened between 2008 and 2009 (Daratech 2009). Geospatial professionals attest to a corresponding dearth of job opportunities during the same period. However, industry leaders interviewed by Daratech were unanimous in their belief that double-digit growth rates enjoyed prior to the global recession would return by 2010. If projections and expectations about market performance hold true, the capacity and effectiveness of U.S. geospatial education programs at all levels will again face formidable challenges in meeting workforce needs.

GEOSPATIAL TECHNOLOGY EDUCATION AND COMMUNITY COLLEGES

GIS programs[3] in higher education have proliferated over the past 20 years. Currently, more than 2,000 of the 4,165 public and private two-year and four-year colleges and universities in the United States use Environmental Systems Research Institute (Esri) GIS software (Esri White Paper 2002; Infoplease 2005). Although other GIS software products are in use, the fact that 98 percent of higher-education institutions with more than 10,000 students license Esri software confirms that the adoption of this particular product is a useful surrogate measure for the adoption of GIS technology in higher education generally. More than 445 of the nation's 1,184 community colleges offer some instruction in GIS, including 145 certificate programs and 69 degree programs (GeoTech Center 2010). However, these statistics do not tell the complex story of GST growth on a campus. Nor do they reveal the issues that can support or impede its spread. These issues include:

- Program situation and orientation: What is the academic culture of the unit in which a GST program is situated? Is the program academically orientated or vocationally orientated?

- Program accountability: How do institutions and programs define and measure success?
- Articulation: To what extent does the program accommodate students who transfer or continue their studies on to other programs and institutions?
- GST as general education: Is GST included in an institution's general education curriculum?
- Program curriculum: What should be included in a GST curriculum and how should curricula be assessed?

Many of these issues are interrelated, but all should be understood by faculty members and administrators who plan to start or sustain a GST program. We consider each issue below in the context of U.S. community colleges.

PROGRAM SITUATION AND ORIENTATION

That geospatial technology is relevant to so many different fields and industries is reflected in the fact that it is hosted in so many different academic departments. Preliminary results of an ongoing survey of two-year college GST programs suggest that, like their counterparts at four-year schools, GST programs at community colleges reside most often in Departments of Geography. However, they also are associated with a wide variety of other disciplines. Other host disciplines identified by 102 survey respondents to date include Computer Science and Information Technology, Natural Resource Management, Geology, Surveying, Engineering, and Biological Science. Each of these is characterized by a distinctive disciplinary cultural that affects conceptions of GST as a subject, as well as norms of faculty status for GST instructions.

GST programs may be academically oriented, vocationally oriented, or a blend of both. Academically oriented courses and programs award academic credit (semester or quarter credits) to denote students' satisfactory completion of assigned activities. Vocationally oriented GST programs are now often referred to as Career and Technical Education (CTE) programs. Besides responding to different clienteles, these distinctions also affect the qualifications, standing, and evaluation criteria for faculty instructors. Respondents to the GeoTech Center's survey suggest that 60 percent of community college GST programs are offered in an academic discipline, while 20 percent of programs are CTE and 24.7 percent a combination of both.

Rules governing faculty qualifications differ between academic and CTE programs. CTE programs often do not require an advanced degree but do require a number of years of relevant professional experience. Thus, many community college GIS courses are taught by CTE faculty who work full-time as GIS professionals and may not be allowed to teach in academic programs. This sometimes leads to segregated faculties and student populations who ostensibly study the same topic. One adverse implication of this separation is that students in CTE programs may earn credits or Continuing Education Units (CEUs) that they are unable to transfer to academic programs later (see below for more discussion about program articulation).

PROGRAM ACCOUNTABILITY

One issue faced at all levels of education is accountability. At two-year and four-year institutions alike, educators face increasingly high expectations to demonstrate success in achieving business objectives as well as educational objectives. For GST programs at community colleges, program success often is judged on "completion" or "conversion" rates—i.e., what proportion of students complete a Certificate or Associate degree program after taking an initial course. Low completion rates can lead to discontinuation of a program. However, for students who are working full-time or who already have a degree, success does not necessarily equate with program completion. Based on 102 responses from GST programs at community colleges, the GeoTech Center estimates that working professionals make up about three-quarters of students served, and that nearly one in five students already possesses a bachelor's degree. These students may only need one or two GST courses with specific content to update or upgrade their skills to go on to be hired or advance in their careers. GST certificate and degree programs at community colleges may need a different definition of success that reflects the needs and aims of the unconventional students who have the most to gain from such offerings.

ARTICULATION

In the context of higher education, articulation refers to the policies, procedures, and interinstitutional agreements that enable students to move to a new institution without losing credits earned at their previous institutions. Some articulation agreements also stipulate that students who complete certain requirements at one institution are assured of acceptance in a degree program at a partner institution. Articulation among GST programs can be conceived as a kind of "institutional interoperablility" that facilitates lifelong learning with the mobility of contemporary life.

In general, U.S. community college GST programs are poorly articulated with corresponding university programs. Preliminary results of the GeoTech Center's survey of community college GST programs suggest that only 35 percent have articulation agreements in place with university programs. Several obstacles account for this low rate. One is the differing missions of these institutions. Faculty members in university GST programs are more likely than their counterparts in community colleges to conceive GIS as a science rather than as a tool. This tendency is reflected in the use of the term *GIScience* at universities, but much less so at community colleges (Wright et al. 1997, Kemp 2003).

Another obstacle that impedes articulation is the fact that community college GST courses tend to be numbered at the 100 or 200 level, while four-year institutions offer them as upper-division undergraduate or graduate courses at the 300, 400, or 500 level (Allen 2005). Sometimes the fact that similar classes or programs are offered by different academic departments further

complicates the problem of credit transfer and substitution. All these factors conspire to impede transfers of course credits between two-year and four-year institutions in the United States. An encouraging trend at universities is to offer introductory geospatial or GIS courses as lower-division courses (UCGIS 2007), which may create new opportunities for articulation. One example of this trend is a lower-division course that articulates between Southwestern College and San Diego State University in California (Tsou and Yanow 2010, see elsewhere in this issue). Faculty at both institutions worked together to design the courses so that they would be compatible and articulate, providing a clear pathway for students from one institution to the next.

GENERAL EDUCATION

The National Research Council (NRC 2005) report, *Learning to Think Spatially: GIS as a Support System in the K-12 Curriculum,* predicts that spatial thinking will play a significant role in the information-based economy of the 21st century. If so, spatial thinking also may become something every educated person needs to be able to do, rather than only those persons with specialized training. Signs of this shift are only now becoming apparent as colleges and universities begin to accept GIS courses to fulfill general education requirements in areas such as science, quantitative reasoning, communications, and analytical thinking (Tsou and Yanow 2010, see elsewhere in this issue). Tsou and Yanow cite several obstacles to the acceptance of GST as a general education topic, including (1) the constraints of teaching facilities and GIS equipment, (2) skepticism among geography faculties, (3) the costs of collecting GIS data and remotely sensed imagery, and (4) low public awareness of geospatial technology. Of all these obstacles, low public awareness may be the most daunting. However, recent developments, including the *Geospatial Revolution* public media project (Penn State Public Broadcasting 2010) and the slow but steady growth of GIS in primary and secondary education (e.g., *GIS for 4-H, The EAST Initiative, Community Mapping Project*), give some hope that even this obstacle may be overcome.

GST CURRICULA FOR COMMUNITY COLLEGES

A variety of national and state organizations, collegiate and secondary programs, and NSF and DOL grant projects have been funded over the past 15 years to improve curricula, provide resources, and document workforce needs for geospatial technologies (Johnson in press). As these diverse groups developed the necessary instructional materials, offered professional development, and published workforce information, concern arose about duplication of effort in the absence of a structure for national coordination or dissemination. This was especially true at the community-college level. For example, several community college–based programs have developed geospatial-related task analyses, known as DACUMs.[4] In many cases, these reports have been replicated for some occupations (such as GIS Technician) but not for others. Coordinating these efforts was one of the goals that the NSF had in mind when it requested proposals for a national Geospatial Technology Center. In 2008, based on recommendations of *A Plan for the National Coordination of Geospatial Technology Education from a Community College Perspective* (Sullivan et al. 2008), the NSF's Advanced Technological Education (ATE) Program funded the National Geospatial Technology Center of Excellence (GeoTech Center). The GeoTech Center's overarching goal is to create a hub for geospatial educators at community colleges that helps coordinate efforts and avoid duplication. Two priority activities have been consolidating results of DACUM analyses (J. Johnson 2010, see elsewhere in this is-

Table 1. National Efforts Focused on GST Education and Workforce Development (Funding Agency/Source)

Year	Activity
1988	NCGIA is formed. (NSF)
1990-1995	*NCGIA Core Curriculum* developed and disseminated. (NSF)
1992 - Present	*Remote Sensing Core Curriculum* developed and updated. (NSF/NASA/ASPRS)
1994	UCGIS is formed.
1995-1999	*NCGIA Core Curriculum for Technical Programs* partially developed. (NSF)
1995 -2000	*NCGIA Core Curriculum for GIScience* partially developed. (NSF)
1998-2006	UCGIS *Model Curricula* project partially developed. (Multiple sources/industry)
2003	GeoWDC *Geospatial Technologies Competency Model* published. (NASA)
2004	GIS Certification Institute formed. (URISA/Independent)
2006	GITA/AAG study, *Defining and Communicating Geospatial Industry Workforce Demand,* Phase I report released. (DOLETA)
2006	UCGIS *Body of Knowledge in GIS&T* is published. (Esri, AAG)
2007	USGIF Program Accreditation Criteria is released. (Industry)
2008	*A Plan for the National Coordination of Geospatial Technology Education* published. (NSF)
2008	National Geospatial Technology Center (GeoTech Center) established. (NSF)
2009	Six new DOL Geospatial Technology occupations established. (DOL)
2010	A new Geospatial Technology Competency Model developed and approved by the DOL. (DOL/NSF)

sue) and helping to complete the DOL's Geospatial Technology Competency Model.

A REVIEW OF EFFORTS TO DEFINE THE INDUSTRY AND GST CURRICULUM

In the 20 years since the *Core Curriculum in GIS,* the demand for GST education has grown dramatically and the practice of GST education at all levels has matured. Several factors account for increasing demand, including the proliferation of GIS use in a broad array of applications areas, increasingly plentiful and accessible data, friendlier software, increased computing power, and a more computer-literate public (Brown et al. 2004, UCGIS 2006). The national-scale initiatives that have advanced GST education and made the GIS education community more cohesive are listed chronologically in Table 1.

One of the earliest national GIS education efforts was conducted by the National Center for Geographic Information and Analysis (NCGIA).[5] Published in 1990, the *NCGIA Core Curriculum in GIS* consisted of a detailed outline for a three-course sequence of 75 one-hour units (Goodchild and Kemp 1992). In 1995, NCGIA started to develop a revised and expanded *Core Curriculum in GIScience* (last updated in 2000) and a *Core Curriculum for Technical Programs* (last updated in 1999). In a 2006 survey of 170 GIS educators, however, the NCGIA *Core Curriculum* still was the most frequently referenced GIS curriculum at that time. In 1992, the NCGIA began a *Remote Sensing Curriculum* project with support from the American Society for Photogrammetry and Remote Sensing (ASPRS 2007).

In 1994, the University Consortium for Geographic Information Science (UCGIS) was formed to provide a "unified voice for the geographic information science research community" (UCGIS 2002). At present, nearly 80 universities and three professional societies are members with several industry and government affiliate members. The leading education-focused effort by the UCGIS is the *Model Curricula* project, which began in 1999. The core element of this ongoing project, the *Body of Knowledge* (BoK) *for GIScience and Technology* (GIS&T), was published in 2006 (UCGIS 2006). The BoK is not a curriculum but purports to include all pertinent GIS&T knowledge broken down into ten "knowledge areas" (KA). In theory, by selecting different KAs, pathways through the BoK could be used to develop the content for a curriculum for different levels of education and disciplines.

Other recent national GIS education efforts have focused on defining core competencies instead of a national curriculum. Core competencies define the knowledge and skills required to carry out specific tasks common to a particular profession or occupation. They are critical links between the workplace and the classroom, for they connect job requirements to educational subject areas (Sullivan et al. 2004). Competencies provide a basis for the development of instructional materials, starting with assessments based on the competencies, and instructional modules based on the assessments. The various uses of competency specifications include:

- Providing an individual (student or professional) tools for self-assessment;
- Helping employers understand and evaluate the education of potential employees and define job titles, descriptions, and promotion ladders;
- Providing a foundation for examination-based professional certification;
- Providing criteria for curriculum assessment;
- Developing benchmarks for program accreditation;
- Facilitating articulation agreements;
- Providing tools to help justify courses for general education standing;
- Easing curriculum sharing among institutions; and
- Facilitating student placement in internships and jobs. (Sullivan 2004, DiBiase et al. 2010)

Although the UCGIS refers to the BoK as an "inventory of the domain" of GIS&T (UCGIS 2006) rather than core competencies, the BoK nevertheless represents an attempt to define parameters for the field of GIS&T, albeit from an academic rather than an industry-driven perspective. In contrast to the BoK, the GeoSpatial Workforce Development Center (GeoWDC)[6] at the University of Southern Mississippi used industry focus groups to develop the original *Geospatial Technology Competency Model* (Gaudet et al. 2003). The Southern Mississippi GTCM attempts to identify the full range of competencies needed by a working geospatial technology professional and includes areas of business, technical, analytical, and interpersonal competencies. Although the BoK provides a much more comprehensive treatment of the technical topics that constitute the geospatial field, the Southern Mississippi GTCM provides a useful framework for identifying the knowledge, skills, and abilities that are required for worker success. Elements of the Southern Mississippi framework can be seen in the DOL's new GTCM (DiBiase et al. 2010).

Many other grassroots efforts to define the core competencies for specific GST occupations have been undertaken at community colleges across the country, some using the DACUM job analysis technique (Johnson 2006). The GeoTech Center has since developed a meta-analytic approach to consolidate results of multiple DACUM analyses for GIS Technicians (Johnson 2010, see elsewhere in this issue).

Since its founding in 2004, the GIS Certification Institute (GISCI)[7] has relied on the BoK to validate courses claimed as educational achievement as part of its portfolio-based GIS professional certification process. Current certification requirements do not include a competency-based examination, mainly because no accepted competency specification existed when the GISCI was formed. However, in 2010, the GISCI announced a GISP Certification Update Initiative that is considering the addition of an examination requirement based on the DOL GTCM and related competency specifications (GISCI 2010).

Another influential geospatial workforce study commissioned by the DOL was *Defining and Communicating Geospatial Industry Workforce Demand* (GITA and AAG 2006). Led by the Geospatial Information and Technology Association (GITA)[8] and also involving the Association of American Geographers (AAG) and the Wharton School of Business at the University of Pennsylvania, the project's Phase I report recommended:

- A standard definition of the geospatial industry,
- A rationale for market segmentation,
- New geospatial occupational titles,
- A methodology for estimating geospatial workforce demand,
- Improvements to the Southern Mississippi GTCM, and
- Actions to close the "gap between geospatial workforce supply and demand."

Two recommendations are particularly relevant to higher education:

- Employers and educators must work together to develop effective strategies to close the gap between geospatial workforce demand and supply. The geospatial industry must articulate its workforce needs to ensure that educators respond with curricula that result in appropriately educated and trained individuals.
- Two-year (community-based) colleges should assume a strong role in training new geospatial technologists and meeting on-the-job training needs of local professionals. (GITA and AAG 2006)

Progress has been made on implementing many of the GITA recommendations. One recommendation came to fruition in late 2009, when the DOL established six new occupational codes related to GST. Among these are Geospatial Scientists and Technologists, Geographic Information Systems Technicians, Remote Sensing Scientists and Technologists, and Remote Sensing Technicians (O*NET 2009). Another recommendation was achieved in 2010 when the DOL approved a new GTCM that provides industry-validated competency specifications for geospatial workers as well as definitions of three geospatial industry sectors (DiBiase et al. 2010, see elsewhere in this issue). Interestingly, the NSF ATE projects intended mainly to support GST education at U.S. community colleges played important roles in the completion of the new GTCM.

COMMUNITY COLLEGE CONTRIBUTIONS TO GST HIGHER EDUCATION

The potential benefits of the new GTCM are not limited to community college educators and students. By the same token, some investments targeted to community college programs have proven to be beneficial to GST education at all levels. For example, the NSF ATE project, A Plan for the National Coordination of Geospatial Technology Education from a Community College Perspective, was a yearlong study that documented challenges and opportunities confronting GST education and training programs at U.S. community colleges. The project yielded recommendations for a National Geospatial Technology Center (NGTC) to coordinate efforts of community college educators (Sullivan et al. 2008). Recommended priorities included:

1. Assessing workforce needs;
2. Completing an industry-validated, nationally recognized set of core competencies;
3. Aligning curricula with professional certification efforts;
4. Creating a clearinghouse for curricula and resources;
5. Improving educational pathways through better coordination and articulation;
6. Providing professional development;
7. Creating an effective communication network;
8. Raising awareness and reaching underserved audiences;
9. Defining the role of GST education in supporting college administrative tasks and entrepreneurialism; and
10. Assessing trends in GST.

One imperative was to consolidate competency-related efforts so that core competencies could be identified and validated and a core GST curriculum could be defined. Soon after its founding in 2008, the GeoTech Center focused attention and resources on a collaboration with the DOL that led to the completion of its GTCM in 2010. The DOL's new GTCM represents a major milestone in the development of a coherent GST field. Potential benefits to four-year as well as two-year institutions and programs include efficient curriculum sharing, benchmarks for program accreditation, widespread articulation, examination-based professional certification, and effective screening and placement of new workers. To realize this potential, derivative products based on the GTCM are needed, including curriculum-assessment instruments, certification examination question banks, model curricula, and model articulation agreements. The GeoTech Center plans to help create such derivative products and to promote their value to GST education at all levels, as well as to community colleges in particular. The GeoTech Center now is poised to play a role for U.S. community colleges that is analogous to the role the UCGIS plays for research universities. As an affiliate member of the UCGIS, the Center will promote an awareness of two-year institutions that offer GST courses and programs and will promote synergistic relationships among institutions at all levels, to the benefit of students as well as the nation's geospatial enterprise. Looking ahead, some of the issues that the Center expects may confront GST higher education include:

- Given the diversity of the geospatial field, and the corresponding diversity of GST programs, what should a model GST curriculum look like?
- How may examination-based professional certification in GIS affect GST curricula?
- Will GST programs become subject to accreditation?
- How can GST programs at two-year and four-year institutions become more effectively articulated?
- Will spatial thinking be widely adopted as an objective for general education?

- What is the required capacity of the GST higher-education infrastructure and to what extent can community colleges help meet workforce needs?
- How can the GTCM and associated derivative works be maintained as the geospatial field continues to evolve?

CONCLUSION

GST is a rapidly growing and changing industry that is increasingly entwined with other information technologies and many sectors of the economy. The speed at which new fields are adopting GST, along with the rate of technological evolution, confounds the educational system's best efforts to keep pace. Although investments in GST education have produced some encouraging results, the national coordination of workforce information and educational resources remains an unmet need. For the United States to remain economically competitive, to achieve greater understanding in protecting our resources, and to reduce the chaos and loss of life associated with man-made and natural disasters, we need an efficient, responsive, and well-coordinated GST educational infrastructure grounded in a better understanding of the knowledge and skills workers need to be successful in the workplace. As a result of the efforts of hundreds of educators nationwide, coordinated by the GeoTech Center, U.S. community colleges are poised to help realize this goal.

NOTES

The GED is an exam developed in the United States for all adults who want an equivalent of a high school diploma. It tests general academic skills and core content that are covered in four years of high school.

[2]A former social program of the U.S. government, Welfare-to-Work focused on weaning single parents and the disabled from their reliance on federal and state income support and encouraging them back into the workforce. For more information, see http://www.opm.gov/wtw/index.htm.

[3]In most cases, GIS and GST can be used interchangeably within the context of higher education. Most GIS courses and programs include some type of remote sensing and/or GPS.

[4]DACUM is an acronym for developing a curriculum. It is a one-day or two-day focus group–like process that illuminates what workers do in terms of duties, tasks, knowledge, skills, traits, and, in some cases, the tools the worker uses (DACUM 2007).

[5]The NCGIA is a consortium of three universities (University of California at Santa Barbara, State University of New York at Buffalo, University of Maine) founded in 1988 with funding from the National Science Foundation.

[6]The GeoSpatial Workforce Development Center (GeoWDC) is part of the National Workforce Development Education and Training Initiative (NWDETI) sponsored by the National Aeronautics and Space Administration (NASA).

[7]The GIS Certification Institute (GISCI) is a 501(c) organization founded in 2004 to certify GIS professionals (GISP).

[8]In 2004, the U.S. Department of Labor and Education Training Administration (DOLETA) awarded $6.4 million to support six projects related to the geospatial technology industry as part of the DOL-administered program, the President's High-Growth Job Training Initiative. The grant to GITA was originally awarded to the Spatial Technologies Industry Association and transferred to GITA in 2005.

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What Education in GIS for Town Planners? A Tunisian Experience

Sami Yassine Turki

Abstract: *Future town planners should possess technical knowledge as users of geographical information systems (GIS) as well as certain skills in designing spatial databases and in spatial analysis. They also should understand GIS not only as a tool to be used in their work but also as part of an approach to organize urban planning and management. A Tunisian institute for urban-planning education has developed an approach to GIS education in which students progress through six levels over a six-year training period. The progression corresponds to the sequence of activities performed by urban planners and highlights the roles of GIS in each activity. At the highest levels, GIS is considered not only as an efficient tool for spatial analysis but also as a way to define and assess urban policies.*

INTRODUCTION

The ISTEUB institute (a higher institute for urban, environmental, and construction technologies—Tunis) was created in 2002 to prepare specialists in urban planning and management and urban environment and construction. The objective was to respond to problems associated with urban sprawl. In Greater Tunis, 500 additional hectares are occupied every year. A portion of this settlement is informal and not compliant with urban plans (AUGT 2004, Turki 2009). Until 2000, only about 100 people were involved in the Tunisian Town Planners Society and most of these were educated outside Tunisia or not as urban planners. The major part of a town planner's work involves conceiving urban-planning documents, for every one of Tunisia's 264 communes should have its own planning document. These ten-year plans are used to regulate land use and estimate future demand in networks, utilities, and services.

At the present time, ISTEUB confers two diplomas in town planning. One is a three-year technician diploma that prepares students to participate in urban studies and work in municipalities. The second is a three-year town-planning diploma that prepares students for leadership roles in urban public policy. The technician diploma program began in 2001. Fifty to 70 students enroll yearly. They come directly from high school without professional experience. The town-planning diploma program, which began in 2004, annually admits 25 to 30 students. To qualify for admission, applicants must have the technician diploma or a comparable degree in town planning or geography, civil engineering, geographical information science, architecture, environmental studies, or other related fields. Some applicants to the town-planning program also possess prior professional experience.

The GIS-related knowledge and skills town planners need are varied; these include spatial analysis, cartography, and spatial database design, among others. This diversity leads to uncertainty about how urban planners should learn GIS and related technologies. This paper presents an approach to GIS education for town planners that is informed by the geomatics paradigm. Bedard (2008, 195) defines geomatics as "a broad paradigm that emphasizes the use of a system approach to chain heterogeneous geospatial information technologies." This paradigm emphasizes an integrated approach to geospatial data acquisition and analysis (Gagnon and Coleman 1990). Consistent with that conception, I argue that GIS education for town planners should emphasize integration of GIS and related technologies into the work processes characteristic of urban studies and management. The following section of this paper describes the diverse contributions of GIS in town planning and management. After that, I explain the ISTEUB rationale for GIS education. Finally, GIS education provided in the two diploma programs is discussed.

GIS FOR TOWN PLANNING AND MANAGEMENT

During the past few years, planners have become more open-minded about using computer technology (Geetman and Stillwell 2009) and application models, such as land-use or urban/transportation-planning models. GIS is one of the most useful technologies for town planning even though it was not designed primarily as a planning support system (Brail 2008). GIS is useful for spatial analysis and cartography, which makes territorial diagnosis easier not only by automating map creation and editing but also by analyzing spatial relationships and dynamics among urban phenomena in ways that are cumbersome without using such technologies.

GIS is also a central technology in urban information systems. Urban information systems were introduced in the 1970s and have evolved since then (Dureau and Weber 1995). Two families of urban information systems can be identified: urban data banks and urban observatories. Urban data banks automate the repetitive tasks involved in updating the large-scale plans that are routinely used to administer urban services. In contrast, urban

observatories enable planners to analyze impacts of public policies, to diagnose dysfunctional aspects of urban policy, and to foster consultation and collaboration among diverse actors. Both kinds of urban information systems are becoming widespread in Tunisia.

THE ISTEUB APPROACH TO GIS EDUCATION

Training and education in GIS and geographical information science has been discussed among academics for more than 30 years (Kemp and Wiggins 2003). The "body of knowledge" published by the University Consortium for Geographic Information Science (UCGIS 2006) outlines the broad range of topics that students and professionals may encounter. There are diverse views on the importance of GIS in urban-planning education (Shen 2007). Marais (2008) discusses the challenges involved in teaching and learning at the intersections of GIS and the planning profession. A key challenge is to bridge the gap between the academic view of what should be learned and the professional view of what skills and knowledge are needed. Legates (2006) analyzed urban studies and planning education in the United States and observed that most undergraduate urban studies programs overlook GIS or spatial thinking. Programs that do include exposure to GIS, he notes, tend to lack clear and explicit educational objectives. Legates also noted that in most graduate planning curricula, GIS was included but the extent and nature of what was taught varied widely. Legates (2009) also studied urban spatial-planning education in the United Kingdom and showed that those programs are similar to counterparts in the United States in regard to GIS.

As professor and director of the town-planning department at ISTEUB, I coordinate the programming of training in GIS and associated fields. I involve faculty colleagues as well as field experts in designing the ISTEUB curriculum. Local experts in town planning and related fields (landscape, urban design, urban transportation planning, etc.) expressed their concern that the curriculum should assure students' adequate understanding of, and ability to apply, key principles. Professional town planners and members of the scientific committee of the institute examined and approved the two diploma programs. The idea was not just to ensure alignment of the education programs with the needs of the town-planning studies but also to prepare students to use GIS in ways that improve the practice of urban planning.

Consensus about the curricula was not easy to achieve. It was necessary to consider a range of scales (metropolis, city, urban project) and intervention modes (planning, design, management). Discussion with various stakeholders made it possible to define required competencies. Afterward, the idea was to select the competencies most needed in urban studies and management in Tunisia. Program assessment by a group of international experts made ISTEUB eligible to become a member of the APERAU network (international francophone association for the promotion of the education and the research in town planning). In the end, the GIS training curricula we adopted consists of six levels, one level per higher-education year. This arrangement is not based on progressive technical difficulties, but, instead, it corresponds to the way urban planners should consider and use GIS in their work. This approach is consistent with Legates's (2009) recommendation that appropriate competencies should be cultivated at different levels of urban-planning education.

GIS EDUCATION FOR TECHNICIANS IN TOWN PLANNING: THE INDISPENSABLE TECHNICAL SKILLS

The technician diploma is conferred after three academic years. The sequence of GIS-related topics presented in the three-year program is outlined in Table 1. The curriculum prepares graduates to participate in urban studies and to work in municipalities. Year 1 is devoted to understanding and representing urban space digitally and cartographically. Students complete courses on spatial analysis and representation techniques. The latter course presents classical techniques of cartography to help students create effective visual representations of their conceptions and analysis of urban spaces.

Year 2 of the technician curriculum deals with urban-planning methods. GIS training focuses on techniques of georeferencing, digitization and storage of the geographical data, spatial database management, and map design. All these techniques are applied in the context of a municipal urban development plan. Students collect and digitize all the data included in the municipal database.

Year 3 emphasizes spatial analysis and advanced techniques in spatial database management. Some students focus on culminating projects related to the realization of spatial databases on particular themes (i.e., green spaces, utilities, networks) and to exploiting the database for urban analysis. As depicted in Table 1, therefore, GIS training objectives and skill acquisition progress in parallel with the sequence of tasks that characterize professional practice in urban planning in Tunisia. In this way, the curriculum assures that GIS skills are gradually acquired and authentically applied.

GIS TRAINING FOR TOWN PLANNERS: GIS IN PROFESSIONAL PRACTICE

The second diploma, called the town-planning diploma, is conferred after three additional academic years. Graduates are expected to become leaders within the Tunisian urban studies and public-policy communities. As such, their GIS expertise must extend beyond routine skills in managing data and designing maps to include designing and managing urban policies. As in the preceding technician curriculum, objectives progress from cartography through database management to spatial analysis (see Table 2).

Table 1. Objectives of GIS Training in the Technician Diploma Program

Objectives	Cartographic Representation of Urban Space	Georeferencing, Digitization, and Storage of Geographical Data	Spatial Database Management	Map Design	Spatial Analysis	Advanced Techniques in Database Management	GIS Project Approach
Year 1	••						
Year 2	•	••	••	••			
Year 3	•	•	•	•	••	••	••

•• Main objective
• Secondary objective

Table 2. GIS Training Curriculum for the Town-Planning Diploma Program

Objectives	Advanced Techniques in Cartography	Advances Techniques in Spatial Analysis	Urban Applications of Remote Sensing	Spatial Database Design	Urban Information System Design and Management	Urban Policy Management with GIS	Collaborative GIS
Year 1	••	••					
Year 2	•	•	••	••			
Year 3	•	•	•	•	••	••	••

•• Main objective
• Secondary objective

In the first year of the town-planning diploma program (the fourth academic year overall), students complete advanced courses in cartography and spatial analysis to improve their ability to design effective maps and to conduct formal analyses of urban space. In Year 2 of the town-planning program (the fifth academic year in total), students complete additional advanced courses in remote sensing and spatial database design. The remote-sensing course focuses on urban applications of aerial and satellite imagery (classification, fusion, vegetation index, etc.).

All the courses included in Years 1 and 2 of the town-planning program improve the use of GIS in urban studies. However, the ISTEUB believes that GIS also should be a way for town planners to build strong relationships between diverse urban actors through what is called "collaborative GIS" (Ballram and Dragicevic 2006). When consensus among planners and policy makers is required, urban data banks and urban observatories provide means to achieve consensus. Furthermore, urban information systems can assist in gaining public support for urban policies. For this reason, a special course is dedicated to collaborative GIS in the Year 3 (the sixth academic year overall). Also included in Year 3 is a group project in which students investigate particular themes (e.g., urban utilities, housing and transportation). Each group has to conceive an observatory not only by identifying data and indicators but also by defining the actors, their responsibilities, and their relationships. To do that, students must define the policy and its objectives and assign roles to each actor. The conception of the observatory is not limited to its technical aspects; rather, it is conceived as a tool to assess policy impacts.

Students are asked to consider the following questions: What decisions can be made to cope with bad situations? Which indicators should be used to assess impacts? Which is the best indicator for each actor? What are the technical processes by which indicators can be calculated? Which database model best accommodates the assessment? Which data sources and data-acquisition techniques are required? With questions such as these in mind, planners-in-training learn to regard GIS as an instrument that improves professional practice. Table 3 outlines the questions and responses associated with an example of a group project.

Students' progress is evaluated yearly. Two modes of evaluation are employed: examinations and portfolios of project work. Written examinations focus on theoretical questions and exercises. A multidisciplinary jury evaluates artifacts of student project work. Multimodal evaluation assures that students achieve both the knowledge and practical skills that stakeholders envision for the ISTEUB diploma. Successful students demonstrate the ability to diagnose an urban problem, select a public-policy option, and design an urban information system in a way that makes it possible to assess this policy. About 20 students earn the town-planning diploma each year, yielding a completion rate above 80 percent.

CONCLUSION

This article describes a two-tiered approach to geospatial education for town planners. Both diploma programs progress through topics in the order in which they are likely to be encountered in

Table 3. Example of a Group Project Concerned with Policies Meant to Promote Green Spaces in Urban Areas

	Indicator	**GIS Study**	**Political Study**
Questions to Solve	What are the best indicators to show if the policy is well applied	What are the data useful to calculate indicators? What are their sources? Which methods allow their collection? Which processes allow the indicators calculation?	Which actor is responsible for data collection? Which actor is responsible for indicator calculation? Which actor should analyze indicators and make decisions? What decisions to make?
Example of Students' Answers	Number of m² of green space per capita	Data: urban green space, total number of inhabitants Sources: remotely sensed imagery (green spaces) and statistical agency (inhabitants) Methods: image classification	Data collection: statistical agency Indicator calculation: urban public agency Decision maker: local authorities Decision: more green spaces

professional practice. Basic techniques are taught in the technician program. The town-planning program focuses on advanced techniques in GIS and on approaches to integrate GIS with professional practice in urban planning.

It is too early to judge the extent to which the ISTEUB approach has achieved its objectives. However, two encouraging trends can be observed. One is that, in 2009, the Tunisian Town Planners Society dedicated its annual seminar to the question of GIS in the practice of urban planning. The second is anecdotal evidence indicating that GIS use is becoming crucial in the urban studies in Tunisia. The ISTEUB is poised to prepare aspiring urban-planning professionals to meet what appears to be a growing need.

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Planning Considerations for Online Certificates and Degrees in GIS

Thomas A. Wikle

Abstract: *Growth in online learning opportunities involving geospatial technologies coincides with efforts to make higher education more accessible to nontraditional students. However, while offering many benefits, the implementation of online certificate and degree programs introduces new challenges for students, faculty, and institutions. This paper provides guidance to colleges and universities presently considering the creation of online programs in geographic information systems with a focus on design criteria and institution readiness. Four groups most impacted by online program development are examined: students, program faculty, academic institutions, and employers. Information is also provided on the range and structure of online GIS degrees and certificates presently offered in the United States.*

INTRODUCTION

Higher education is experiencing its most profound period of change since passage of the GI Bill following World War II. Along with touching almost every other aspect of our lives, the Information Revolution is changing where learning takes place, the methods used to teach, and how students interact with instructors and peers. The age of high-tech, Web-based instruction has arrived. The rush to offer online courses is being driven not only by calls for higher education to be more accessible and responsive but also by the potential for institutions to generate new revenue (Bogue and Hall 2003, Burke 2005, Leveille 2006). As the number of students enrolling in Web-based courses increases, educators, administrators, and employers must understand the benefits, problems, and opportunities associated with online learning.

In recent years, online instruction involving geographic information systems (GIS) has become available at U.S. colleges and universities through programs ranging from traditional (face-to-face) courses that include an online component to 100 percent online degrees and certificate programs. The growth in online GIS instruction corresponds with the increasing demand for a geospatial workforce that possesses greater knowledge and improved competencies—at a time marked by nontraditional students searching for convenient access to higher education. For GIS professionals employed full-time, online learning offers an alternative to inflexible class schedules and work-to-school commutes. However, along with their convenience, new online GIS courses and programs can generate substantial challenges for instructors, students, and institutions. For example, faculty must adapt to new teaching pedagogies requiring significantly greater course preparation and correspondence time. Students enrolled in online courses face isolation from peers, slow Internet connections, and problems using complicated GIS software. Questions easily addressed face-to-face may require substantially more time to resolve through chat rooms, discussion boards, or e-mail correspondence. Institutional challenges include the identification of resources needed for course development and maintenance, the selection of appropriate assessment procedures, and the successful navigation of intellectual property issues. This paper explores benefits and barriers associated with the development and sustainability of certificate programs and degrees in GIS. The principal goal is to provide guidelines for institutions that are considering the development of a fully online certificate or degree in GIS.

The terms *distance learning* and *distance education* represent a range of activities from correspondence study to computer-assisted learning and online instruction. Distance education has been a part of American higher education since it was introduced by Illinois Wesleyan College in 1873. Students enrolled in early correspondence courses worked independently, returning assignments and receiving the course instructor's feedback through the mail. New venues for distance learning were later adapted for technologies such as radio, prerecorded sound tapes and videotapes, and television.

Student motivations for enrolling in distance-education courses include the desire to improve job effectiveness, enhance opportunities for salary increases, or achieve professional advancement. For public institutions, distance education became an alternative for the geographically isolated who might not otherwise attend a college class. Criticisms of early distance courses were often similar to those directed at today's online courses: overcommercialization, high student attrition, and lack of face-to-face contact between student and instructor.

ONLINE INSTRUCTION

Online or Web-based courses emerged in the 1990s with the growing availability and affordability of personal computers and Internet access (Daniel 1994). As Kriger (2001) notes, universities began offering online courses to improve access for nontraditional students during a period of shrinking public funding for higher education. The initial expansion of online courses took place at comprehensive public institutions often through an office re-

sponsible for outreach or continuing education. In recent years, online instruction has become more common at other types of institutions, including for-profit universities and small liberal arts colleges. At many institutions, the number of students enrolled in online courses is increasing at a faster rate than the overall student growth rate (Molenda and Harris 2001, Waits and Lewis 2003).

Web-based instruction can be divided into two categories: (1) asynchronous, in which students work independently and outside a preestablished schedule, and (2) synchronous, in which students and the instructor are connected in real time through live lectures or chat-room discussions (Sener 2002, Burgress and Strong 2003). Courses also differ in the degree to which they are instructor-led or are guided by objectives defined by students. Most educators define an online course as having at least 80 percent of its content delivered through the Web. According to Allen and Seaman (2005), courses with 30 percent to 79 percent of online content are considered *blended,* meaning that a significant portion of course content is offered online, but at least some course content is delivered through face-to-face meetings. Courses with less than 30 percent of online content are considered *Web-facilitated.*

Early initiatives involving the Internet and GIS instruction include *The Geographer's Craft* and other Web sites designed to disseminate teaching materials (Foote 1999). Compared to larger introductory courses, online GIS courses have not evolved rapidly, which can be attributed to their small enrollments and higher per-student development and maintenance costs. High development costs have led some institutions to create programs for sharing online GIS instructional materials. Examples include the UniGIS Consortium, dialogPLUS, and the EduGI Project (Wright et al. 2002, Chalmers et al. 2004, Painho et al. 2007).[1] UniGIS is a franchised international program for distance GIS education that includes 17 universities in 14 countries. Students can apply for a postgraduate diploma or a master's degree from any member institution. Funded jointly by the U.S. National Science Foundation and the U.K. Joint Information System Committee, dialogPLUS was developed by the faculty at Pennsylvania State University, the University of California at Santa Barbara, the University of Southampton (U.K.), and the University of Leeds (U.K.) for the exchange of teaching materials. A similar initiative for disseminating materials called the Online Center for Global Geography Education provides university faculty with materials that can be used by students involved in interdisciplinary projects.[2] Established in February of 2006, the EduGI Project has eight partner institutions and 61 courses that have been adapted for exchange. The Environmental Systems Research Institute (ESRI) became an early leader in the development of online GIS instruction with more than 20,000 persons enrolling in its virtual campus each year. Virtual campus modules are also used as part of college-level and university-level GIS courses with students having free access at institutions that maintain an educational site license for ESRI's ArcGIS software.

Projections for growth in the geospatial technology industry continue to be optimistic. A recent survey by the American Society for Photogrammetry and Remote Sensing predicts that annual expenditures within the remote-sensing and GIS industries will exceed $6 billion by 2012. As the geospatial industry grows over the next decade, new challenges will arise for institutions to create learning opportunities for GIS professionals (Wright et al. 2002, Gaudet et al. 2004, Mondello et al. 2004, Elsner 2005, Wing and Sessions 2007). Anytime, anywhere learning possible through online teaching will continue to serve as an attractive alternative for addressing the demand for GIS education and training. Therefore, an important question is whether institutions that have only recently begun offering online GIS courses are prepared to support fully online certificates and degrees in GIS.

Although some research has examined online GIS courses, few studies have looked at the development or implementation of online GIS degrees or certificates. Wright and DiBiase (2005) discuss the potential for developing rigorous online GIS programs, while Car (2008) reviews quality-assurance strategies for postgraduate GIS distance learning. Other studies have evaluated student satisfaction with distance GIS courses (DiBiase and Rademacher 2005) and the implementation of online GIS courses at the graduate level (Onsrud 2005). Another issue is how online GIS courses differ from other online courses (Elsner 2005, Detwiler 2008). The subject of planning new online courses and programs also must be considered (Cookson 1998, Patton and Hines 2001, Caffarella 2002, Chapman 2006). As a starting point for the preparation of new programs, this paper examines four stakeholder groups most affected by efforts to offer GIS instruction online: (1) students as direct beneficiaries of online education, (2) faculty involved in the design and teaching of online GIS courses, (3) academic institutions through which online GIS courses are taught, and (4) employers as indirect beneficiaries of knowledge and competencies provided through online GIS courses and programs. The approach used here considers four of the Sloan Consortium's "Five Pillars" for quality online education: learning effectiveness, access, faculty satisfaction, and student satisfaction (see Sloan Consortium 2010).

GIS STUDENTS

Sometimes called the *Millennials,* today's traditional college students began using computers and the Internet at an early age. Attracted by the ability to complete material at their own pace without classroom attendance, traditional students often choose online courses even when face-to-face courses are available. Flexibility provided by Web-based learning also appeals to older students, including full-time GIS practitioners (Wright et al. 2002 Pittinsky 2003) and international students who may have limited educational opportunities (Bartley and Golek 2004).

Online instruction takes place within a learning environment that is fundamentally different from that of a traditional classroom (see Figure 1). Lecture and discussion are replaced by a multimedia format using text, embedded links, photographs, sound recordings, video clips, and animations. Most closely approximating a classroom experience are meetings where students see and hear each other and the instructor during real-time discussions. These

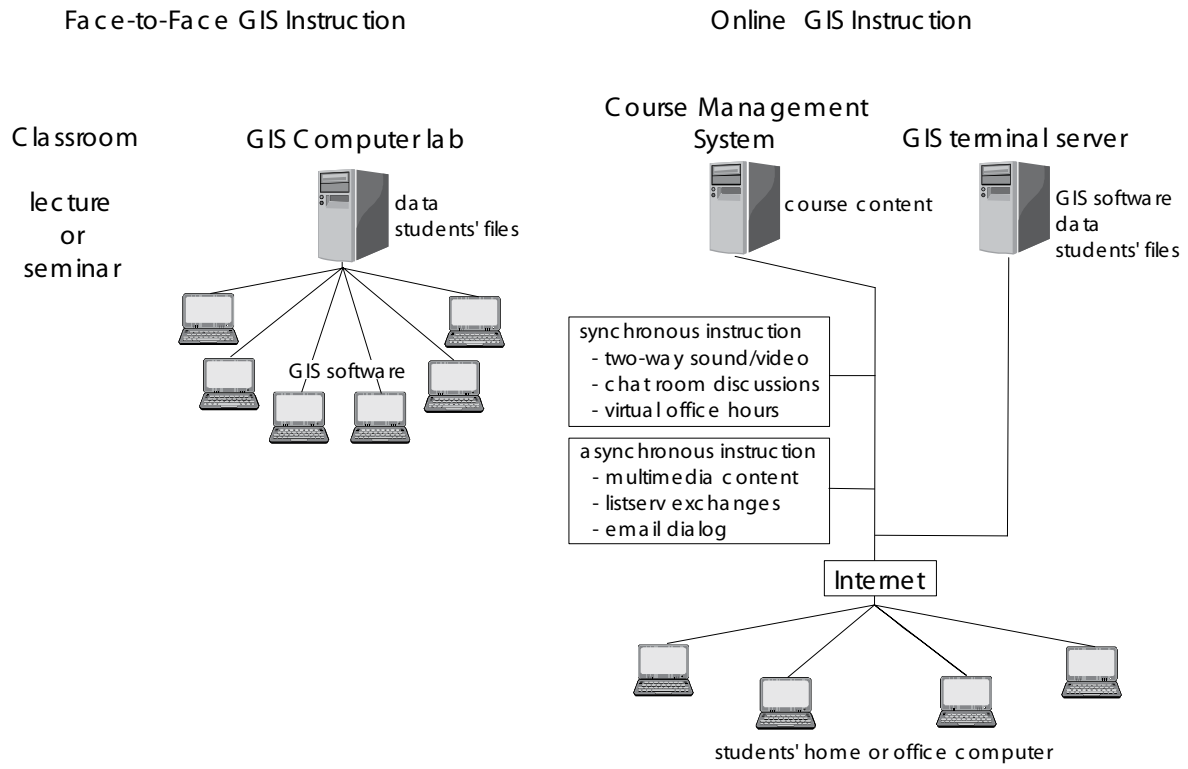

Figure 1. Comparison of face-to-face and online GIS instruction

types of synchronous class sessions require students to have fast Internet connections and often Web cameras and headsets with microphones. A benefit of this type of instruction is that lectures and discussions can be saved for later review during students' most productive learning times.

Asynchronous learning enables students to access course materials at any time with peer interaction limited to postings such as threaded discussions. A disadvantage is that because class attendance is not required, students who lack self-discipline may be slow in submitting assignments. Perhaps the greatest challenge for online students is adjusting to an environment without face-to-face contact with classmates and the instructor (Hara and Kling 1999, Schmidt and Gallegos 2001, Lawhon 2003, Lehmann 2004). The lack of personal interaction has been suggested as a contributing factor in higher attrition rates among online students (McVay 2000, Woodley 2004, Powell and Keen 2006). As noted by DiBiase and Kidwai (2010), attrition also may be tied to maturity for younger students often devote less time to course material compared to older peers. Beyond social issues, online instruction creates logistical challenges for students who are required to complete proctored exams at approved locations or who may live in remote time zones that makes it difficult to receive help from technical personnel. Part-time students, who frequently are older, also may have difficulty locating financial aid to support their coursework or academic programs.

FACULTY

Faculty pioneers of online instruction were either savvy in writing or adapting HTML programming or well supported by Web designers and technicians. At many institutions, faculty teaching online courses are supported by learning designers who are specialists in transferring content into Web-based formats. However, despite the increasing availability of support specialists, faculty who may be considering Web-based instruction often are unaware of the commitment necessary to create and manage an online learning environment. For example, compared to a traditional lecture course, a Web-based course may require substantially more preclass preparation (National Education Association 2000, DiBiase 2000, Bender et al. 2004) and time for corresponding with students via e-mail, chat rooms, or discussion forums. Wolcott and Betts (1999) describe this additional commitment as the "hidden work" of online teaching. The quantity of one-on-one correspondence involved in teaching online has been noted as a principal area of concern among faculty balancing other duties such as research and service (Kovel-Jarboe 1997). A related issue is course maintenance. For example, after a course has been developed, a decision must be made about who is responsible for updating links to Web sites and readings and for revising course materials when Web applications or GIS software change (Elsner 2005).

As institutions develop ambitious plans for offering new Web-based programs, full-time faculty have fallen under increased

pressure to become involved in online teaching (Lawhon 2003, Zhu et al. 2003, Shepherd, Alpert and Koeller 2007). Unfortunately, distance learning is sometimes pushed through by campus administrators without serious consideration of resource needs or other implementation factors. These include issues ranging from faculty training to technical support and faculty compensation (Bonk 2001, Shelton and Saltsman 2006).[3]

In the absence of training, first-time instructors often fail to take advantage of the Internet's enormous potential. Many utilize the Web for simply adapting text-based versions of lecture notes containing Web links (Whitlock 2001). Ko and Rossen (2001) suggest that faculty training should examine issues ranging from the development of effective online teaching strategies and use of course management systems to techniques for encouraging student participation and interaction. Some of the most successful online programs, such as Pennsylvania State University's World Campus, utilize "practitioner faculty" who can relate to adult professional students. As noted by Irani and Telg (2002), the challenge of preparing faculty to make Web-based instruction effective may be the single most important issue facing colleges and universities in the coming decade.

Copyright and intellectual property issues can also become barriers to the implementation of GIS courses offered online. As noted by Wallace (2004), mechanisms available to online instructors for gaining copyright clearance for graphics and other materials have not kept pace with advances in computer visualization and electronic delivery. In most cases, teaching faculty must assume the time-consuming responsibility of obtaining clearance for all materials they use online. Of special concern is that instructors and institutions can be liable for copyright violations. Another issue involves the ownership of materials used in teaching online courses. Because faculty can receive extra compensation for the development of online courses, administrators may consider course-related materials "work for hire," meaning that the institution, rather than the instructor, retains ownership (Levine and Sun 2002). This stance is in contrast to commonly held faculty views on intellectual property. The American Association of University Professors has taken the position that faculty should retain control over online content they create as well as make decisions regarding modification or distribution of those materials (AAUP 1998). In searching for a middle ground, some institutions have utilized Creative Commons licensing that enables universities to own the copyright for online materials while preserving the course author's rights to reuse and share materials for noncommercial activities (Creative Commons 2010).

Compensation and evaluation of online courses also remain problematic. At some colleges and universities, online courses have been integrated within regular faculty teaching responsibilities in what faculty and administrators refer to as "in-load." However, other institutions may apply a system where faculty receive overload pay for teaching online courses at a flat rate per course, as a percentage of course revenue, or as payment on a per-student basis (Kovel-Jarboe 1997). Because of differences in how time is spent interacting with online and face-to-face students, administrators may have difficulty evaluating the contributions of faculty assigned to teach online courses within their regular teaching load. This is an especially serious problem when administrators and faculty committees consider time and effort devoted to teaching during tenure and promotion deliberations. A survey by Adams (2003) found that teaching online courses was not viewed as having high value by most tenure and promotion committees, with a perceived importance lower than that of research and teaching traditional courses.

HIGHER EDUCATION INSTITUTIONS

Driven by the potential for improving access to higher education, online courses have grown rapidly at U.S. colleges and universities. Administrators are quick to note how online programs help underserved populations and increase the overall accessibility of higher education without placing an additional burden on classroom or laboratory space. However, as Berg (2002) observes, the potential for generating new revenue has become an underlying force driving online course and program development. As noted by Jewett (2000), distance learning will generate revenue through economies of scale after an initial capital investment in course development. Without the constraints of limited classroom or laboratory spaces, online courses can generate substantial profits. These factors have been responsible for the success of for-profit distance institutions such as the University of Phoenix (Inglis 1999).

A key issue for the expansion of online GIS courses is balancing costs with anticipated course revenue. Institutional costs associated with online GIS courses include capital (servers and other infrastructure), recurrent expenses (instructor salaries, technological support), production costs (the cost of developing course content), and delivery costs (Morgan 2000). Costs also can be evaluated in terms of fixed costs, which do not change with increasing numbers of students, and variable costs, which increase with each additional student enrolled (Bartolic-Zlomislic and Bates 2000). Fixed costs for GIS courses include hardware and data needed to provide access to course materials and the portion of faculty and staff salaries tied to preparing and maintaining course materials. Course preparation costs can vary considerably depending on the level of sophistication used in delivery. For example, Curtain (2002) estimated that multimedia courses can be 200 percent to 500 percent more expensive than simple text-only online courses.

Variable costs include the added time per student needed for correspondence and evaluating student work. Self-paced online courses have high fixed costs and relatively low variable costs since enrollment capacities are not limited by available seating or laboratory equipment. In comparison, the largest cost in instructor-led online courses is instructor time, which increases proportionately to student enrollment. In some cases, online courses can offer a savings in the cost of consumable materials since course handouts can be sent electronically instead of distributed in hard copy. Compared to those of nontechnical courses, variable costs for online versions of GIS courses also may be higher because of the

time needed for instructors and students to work through software, data, and analysis problems that would not be an integral part of a nontechnical course.[4]

Perhaps the single most important issue facing institutions as they develop online courses and programs is quality (Carnevale 2003, Smathers 2001). As noted by Zernike (2006), there is a danger that online students are earning a degree in lieu of receiving an education. Online courses and programs that lack structure, substance, and rigor will be viewed negatively by employers. Likewise, courses with too many students relative to available resources will overwhelm faculty and support personnel, reducing one-on-one contact between student and instructor. Inadequate technical support may frustrate students when they experience problems using course management software or GIS packages. Efforts to streamline and standardize Web-page design can lead to faculty being required to utilize cookie-cutter templates for online courses. As Kriger (2001) warns, too much standardization in course design can inhibit exposure to new ideas. Finally, online courses may require rethinking in the way faculty teaching is evaluated. Although administrators cannot observe faculty in face-to-face class sessions, online courses provide a wealth of information that cannot be evaluated during a live lecture, including transcripts of student and faculty discussions, copies of student assignments and presentations, and performance records that extend over the entire course.

A common criticism related to quality is that distance instruction is less effective than traditional classroom learning in terms of student outcomes. Russell (1999) summarizes findings of studies showing no difference in the performance of online and face-to-face students enrolled in similar sections of the same course. However, others have demonstrated methodological problems in so-called "no significant difference" studies in which researchers evaluated noncomparable groups of students enrolled in online and traditional courses (Joy and Garcia 2000). In many cases, online students who performed the same or better than peers in face-to-face sections were found to be more mature and inclined to work independently. Other issues have been suggested as better predictors of success in an online course such as a student's maturity, work ethic, or time-management skills (Smathers 2001, Zhao et al. 2005, Haigh 2007, Detwiler 2008).

EMPLOYERS

The final stakeholder group includes organizations with employees who have completed or plan to complete online courses, certificates, or degrees in GIS. Online education can be beneficial to employers through new knowledge and competencies gained by their employees. Most important, employees can complete courses and programs without the need for a leave of absence or, in many cases, any time spent away from work. However, some online courses and programs suffer from perceptions of being inferior to their face-to-face counterparts. For example, research has shown that job applicants with traditional degrees are preferred to those with online degrees (Adams et al. 2007). The perceived value of an online degree also can cause problems for current employees in cases where their employers are willing to provide tuition support for traditional courses but not for online courses (Adams and DeFleur 2006).

GIS CERTIFICATE AND DEGREE PROGRAMS OFFERED ONLINE

As the demand for geospatial education continues to increase, an effort is growing to introduce fully online academic programs in GIS. To gain a feel for the range of online certificates and degrees in GIS, a reconnaissance of U.S. programs was carried out in December of 2009 and updated in April of 2010. Several sources were used to identify online degree and certificate programs, including Web-based lists maintained by the ESRI, URISA, the University Consortium for Geographic Information Science (UCGIS), and Berdusco (2003).[5] Internet keyword searches were used to identify programs not included on these lists. Some programs that describe themselves as "online" were found to offer only one or two online courses within a program that was taught mostly face-to-face. As shown in Table 1, a total of 36 online certificate and degree programs offered at least 40 percent of their coursework through an online format. The majority of programs were for undergraduate or graduate certificates. Most undergraduate certificates can be earned in 9 to 24 semester credit hours concurrently with a bachelor's degree. A few also are available as stand-alone programs that can be completed independently from a degree.

For the most part, online certificates are similar to resident (face-to-face) certificates in terms of administration. For example, while undergraduate programs have no entrance requirements, admission to graduate certificate programs require academic transcripts showing completion of a baccalaureate degree. Depending on the program, some graduate certificate programs also require letters of recommendation and a minimum undergraduate grade-point average. While a few programs are staffed by industry practitioners, most list only full-time faculty. Some programs require students to attend special in-person class sessions to provide opportunities for collaborative problem solving that can be difficult to implement in an online environment.[6]

American Sentinel University is the first institution to offer fully online degrees at the undergraduate level. These include a 60-hour Associate of Science (AS) degree that requires 42 hours of general education coursework and 18 hours of coursework in the major and a 120-hour Bachelor of Science (BS) degree that requires 60 hours of general education coursework and 60 hours of coursework in the major. At the present time, online graduate degree programs are limited to the master's level. Northwest Missouri State University was the first to offer a fully online MS degree in GIS. As noted by Drews (2003), the program is designed to be completed by a student employed full-time in four to five years utilizing eCollege software that facilitates grading, threaded discussions, and drop boxes for submitting assignments. Another innovative approach is Penn State's World Campus where students utilize GIS to address problem-based scenarios.

Undergraduate Certificates		Percent Online
California State University, Bakersfield	Certificate in Geographic Information Systems	40%*
Elmhurst College	Geographic Information System Certificate	100%
Fort Hays State University	Geographic Information System User Certificate	100%
Haywood Community College	Geospatial Technology Certificate	100%
Louisiana Tech University	Certificate in Geographic Information Systems	100%
Northern Illinois University	Undergraduate Certificate in Geographic Information Systems	100%
Roosevelt University	Certificate in Geographic Information Systems	100%
University of Maine, Machias	Certificate in Geographic Information Systems	blended
University of West Florida	Certificate in Geographic Information Systems	100%
Graduate Certificates		Percent Online
University of Central Missouri	Graduate Certificate in Geographic Information Systems	100%
Eastern Michigan University	Graduate Certificate in Geographic Information Systems for Educators	100%
Emporia State University	Certificate in Geospatial Analysis	100%
Mississippi State University	Geospatial and Remote Sensing Certificate Program	100%
Northeastern University	Graduate Certificate in Geographic Information Systems	100%
Northern Arizona University	Graduate Certificate in Geographic Information Systems	100%
Northern Illinois University	Graduate Certificate in Geographic Information Analysis	100%
Johns Hopkins University	Graduate Certificate in Geographic Information Systems	100%
Pennsylvania State University	Post Baccalaureate Certificate in Geographic Information Systems	100%
Saint Mary's University of Minnesota	Professional Certificate in Geospatial Technology	100%
University of Central Arkansas	Graduate Geographic Information Systems Certificate	100%
University of Denver	Certificate in Advanced Study of Geographic Information Systems	100%
University of Maryland	Graduate Certificate in Geospatial Information Sciences	blended
University of North Dakota	Graduate Certificate in Geographic Information Science	100%
University of Southern California	Graduate Certificate in Geographic Information Science and Technology	90%
Degree Programs		Percent Online
American Sentinel University	Associate of Science in Geographic Information Systems	100%
American Sentinel University	Bachelor of Science in Information Systems, GIS Emphasis	100%
Northeastern University	Master of Professional Studies in Geographic Information Technology	100%
Northern Arizona University	Master of Applied Geospatial Sciences	100%
Northwest Missouri State Univ.	Master of Science in Geographic Information Systems	100%
Pennsylvania State University	Master of Geographic Information Systems	100%
Salisbury University	Master of Science in GIS and Public Administration	100%
University of Central Arkansas	Master of Geographic Information Systems	100%
University of Colorado	Master of Science in Civil Engineering, GIS Specialty	100%
University of Denver	Master of Science in Geographic Information Science	100%
University of Maryland	Master of Professional Studies in Geospatial Information Sciences	blended
University of Southern California	Master of Science in Geographic Information Science and Technology	100%

* the remaining instruction is face-to-face.

Table 1. Online GIS Programs in the United States

Because students must complete GIS assignments using home or office computers, most online certificate and degree programs list minimum standards for computer hardware, Internet connection types, and other technical requirements.[7] Some stipulate equipment for two-way communication such as video cameras and headsets. With a few exceptions, online programs utilize ESRI's ArcGIS™ software.[8] In most cases, students are either provided with a trial version of the software as part of their enrollment or advised to purchase student editions.

MANIFESTO FOR NEW ONLINE PROGRAMS IN GIS

Coupled with the demand for geospatial training, the importance of the Web as a learning tool will continue accelerating efforts to develop fully online GIS courses and programs in the coming years. Colleges and universities are likely to see increased competition as for-profit virtual universities begin offering online GIS programs. Given the array of challenges involved in developing Web-based instruction, it may be helpful to consider five critical issues for preparing institutions to offer successful online certificate and degree programs in GIS.

Issue 1: Faculty Training

Faculty training is the single most critical factor in developing and sustaining online GIS courses and programs. Opportunities for faculty to gain experience in developing online courses must be expanded along with incentives for faculty participation. In addition, administrators responsible for developing reward structures must recognize that online course development involves a substantial commitment on the part of faculty who may be balancing other responsibilities such as research and service. Discussions also should consider how online teaching will be evaluated relative to other accomplishments during annual reviews and tenure and promotion deliberations. In addition to assisting faculty with preparing content, training programs should help faculty learn how to communicate with students in an online environment (White and Weight 2000). Another important issue is recruiting and mentor online faculty. It will be difficult to recruit faculty to teach online courses if they do not have a clear conception of how their courses can be taught in an online environment. This can be addressed through orientation sessions led by experienced faculty teamed with professional learning designers who can help explain the transition to online teaching and learning. As faculty begin the process of developing online courses, they should be

paired with peer mentors who are faculty members experienced in teaching online courses (Shepherd, Alpert and Koeller 2007).

Issue 2: Strategic Planning

Planning also is essential to the success of online courses and certificate or degree programs. De Neufville (1986) describes planning as " . . . a set of activities intended to improve the quality of decisions for a community" (46). Effective planning begins with administrators and faculty developing a shared vision for what the program will accomplish and how. For example, when developing the vision for a GIS degree program, it is important to decide if the goal is to serve existing student populations or attract new ones. Planning must also include budgeting financial resources to support faculty, staff, technology, and student services. Fully online degree programs require an institution-wide planning effort that includes the development of supporting general education and prerequisite courses in English, math, and statistics and many other subject areas. Planning online programs also involves key decisions such as the way course instructors are selected and how a common course management system is chosen. Institutions also need to develop planning strategies to prepare students for the transition to online learning. Fink (2002) found that students who were poorly prepared for online learning negatively affected other students and the instructor. Finally, colleges and universities should consider partnerships or consortia that enable institutions to collaborate in offering GIS programs. As noted by Matthews (2002), partnerships enable institutions to share courses, marketing expertise, and other resources.

Issue 3: Institutional Commitment

In addition to training faculty in online pedagogies, institutions must be prepared to provide the infrastructure and financial support needed for implementing online courses and programs in GIS. Not surprisingly, a recent survey of administrators and faculty listed monetary support as the most important factor influencing the success of online programs (Kim and Bonk 2006). Faculty must have access to instructional specialists such as learning designers, graphic artists, videographers, and programmers for assistance in creating, maintaining, and updating course curricula (Oblinger and Hawkins 2006). Another institutional issue is support for students. Online certificate and degree students must be provided with the same services available to traditional students. Additional support personnel must include academic advisers prepared for interaction with off-campus students and technicians available 24/7 to assist with connectivity problems. Other student services that must be provided include student admission, financial aid, bursar facilities, the bookstore, and library resources.

Issue 4: Industry Advisory Boards

Employers must become partners in the process of planning and implementing resident and online certificate and degree programs in GIS. The creation of a program advisory board can facilitate input from industry representatives during initial curriculum development. Periodic advisory board meetings provide a venue for recommending program modifications. Advisory boards can also be helpful in developing buy-in that encourages organizations to support their employees pursuing online learning opportunities. Program alums should be invited to participate in advisory board meetings.

Issue 5: Program Accreditation

Professional organizations of GIS practitioners such as URISA should become involved in the assessment and evaluation of GIS programs. GIS took a major leap forward with the introduction of certification for GIS professionals and the development of the *Geographic Information Science and Technology Body of Knowledge*, which defines skills and competencies important to GIS professionals (DiBiase et al. 2006). With an increasing number of GIS professionals receiving their training through college and university certificate and master's degree programs, an important and lingering issue is how the programs themselves should be evaluated. This issue has become even more critical with the rapid expansion of online programs. As noted by Chalmers et al. (2004), none of the hundreds of certificate or degree programs available in the United States have been subject to formal review. Program accreditation has been suggested as a mechanism for the evaluation of GIS programs using explicit criteria such as faculty qualifications, the quality of the curriculum offered, and student outcomes (Goodchild and Kemp 1992, Obermeyer 1993, DiBiase 2003, Kemp 2003). Although the *Body of Knowledge* is an important step in guiding course content, it will become increasingly important for programmatic issues to be considered such as the quality of faculty and access to library resources and other services. Organizations such as URISA should play a leading role in developing explicit criteria for best practices in the development of online certificate and degree programs.

CONCLUSION

In the coming years, online learning will offer unprecedented opportunities to increase the accessibility of geospatial education. As guardians and facilitators of advanced learning, colleges and universities must assume a leadership role in the agenda defining how online pedagogies will be integrated within or, in some cases, replace face-to-face instruction. This will involve new opportunities for training, rethinking some methods for evaluating teaching, and creating policies that respect intellectual property. Resources must also be available for periodic retooling, enabling faculty to incorporate new pedagogies as technologies change. While the *GIS&T Body of Knowledge* provides a means for selecting online content that will ensure students are exposed to the breadth of knowledge needed to develop basic GIS competencies, institutions will also need to develop strategic plans for implementing new programs on their campuses. This program planning cannot take place in a vacuum but must involve dialogue with other campus units. Most important, a well-structured framework for online course and program assessment must be put in place that involves input from both GIS practitioners and employers.

NOTES

[1]dialogPLUS is described at http://www.dialogPLUS.soton.ac.uk/. In the United Kingdom, the term *open* often means the same as *distance.* Distance universities in the United States include California Virtual University and Western Governors University.

[2]This project is jointly sponsored by the National Science Foundation. See www.aag.org/education/center.

[3]A notable exception is the University of Maryland's faculty teaching program for online courses.

[4]In a comparison, Walker (2004) found online GIS courses to cost less than half of a face-to-face course on a per-student basis.

[5]ESRI's list can be found at http://edcommunity.esri.com/universityprograms/. URISA lists programs at http://www.urisa.org/career/colleges. The University Consortium for Geographic Information Science (UCGIS) maintains a list of distance programs at http://www.spatial.maine.edu/~onsrud/PubCommonsOfGISci/DistEdGradCourses.htm. Although somewhat dated, Berdusco (2003) provides the most comprehensive list at http://www.ucgis.org/priorities/ education/GIS_Cert+Masters_Prog/ Berdusco.htm.

[6]For example, the University of Maine at Machias requires students to attend three weekend days of on-campus instruction. Likewise, the University of Southern California's graduate certificate program mandates a one-week field excursion involving GPS/GIS field techniques.

[7]Minimum hardware specifications list parameters such as screen resolution, processor speed, hard drive capacity, and Internet connection type.

[8]Students must purchase a discounted Student Edition of ArcGIS. Software also included IDRISI (Clark University) and access to industry-standard GIS software via broadband Internet.

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What GIS Technicians Do: A Synthesis of DACUM Job Analyses

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Abstract: *The U.S. Department of Labor Employment and Training Administration (DOLETA) has created a new standard occupational classification code for GIS/Geospatial Technician. This entry-level job has long been sought after by graduates of the 164 community college GIS certificate programs currently in operation in the United States. The formal recognition of this job has created an opportunity for these colleges to realign their curricula to meet workforce needs. This study was undertaken by the National Geospatial Technology (GeoTech) Center to assist in this effort to validate the DOLETA's occupation-specific workforce requirements. Validation is performed using the DACUM (Developing A CUrriculuM) job-analysis technique, which relies on workers themselves to describe and define their jobs. Building on the strength of this approach, the GeoTech Center developed and applied a meta-analytic technique for consolidating multiple DACUM job analyses into a single national assessment. Using eight GIS technician job analyses from across the country, this assessment identifies 55 common task categories, 35 knowledge and skill categories, and 27 behavior categories that are ranked and documented. This helps to clarify the job responsibilities of GIS technicians and complements the DOLETA's workforce information.*

INTRODUCTION

Who are GIS technicians and what do they do? This is an important question now that the U.S. Department of Labor Employment and Training Administration (DOLETA) has recognized this job title with a new standard industrial classification (SIC) code. DOLETA also identified an associated list of occupation-specific job tasks, interests, work values, wages, and related information (DOLETA 2009). This information can serve as the basis for new job descriptions, curriculum resources for education and training, criteria for inter-institutional program articulation, and requirements for professional certification. However, because it was developed by DOLETA workforce analysts rather than the workers themselves, the information will be most valuable if validated by workforce practitioners.

The National Geospatial Technology Center (GeoTech), funded by the National Science Foundation (NSF) to support community college geospatial programs, conducted an initial validation of this workforce information for GIS technicians. With help from the GIS Certification Institute (GISCI), it developed and applied a meta-analytic technique for consolidating multiple DACUM (Developing A CUrriculuM) job analyses into a single national assessment. It includes a summary list of GIS technician job tasks identified and validated entirely by industry practitioners. This assessment helps to authenticate the DOLETA's list of workforce requirements for this job.

GROWING NEED FOR GEOSPATIAL COMPETENCIES

The recent development of the Geospatial Technology Competency Model (GTCM), discussed elsewhere in this issue (DiBiase et al. 2010), was a watershed event for the geospatial industry. It culminated years of effort to develop an industry model framework for geospatial occupations. Of particular interest to many workers and educators alike are the responsibilities associated with newly recognized geospatial job titles (DOLETA 2009). This workforce information can impact salaries, job placement and advancement as well as training and curriculum development activities.

The GTCM consists of a pyramid made up of building blocks of worker competencies. At the bottom or foundation level are personal effectiveness and academic and workforce competencies, followed by industry-wide and industry-sector technical competencies. At the top are the occupation-specific competencies, which have been initially defined by the DOL using its standard occupational review process. While useful as an overview, these competencies tend to be inadequate for developing detailed job descriptions and training materials.

Approximately 164 two-year community colleges offer GIS certificate or degree programs in the United States (NGTC 2010a). Most of these programs are meant to prepare students for jobs as GIS technicians. Despite this shared commitment to geospatial workforce development, few educational content standards are available to guide and coordinate their efforts. The result is an assortment of classes, curriculum, and certificate/degree requirements generating confusion among prospective students as well as their advisers.

The GIS Certification Institute (GISCI) is an independent nonprofit organization formed in 2004 to certify GIS professionals. The lack of identified geospatial workforce competencies was an important factor affecting its pragmatic decision to use a portfolio-based system for certification rather than using a competency-based examination approach. The GISCI recently announced a GISP Certification Update Initiative to reconsider the portfolio-based approach in light of DOLETA's GTCM and related developments, including the results of this study (GISCI 2010).

In 2006, the DOLETA identified the geospatial industry as an important emerging high-growth area for the U.S. economy (DOLETA 2006). In response, it sponsored a study entitled "Defining and Communicating Geospatial Industry Workforce Demand" (GITA and AAG 2006). The resulting project report highlighted the growing demand for geospatial workers and ways to prepare workers to meet it. It also helped to define and clarify the multifaceted geospatial industry and recommended two new standard occupational classifications (SOC): GIS/Geospatial Technician and GIS/Geospatial Analyst. The Department of Labor had previously observed that "occupation titles (in this field) were inadequate" and that "evaluating the competencies in the geospatial technology user community could be of great value in planning training" (DOLETA 2005, 20).

Also in 2006, the University Consortium for Geographic Information Science (UCGIS) and the Association of American Geographers (AAG) published the *Geographic Information Science and Technology (GIS&T) Body of Knowledge*. This document offered "a vision of how higher education should prepare students for success in the variety of professions that rely upon geospatial technologies" (UCGIS 2010). It was designed "to be applicable across the undergraduate, graduate, and postbaccalaureate/professional sectors of the GIS&T educational infrastructure" (UCGIS 2006, 42). Unfortunately for educators, it does not specifically address the competencies required by entry-level GIS technicians who typically seek training at two-year community colleges.

An influential predecessor to the DOLETA's GTCM was a 2003 report prepared by workforce development specialists at the University of Southern Mississippi (Gaudet et al. 2003b). Although wider in scope, the original Geospatial Technology Competency Model provides less detail about the domain-specific knowledge and skills than does the *Body of Knowledge*. It also specifically avoids referencing job titles and work-oriented tasks because "they can become dated as work undergoes dynamic change" (Gaudet 2003, 23). Instead, it uses role profiles (novice to expert) to classify workers and assign competencies. However, because GIS technicians can take on multiple roles at various levels of expertise (e.g., data acquisition, data management, visualization), this document also falls short of providing the guidance educators need.

Industry associations and firms provide other pieces of the puzzle. For example, URISA has published a guide, "Model GIS Job Descriptions," which outlines typical job responsibilities for various geospatial occupations, including GIS technicians (URISA 2000). ESRI, a leading GIS software firm, also recently introduced a new technical certification program to validate an individual's "expertise and knowledge of ESRI software and related technology" (ESRI 2010).

Efforts to define required geospatial worker competencies certainly are not unique to the United States. For example, the European Computer Driving License Foundation, which recently developed an examination-based GIS certification process for the Italian market, has generated interest both regionally and globally. The examination, developed by Laboratorio di Sistemi Informativi Territorialied Ambientali of Sapienza University of Rome together with Associazione Italiana per l'Informatica ed il Calcolo Automatico, has spawned the creation of at least one popular professional preparation course at Sapienza University (ESRI 2009, 9).

In the United States, the recently completed DOLETA GTCM is mobilizing renewed attention to the need to more clearly define job-related geospatial competencies. Associated with the GTCM are several new geospatial occupations, including that of GIS technician, which are described in DOLETA's O*NET online occupation clearinghouse. This study aims to validate this occupation description to assure its alignment with current workforce requirements.

DEFINING COMPETENCIES FOR GIS TECHNICIANS

According to the DOLETA, a competency is "the capability of applying or using knowledge, skills, abilities, behaviors, and personal characteristics to successfully perform critical work tasks, specific functions, or operate in a given role or position" (Ennis 2008, 4). The identification of "critical work tasks," therefore, is an initial step in defining competencies for GIS technicians. These normally are documented through a formal job analysis.

The purpose of a job analysis is to systematically identify the work activities, tasks, responsibilities, knowledge, skills, and abilities required to perform a job. Various job-analysis techniques are available, involving both work-oriented and worker-oriented methods. These include using questionnaires, observation, worker diaries/logs, interviews, focus groups, work records, information searches, and critical incident evaluations (Brannick, Levine, Morgeson 2007). While most rely on various indirect sources for collecting job information, the DACUM job-analysis technique relies directly on the workers themselves to describe and define their jobs.

DACUM JOB ANALYSIS

DACUM is a formal job-analysis technique that has been used worldwide for more than 30 years. It is quick to administer, self-validating, and instills ownership among those who take part in the process (Hartley 1999, 22). The methodology involves a structured one-day to three-day workshop in which a trained DACUM facilitator guides a panel of five to 12 "expert workers" as they systematically describe and define their jobs or occupations. Input from this panel typically is recorded on note cards and arranged as a storyboard in front of the panel. The process relies on a series of brainstorming activities in which participants discuss and reach consensus on a set of specific "tasks" that make up their jobs. These tasks are organized into categories called "duties" and presented, along with associated knowledge, skills, and behaviors, in a summary job profile called a "DACUM research chart" (Norton 1997).

The DACUM methodology defines a task as a statement that concisely describes a work activity in performance terms. It usually

consists of a single action verb, an object that receives the action, and a qualifier, as in "create map template." Tasks represent the smallest unit of a job activity with a meaningful outcome. They can be assigned and, in a finite amount of time, will result in a product, service, or decision. All tasks consist of two or more steps and can be observed and measured. "Duties," on the other hand, are more general than tasks and describe a large area of work in performance terms. They also denote clusters of related tasks as in "manage data." Both tasks and duties avoid reference to "enablers," such as knowledge, skills, worker behaviors, tools, equipment, and supplies. As the term implies, these enable workers to perform tasks at a specified level of competency (Norton 1997).

A strength of the DACUM methodology is that all job tasks can be linked directly to a panel of expert workers who have been identified by name, title, and organization. Together, these individuals reached a consensus that, as GIS technicians, they are required to perform these job responsibilities. This legitimizes the list of job tasks and effectively eliminates those that are either outdated or performed largely by workers with other job titles.

Of course a particular DACUM panel may not fully represent all workers with a given job title. This may result from the mix of business sectors, worker experience, or personal characteristics on the panel. It also may stem from the fact that certain job tasks are performed by GIS technicians in one region of the country but not in another (e.g., urban versus rural locations) or that job tasks evolve over time. Supporting such critiques are results of Willet's 1989 study, which compared DACUM findings with those from two other occupational-analysis techniques. Willet found that DACUM identified only 73 percent of the competencies believed to be associated with a particular job, but that the rate was increased to 94 percent when the DACUM results were combined with those from an "information search" analysis. Willet thus recommended that DACUM results be combined with those from an information-search analysis to obtain an adequate list of competencies. However, this proposed solution negates a key strength of DACUM analyses while increasing the likelihood of including extraneous tasks. An alternate approach for obtaining a comprehensive list of job tasks using only DACUM job analyses was therefore developed. This involves using a meta-analytic approach for consolidating multiple DACUM job analyses into a single summary assessment.

A META-ANALYTIC APPROACH FOR CONSOLIDATING MULTIPLE DACUM ANALYSES

While the DACUM job analysis technique has the advantage of being entirely worker-generated, its results can vary somewhat depending on its location, timing, and mix of panel participants. To overcome these limitations and still arrive at an accurate and comprehensive list of job tasks for GIS technicians, the GeoTech Center developed a systematic procedure for combining multiple DACUM research charts into a single meta-analysis.

By definition, "a meta-analysis combines the results of several studies that address a set of related research hypotheses . . . by identifying a common measure of effect size for which a weighted average might be the output" (Wikipedia 2010). This technique was considered suitable for this work because all DACUM job analyses are conducted in a similar manner. They are directed by trained DACUM facilitators who follow an established set of procedures for collecting job-related information and compiling it into a DACUM research chart. This standardized output format facilitates the grouping of individual DACUM components from multiple job analyses into a single consolidated assessment.

When the present study was undertaken, a total of six DACUM job analyses for GIS technicians previously had been conducted at various U.S. locations. The GeoTech Center then conducted two additional analyses. In total, the eight DACUM analyses combine input from 76 current or former GIS technicians. The results of three of these job analyses also were validated by a survey of local GIS professionals. This increased the number of geospatial professionals providing input into this analysis by an additional 413. Then, with help from industry experts, the results were carefully consolidated into a single summary assessment.

The eight DACUM panels identified a total of 476 job tasks that subsequently were grouped into 55 task categories. These categories, listed in Table 1, are organized according to the number of DACUM panels that contributed to each and by the number of similar tasks aggregated in each category. For example, the two highest-ranked task categories—"Design & create maps" and "Develop/document procedures"—are the only categories identified by all eight panels. "Design & create maps" is listed above "Develop/document procedures" because it includes the greatest number of aggregate related tasks, suggesting a higher level of complexity.

Some of the task categories listed in Table 1 are not mutually exclusive. Task categories generalized from input by some DACUM panels may be subsumed in broader categories identified by others. For example, "join & relate data" is a category identified by only two panels but it also could be included as part of the "conduct geoprocessing" category, which was identified by seven panels.

Also included in Table 1 is information on the importance and perceived learning difficulty of each task category based on the validation survey results. Tasks from three job analyses in California, Illinois, and Georgia were mailed to larger groups of GIS professionals for validation purposes. Respondents rated each task on its importance to the job performance of GIS technicians as well as its perceived learning difficulty. These values were weighted by the number of survey respondents and then combined within each task category. The median value for each task category is included on this table, along with the number of survey responses used to generate it. Because tasks from only three out of the eight job analyses were validated in this manner, not all tasks or task categories have this associated information.

Table 1 shows the combined results from eight DACUM job analyses for GIS technicians. As illustrated in Figure 1, these were conducted at various U.S. locations between 1996 and 2009.

Table 1. Tasks Performed by GIS Technicians Ranked by Consensus among DACUM Panels and Task Complexity

Task Categories	DACUM Panels	Aggregate Related Tasks	Median Importance	Validation Survey #	Median Learning Difficulty	#
Design & create maps (G1)	8	34	medium	846	medium	785
Develop/document procedures (F4)	8	13	medium	296	medium	265
Conduct geoprocessing (D1)	7	26	medium	1,298	medium	1,156
Acquire data (C1)	7	20	medium	471	medium	426
Create/update data (C6)	7	16	high	1,112	medium	1,018
Validate data (C3)	7	14	high	571	medium	502
Collect field data electronically (B2)	7	12	high	594	medium	534
Create reports (G2)	7	9	medium	525	medium	482
Convert data (C9)	7	8	high	356	medium	317
Organize data (C2)	6	15	medium	824	medium	734
Maintain equipment & supplies (F8)	6	15	medium	727	low	624
Import/export data (C5)	6	12	medium	344	medium	303
Participate in conferences/workshops (H2)	6	12	medium	691	low	628
Create/update metadata (C7)	6	11	high	510	medium	448
Provide training (H3)	6	11	medium	434	medium	396
Develop & make presentations (G4)	6	10	medium	434	medium	370
Evaluate data (A6)	6	9	high	272	medium	252
Evaluate data sources (A7)	6	6	high	318	medium	293
Coordinate project activities (F1)	5	14	high	62	high	60
Disseminate products (G5)	5	14	medium	306	medium	277
Georeference data (C8)	5	10	high	773	medium	703
Communicate with others (H1)	5	10	high	321	low	290
Define data requirements (A1)	5	9	medium	213	medium	194
Backup/restore data (C4)	5	7	medium	351	low	311
Attend training (H5)	5	7	medium	484	low	437
Conduct geostatistical analysis (D5)	5	6	medium	218	medium	196
Develop project timeline/schedule (F6)	5	6	medium	173	medium	158
Review job-related information (H9)	5	6	medium	262	medium	238

Table 1. Tasks Performed Continued

Task Categories	DACUM Panels	Aggregate Related Tasks	Validation Survey Median Importance	#	Median Learning Difficulty	#
Develop software applications (E2)	4	13	medium	246	high	225
Design/edit databases (E1)	4	9	high	45	high	44
Maintain software (E5)	4	8	high	38	medium	36
Perform queries (D2)	4	6				
Digitize data (B4)	4	5	high	331	low	301
Geocode data (B5)	4	5	high	380	medium	333
Define software/hardware requirements (E3)	4	5	medium	30	medium	28
Promote/represent GIS (H7)	4	5	medium	151	medium	145
Provide technical support (H8)	4	4	medium	129	medium	118
Prepare/assess cost estimates (F5)	3	7	medium	29	medium	29
Identify client needs/deliverables (F7)	3	7				
Conduct network analysis (D3)	3	6	medium	740	medium	631
Create tables & charts (G3)	3	6	medium	210	medium	192
Optimize database performance (E4)	3	5	medium	281	medium	240
Develop user guides (H4)	3	5	medium	58	high	55
Define feature behavior (A3)	3	4	medium	162	high	144
Conduct image analysis (D4)	3	4	medium	29	high	28
Develop data maintenance schedule (A4)	3	3	high	30	medium	28
COGO legal descriptions (B1)	3	3	medium	254	medium	227
Scan nondigital data (B6)	3	3	medium	305	low	277
Supervise interns (H10)	3	3	medium	112	medium	97
Determine project scope (F2)	3	3	low	173	medium	157
Determine resource requirements (F3)	2	4				
Join & relate data (A2)	2	3	high	436	medium	397
Establish data custodianships (A5)	2	3	medium	47	medium	45
Collect field data manually (B3)	2	3	medium	335	low	284
Acquire professional certification (H6)	2	2	medium	256	medium	225

Task ranking is by number of DACUM panels followed by aggregate number of related tasks.
Task categories are not mutually exclusive. Some categories also may be part of another more general category.
Source: National Geospatial Technology Center, 2010.

At the core of each job analysis was a panel of expert workers, all of whom were either working or had recently worked as GIS technicians or were the immediate supervisors of someone in this position. Approximately 32 percent of panelists were GIS technicians, 23 percent were GIS analysts, 13 percent were GIS specialists, 13 percent were GIS managers, and 8 percent were GIS coordinators. Overall, approximately 65 percent were male and 35 percent were female. More detailed information about these DACUM panels is available on Supplemental Table 3 for this paper at the GeoTech Center Resource Repository (NGTC 2010b).

IDENTIFYING DACUM JOB ANALYSES FOR GIS TECHNICIANS

This meta-analytical process began with a literature search to locate all previously completed DACUM Research Charts for GIS technicians. A total of six were identified that met the minimum requirements for a DACUM job analysis. This means they were conducted by a trained DACUM facilitator over a period of one to three days using a panel of at least five expert workers. As indicated in Figure 1, these were located in Portland, Maine (1996), Aberdeen, Washington (1997), Waco, Texas (2002), Cedar Rapids, Iowa (2002), San Diego, California (2005), and Auburn, WA (2007). Those in Cedar Rapids and San Diego were conducted over two days, while the others were completed in only one day. Results from the San Diego job analysis also were validated by a survey of local GIS professionals.

To improve the reliability of these findings, two additional two-day DACUM job analyses were conducted in areas not previously studied. Using partner colleges within the National Geotech Center, these additional analyses were held at Lake Land College in rural Mattoon, Illinois, and Gainesville State College in urban Atlanta, Georgia. They increased both the regional and professional diversity of this meta-analysis. Their results also were validated by surveys of local GIS professionals.

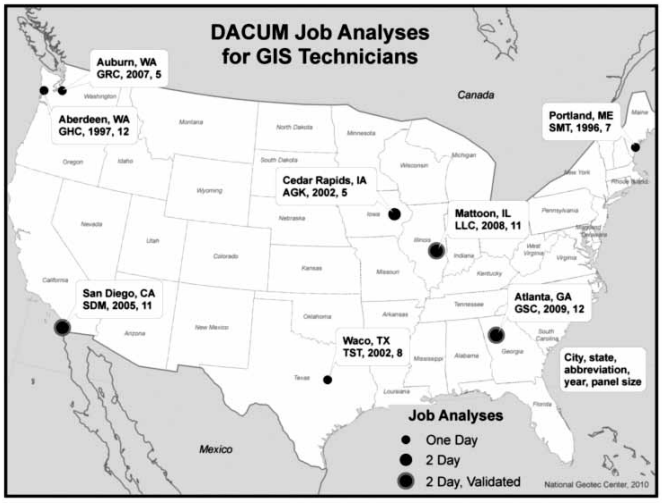

Figure 1. DACUM job analyses for GIS technicians

CREATING TASK CATEGORIES

Information from these eight DACUM job analyses for GIS technicians was collected, entered into a database, and then organized into a common set of tasks, knowledge, skill, and behavior classes. The contents of each class then were organized into categories by topic and, for validation purposes, were shared with GISCI's Core Competency Working Group for its final review and input.

Each of the final 55 task categories listed in Table 1 aggregates between two and 34 tasks included in one or more of the eight DACUM research charts used in this analysis. A detailed listing of all the 476 job tasks aggregated into these 55 task categories is available in Supplemental Table 5 for this paper at the GeoTech Center Resource Repository (NGTC 2010b). Because this table contains a complete listing of all original task statements, it should be relied on to obtain a clear understanding of the meaning and content of each task category.

Consistent with standard DACUM procedures, in which job "tasks" are considered components of job "duties," the task categories identified in this meta-analysis were then generalized into duty categories. These were derived from the original duty classifications listed in Supplemental Table 5 for this paper at the GeoTech Center Resource Repository (NGTC 2010b). Accordingly, the following eight duty categories were identified in this meta-analysis:

Manage Data	Manage Software
Generate Data	Manage Projects
Process Data	Generate Products
Analyze Data	Professional Development

These may be considered the generic duties for which most GIS technicians in the United States are currently responsible. Each of these duty categories contains between five and ten task categories that are listed in Supplemental Table 4 for this paper at the GeoTech Center Resource Repository (NGTC 2010b).

CREATING KNOWLEDGE, SKILL, AND WORKER BEHAVIOR CATEGORIES

In addition to providing job tasks and duties, all eight DACUM panels also generated lists of knowledge, skills, and worker behaviors considered important for GIS technicians to properly perform their jobs. These normally are collected near the end of a DACUM workshop after all duties and job tasks have been properly identified and recorded.

As part of the meta-analytic process, these, too, were grouped into knowledge, skill, and behavior classes and then consolidated into subcategories within each group. This process resulted in 35 knowledge and skill categories containing a total of 230 individual values and 27 behavior categories representing 102 discrete values. A detailed listing of these knowledge and skills and behaviors organized by category is available in Supplemental Table 6 for this paper at the GeoTech Center

Table 2. Priority Knowledge, Skills, and Behaviors for GIS Technicians

Knowledge and Skill Categories	DACUM Panels	Aggregate Related Knowledge and Skills	Validation Survey Median Importance	Validation Survey Responses
Communication: verbal/presentation/writing (2)	8	23	medium	753
Critical thinking/problem solving (10)	7	13	high	318
Organizational (24)	7	11	high	343
Mathematics (geometry, statistics) (23)	7	9	medium	391
Time management (32)	7	7	high	291
Cartography (1)	6	8	medium	416
Computer programming (7)	6	6	medium	280
Computer basics (3)	5	12	medium	311
Computer database (4)	5	12	medium	253
Land divisions, measurements (20)	5	11	medium	511
Photogrammetry/remote sensing (25)	5	8	medium	264
Computer software (8)	5	7	medium	331
Map reading (22)	5	5	high	228
Troubleshooting (33)	5	5	high	238
Industry applications (18)	4	11	medium	264
Data types, transfers & conversions (12)	4	8	high	628
Geography (15)	4	7		
Standards (client, customer, industry) (30)	4	7	medium	594
Coordinate systems, projections (9)	4	6	high	235
Computer keyboarding (5)	4	4	medium	237
Scale (28)	4	4	HIGH	237
Geoprocessing, modeling (16)	3	6	medium	512
Data models (11)	3	5	high	157
Jargon, acronyms (19)	3	4	medium	155
Research (27)	3	4	medium	155
Computer networks (6)	2	4	medium	52
Equipment operation (14)	2	4	medium	155
Engineering drawings (13)	2	3	medium	53
Spatial thinking (29)	2	3	high	156
Units of measure/conversion (34)	2	3	medium	392
GPS (17)	2	2		
Queries & analysis (26)	2	2	medium	224
Web development (35)	1	3		
Legal issues (21)	1	2	medium	136
Teaching (31)	1	1		

Table 2. Priority Knowledge, Continued

Behavior Categories		Aggregate Related Knowledge & Skills	Validation Survey (median) Importance	Responses
Detail-orientated (5)	8	10	high	371
Self-motivated/independent (24)	6	14	high	366
Team player (26)	6	11	high	50
Analytical (2)	6	7	high	366
Punctual/reliable (21)	5	5	high	81
Multitasking (13)	4	4	high	209
Follow procedures (10)	3	5		
Positive attitude (18)	3	4	high	155
Self-improvement (23)	3	4	high	52
Ethical/respectful (9)	3	3	high	236
Industrious, persistent (11)	3	3		
Dress code, etiquette, hygiene (7)	2	3	medium	76
Open-minded (15)	2	3		
Outgoing, friendly (16)	2	3	medium	81
Trustworthy, honesty, integrity (27)	2	3	medium	519
Visionary (28)	2	3		
Adaptable, flexible (1)	2	2	high	52
Common sense (3)	2	2	high	237
Professionalism, maturity (20)	2	2		
Resourceful (22)	2	2	high	285
Sense of humor (25)	2	2	high	548
Networking (interpersonal) (14)	1	2		
Creative (4)	1	1	high	157
Diplomatic (6)	1	1	high	157
Enthusiastic (8)	1	1	high	157
Leadership (12)	1	1		
Patient (17)	1	1		

Ranking is by number of DACUM panels followed by aggregate number of related knowledge, skills, and behaviors.

Categories are not mutually exclusive. Some knowledge, skill, and behavior categories also may be part of another more general category.

Source: National Geospatial Technology Center, 2010.

Resource Repository (NGTC 2010b).

These knowledge, skill, and behavior categories are listed in Table 2, where they have been sorted by the number of DACUM panels represented by each and the aggregate number of values they contain. For example, all eight panels noted GIS technicians should have strong "communication: verbal/presentation/writing" skills and also should be "detail-orientated." Although some of these categories overlap because of the nature of the data collection and consolidation process, they are useful in describing the traits most valued by industry practitioners in this job.

Also in Table 2 is an indicator of the importance of these categories to the job performance of a GIS technician. This information came from the three job analyses that included post-workshop validation surveys. Values for individual knowledge, skills, and abilities were first weighted by the number of survey respondents and then combined within each category. Listed is the overall median importance value for each category along with the corresponding number of respondents. However, because this represents only a portion of the knowledge, skills and abilities included in this meta-analysis, not all values or categories have been rated.

LIMITATIONS OF THE DACUM JOB ANALYSIS

Limitations of the DACUM job analysis technique include the challenge inherent in getting a representative group of exemplary workers to spend one or more days serving on a DACUM panel. Once there, these participants also may have trouble describing their jobs correctly in terms of duties, tasks, knowledge, skills, and behaviors (Hartley 1999, 12). To minimize this, a significant amount of time often is spent on panel orientation at the beginning of a workshop. Ultimately, however, it is the responsibility of the DACUM facilitator to assist workers in correctly describing and assigning what they do to one or more of these classifications. This, of course, takes time, which is why a minimum of two days often is recommended for a comprehensive DACUM job analysis. Because half the analyses included in this study were conducted in only one day, it is likely that not all of them are complete and that certain tasks may not be described as fully or as accurately as they should be. The effect of this on the final results, however, should be minimal because of the aggregating effect of the meta-analytic process used.

CONCLUSION

This meta-analytic assessment of multiple DACUM job analyses for GIS technicians uses workforce practitioners to identify the principal task categories for this job along with related knowledge, skills, and abilities needed to properly perform them. It was developed by the National GeoTech Center with help from GISCI's Core Competency Working Group as a way to help to validate the job information for GIS/Geospatial Technician developed by the DOLETA as part of its new Geospatial Technology Competency Model.

The study was conducted using a meta-analytic approach for independently identifying and quantifying job tasks performed by GIS technicians. It builds on the underlying strength of the DACUM job analysis technique that uses expert workers to define and document their jobs. Accordingly, all task categories and related knowledge, skill, and behavior categories were independently identified by multiple panels of existing and former GIS technicians and ranked accordingly. The categories include both simple and complex groupings of tasks, knowledge, skills, and abilities considered by GIS technicians to be critical to the successful performance of their jobs. This information will help the National GeoTech Center develop workforce skills and competency resources to guide program development for undergraduate geospatial technology education programs. Following this study, the Center plans to conduct DACUM job analyses for other geospatial occupations, beginning with Remote-Sensing Technician. The meta-analytic assessment introduced here provides a means to consolidate multiple DACUM analyses in a way that preserves the DACUM method's strengths while redressing its potential pitfalls.

About the Author

John Johnson has an undergraduate degree in Geography and master's degrees in Urban and Regional Planning and Business Administration. With more than ten years of experience working as a GIS consultant and educator, he has helped to develop two community college GIS programs and has served on a number of related projects. He currently is working as a DACUM facilitator and curriculum specialist for the National Geospatial Technology Center.

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Mapping Geospatial Education at U.S. Community and Technical Colleges

Mike Rudibaugh and Brooke Ferguson

Abstract: *This research explores recent geographic trends associated with the development and distribution of geospatial technology programs at U.S. community and technical colleges. Specifically, the paper attempts to define, describe, and map the ways in which community and technical colleges have responded to an increasing geospatial workforce demand. We developed a geographic information systems (GIS) database to provide a baseline analysis of the locations and characteristics of community and technical colleges across the country. Colleges that provide geospatial education and training were classified and mapped. Examining regional variations in the distribution of these colleges, we found that colleges in the western United States are more likely to offer geospatial courses and certificate and/or degree programs than are colleges elsewhere in the country. This exploratory analysis demonstrates that GIS is a useful methodology for monitoring and assessing impacts of public investments in the U.S. geospatial education system.*

INTRODUCTION

Immediately after its founding in 2008, the National Geospatial Technology Center (GeoTech Center) undertook a baseline assessment of the state of geospatial education and training at U.S. community and technical colleges. Fittingly, the assessment relied on geographic information systems (GIS) technology. The baseline assessment will be used subsequently to assess the Center's impact on the spatial distribution of geospatial education and training at two-year community and technical colleges.

Previous research suggests that geospatial firms and related businesses tend to locate near institutions with geospatial higher-education programs (Thrall and Campins 2005). Thus, the spatial distribution of geospatial education and training at two-year colleges should both reflect and influence patterns of geospatial workforce demand. The National Science Foundation (NSF) Advanced Technology Education (ATE) program created the GeoTech Center to coordinate a national strategy to increase the capacity of community and technical colleges to provide geospatial education and training. To date, no known research has used GIS to evaluate ATE centers in regard to their responses to, and impacts on, the spatial distribution of workforce demand. This research aims to help fill that gap.

METHODS AND FINDINGS

For this paper, we define geospatial technology as geographic information systems (GIS), global positioning systems (GPS), and remote sensing, because these technologies are the foci of the GeoTech Center's project proposal. Recent job analyses performed by the Center indicate that GIS technicians' duties involve all three mapping technologies (Johnson 2010). Related NSF ATE projects (e.g., iGETT—Integrated Geospatial Education and Technological Training) confirm an increasing convergence of GIS, GPS, and remote sensing in technicians' work roles.

In the fall of 2008, the GeoTech Center began to compile a list of the nation's community and technical colleges. Using a variety of sources from the American Association of Community Colleges (AACC) and Esri's Educational Customer Database and ArcGIS geocoding service, the Center identified and located 1,184 community and technical colleges. Center staff and student workers then assigned each college to one of five classes according to the level of geospatial education and training offered. The five levels included:

1. No geospatial courses
2. Geospatial courses (but not certificates or degrees)
3. Geospatial certificate programs
4. Geospatial degree programs
5. Both certificate and degree programs

The numbers of colleges by class appear in Table 1. Classified college locations are mapped in Figure 1.

Table 1. Classes of U.S. Community and Technical Colleges by Geospatial Offerings

	Number of Colleges
No Geospatial Offerings	733
Geospatial Courses	287
Geospatial Certificate Programs	96
Geospatial Degree Programs	19
Both Certificate and Degree Programs	49
Total	1184

Figure 1 reveals the spatial distribution of geospatial education and training at U.S. community and technical colleges. Of the 451 colleges with geospatial offerings in 2009, 164 (36 percent) offered certificate and/or degree programs. To validate the classification, GIS students at Lake Land College checked each college's Web site for information about its geospatial offerings in the fall of 2008. In addition, the GeoTech Center staff added

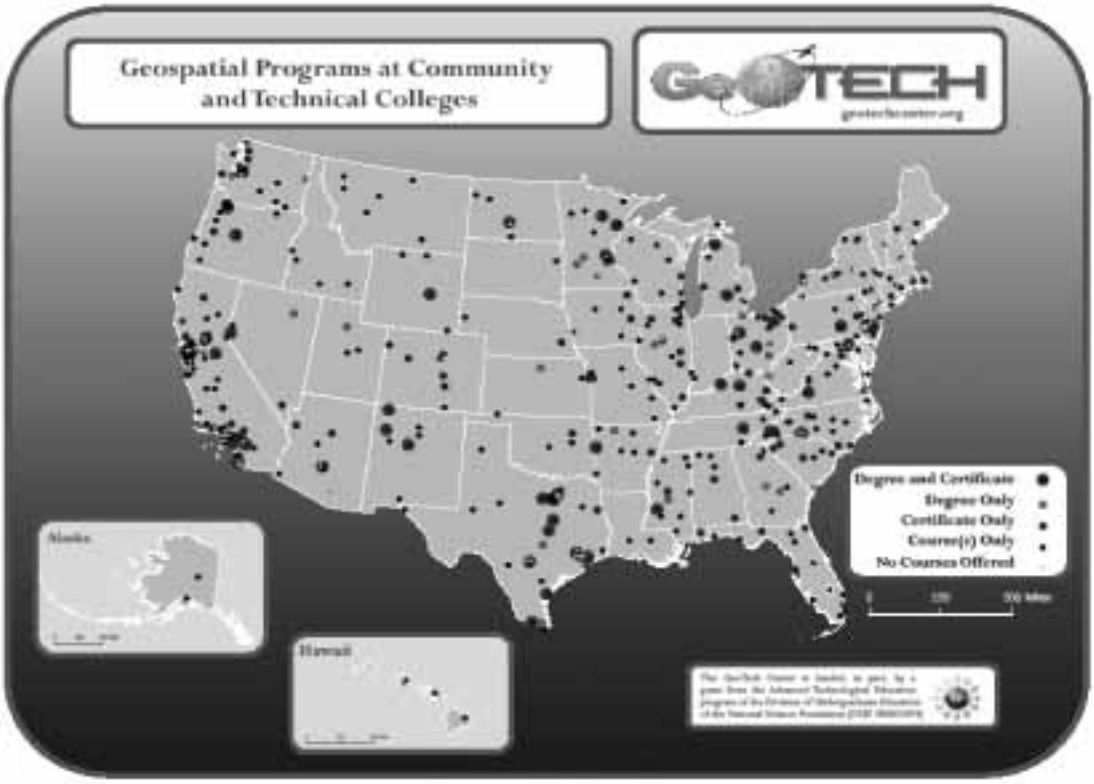

Figure 1. Geospatial programs at community and technical colleges (2009)

faculty contact information, including instructor names, e-mail addresses, telephone numbers, and host departments. The Center subsequently deployed the database as an interactive Web-based map viewer. This tool, available at http://geotechcenter.org, provides educators, administrators, and current and prospective students with an unprecedented geographic perspective on the landscape of geospatial education and training at U.S. community and technical colleges.

One of the selection criteria for GeoTech Center project partners was to reflect the geographic distribution of geospatial education and training at two-year colleges nationwide. An intended outcome of our database development, classification, and mapping effort was to produce a baseline inventory of each partner's nearest neighbor institutions, as well as rates of adoption of geospatial education and training within each partner's neighborhood. To this end, we assigned all of the community colleges within the dataset to nine Thiessen polygons according to proximity to one of the GeoTech Center's nine partner institutions. The nine partners and their corresponding regions are listed in Table 2.

Table 2. GeoTech Center Partners by Region

College	Region
Gainesville State College - GSC	Southeast
Lake Land College - LLC	Midwest
Southwest College - SWC	West
Central New Mexico College - CNMC	Mountain West
Bismarck State College - BSC	Upper Midwest
Kentucky Community and Technical College - KCTC	Mid-south
Cayuga Community College - CCC	Northeast
Central Piedmont Community College - CPCC	East
Del Mar College - DMC	South

The numbers of colleges by region appear in Table 3. College locations mapped by proximity to GeoTech Center (NGTC) partner schools are shown in Figure 2.

Table 3. Community and Technical College GST Education by Region

Partner	N	No Geospatial	Course	Certificate	Degree	Both Certificate and Degree	Percent Geospatial
GSC—Southeast	130	87	25	12	3	3	33%
LLC—Midwest	205	136	47	14	3	5	34%
SWC—West	218	86	87	33	2	10	61%
CNMC—Mountain	64	38	16	6	1	3	41%
BSC—Upper Midwest	63	36	21	0	3	3	43%
KCTC—Mid-south	84	56	12	7	3	6	33%
CCC—Northeast	211	152	43	11	1	4	28%
CPCC—East	108	78	24	4	0	2	28%
DMC—South	101	67	18	2	1	13	34%

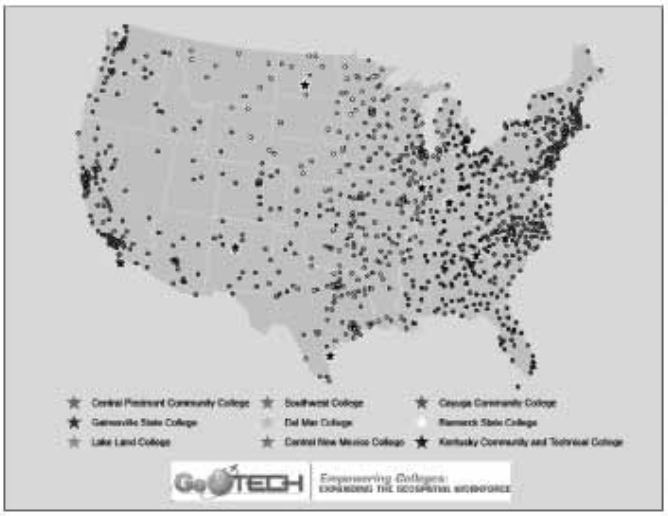

Figure 2. College regions by proximity to GeoTech Center (NGTC) partner schools

DISCUSSION

In the absence of enrollment data (which are not yet available), the distribution of institutions with programmatic offerings revealed in Figure 1 serves as a surrogate for the distribution of geospatial education and training capacity in the U.S. two-year college system. Interestingly, the distribution of programmatic offerings (implied capacity) does not appear to mirror the distribution of the U.S. population. If capacity were explained by population alone, we'd expect a greater concentration of certificate-granting and degree-granting programs in the eastern United States. One hypothesis arising from the distribution shown in Figure 1 is that U.S. community and technical colleges have not yet fully responded to geospatial workforce needs. To test this hypothesis, a model of geospatial workforce demand must be developed, and its correspondence to the distribution of community and technical college capacity must be evaluated.

Table 3 and Figure 2 reveal the uneven rates of adoption of geospatial education and training among U.S community and technical colleges. The region that spans the West Coast exhibits a singularly high rate of geospatial offerings. Contrary to expectations, two-year institutions in the East and Northeast have the lowest rates. Many regional and local factors may contribute to this pattern, including:

1. Competition: Two-year institutions' proximity to four-year schools with geospatial programs;
2. Institutional interoperability: Students' ability to transfer credits from two-year to nearby four-year programs (i.e., articulation);
3. Labor supply: Shortages or surpluses of qualified workers in local labor pool;
4. Labor demand: Local need for entry-level employees with two-year degrees or certificates.

This exploratory research suggests that workforce needs vary across the United States. If so, then the GeoTech Center needs to tailor its outreach efforts to the varying regional and local needs of community and technical college educators. Evidence reported here suggests that the GeoTech Center should focus on awareness-building efforts in regions other than the West. The Center also should investigate the possibility that Southwest College and its western neighbor institutions are responding more effectively to

workforce needs than are other regions or if the western region has distinctive characteristics that explain its higher rate of geospatial offerings. Conversely, the Center needs to determine whether two-year institutions in other regions are responding appropriately to workforce needs and, if not, what kinds of outreach will be most effective in helping those institutions increase capacity.

CONCLUSION

As reported elsewhere in this special issue, the U.S. Department of Labor Employment and Training Administration (DOLETA) predicts that the U.S. economy will need to add more than 72,000 additional GIS technicians, and nearly 340,000 geospatial workers overall, between 2008 and 2018 (DiBiase 2010). However, DOLETA does not discuss how the need for geospatial workers will vary geographically. Further research along these lines should include a predictive model of the distribution of geospatial workforce needs. Absent such a model, decisions by community and technical colleges to offer or expand geospatial education and training will be based on perceived local needs, and the goal of a coordinated national strategy may remain unfulfilled. Meanwhile, however, this research demonstrates the utility of GIS as a tool to monitor and assess national investments intended to increase U.S. capacity in geospatial workforce development.

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Enhancing General Education with Geographic Information Science and Spatial Literacy

Ming-Hsiang Tsou and Ken Yanow

Abstract: *General education (GE) is an essential component within higher education. GE courses provide students with the opportunity to improve their critical thinking and problem-solving skill set, to develop their attitude of inquiry, and to advance their fundamental knowledge of the arts, sciences, and technologies. In this paper, we present a rationale for GE-level geographic information science and technology (GIS&T) courses at both the university and community college levels. Three contemporary examples of GIS&T courses are discussed and compared. The main goal of GE-level GIS&T courses is to equip students with a foundation in spatial literacy rather than to provide vocational training for future GIS professionals. We argue that with a solid foundation in spatial literacy, students will be better prepared to consider the crucial scientific and social questions of the 21st century. We believe that the dramatic progress of Web-based GIS and mobile GIS, along with the easy access to global geospatial datasets and virtual desktop access, will help GIS educators create more GE-level GIS&T courses in the coming years.*

GENERAL EDUCATION: THE CONSCIENCE OF HIGHER EDUCATION

In his 1988 book, *The Meaning of General Education: The Emergence of a Curriculum Paradigm,* Gary Miller defines general education as " . . . the conscience of higher education, the part of a university that is concerned most directly with the individual student's responsibility to society at large" (Miller 1988, 2). After a series of historical events (including the Industrial Revolution, the Great Depression, and World War II), a new paradigm in higher education began to develop in the United States and all around the world. Offering a comprehensive general education (GE) core curriculum supposedly would provide students with a fuller realization of democracy, a sustainable learning environment, and a global understanding of and cooperation with mankind (Kennedy 1952). As Miller noted (1988, 5),

> General education is [a] comprehensive, self-consciously developed and maintained program that develops in individual students the attitude of inquiry; the skills of problem solving; the individual and community values associated with a democratic society; and the knowledge needed to apply these attitudes, skills, and values so that the students may maintain the learning process over a lifetime and function as self-fulfilled individuals and as full participants in a society committed to change through democratic processes.

Ultimately, general education provides students with the opportunity to improve their critical thinking and problem-solving skills, while advancing their fundamental knowledge of the arts, sciences, and technologies. Rather than providing professional career development or a discipline (major) requirement, GE courses were put in place to ensure a well-rounded undergraduate education. The breadth of the GE curriculum traditionally has included courses in literature, language arts, science, and humanities. However, as technological trends impact discoveries and creative works in the sciences as well as the humanities, the GE curriculum must adapt accordingly. In the recent Trends and Emerging Practices in General Education survey (Hart Research Associates 2009, 5), industry leaders and business executives determined that they would like to see colleges and universities place greater emphasis on the following topics in general education:

1. Science and technology (82 percent: should place more emphasis),
2. Applied knowledge in real-world settings through internships and other hands-on experiences (73 percent),
3. Critical thinking and analytical reasoning skills (73 percent),
4. Communication skills (73 percent), and
5. Global issues (72 percent).

In addition, recent studies in general education indicate that quantitative reasoning skill requirements are becoming more and more important in doctoral-granting universities (e.g., Bourke et al. 2009). This leads us to consider the potential role of geographic information science and technology (GIS&T) in helping to develop such skills at the GE level.

The discipline of geography traditionally has provided several popular GE courses that seemingly meet many of the requests noted in the Hart report (Harper 1982). For example, physical geography introduces students to earth systems, including physical and anthropogenic factors that shape their world. Human geography looks deeper into patterns of human activities in a range of scales. Although many geography courses cultivate spatial awareness, and consider topics that address aspects of the Hart report, few of them specifically emphasize quantitative problem solving or technology. We believe that a GE-level GIS&T class could serve as a vehicle for advancing spatial literacy as well as quantitative problem-solving skills.

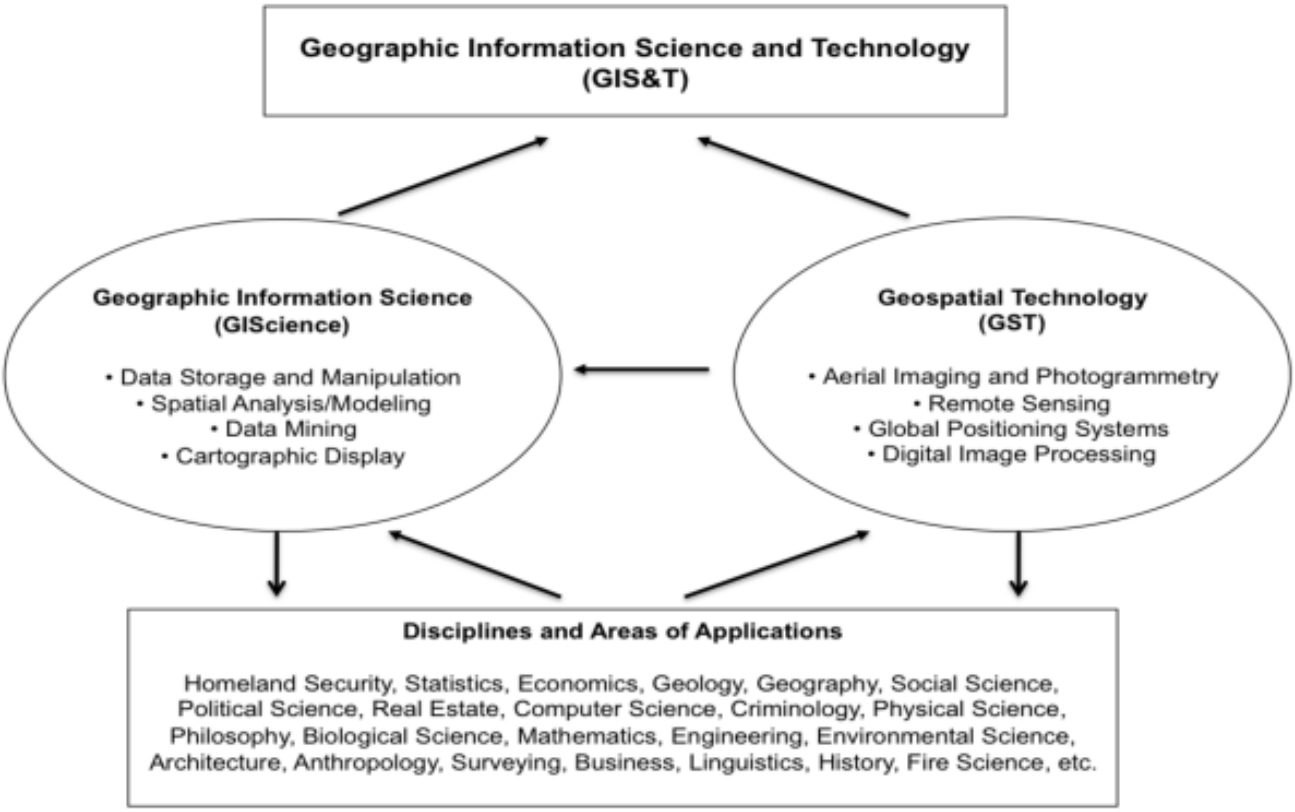

Figure 1. Geographic information science and technology

The content of a GIS&T course can cover all five of the major topics noted in the Hart report. For example, GIS&T introduces both GIScience and geospatial technology (topic #1). Students can learn spatial literacy and geographic knowledge in real-world scenarios via focus- group discussions, hands-on GIS exercises, and Web-based forums (topic #2). Spatial thinking methods, spatial analysis functions, and GIS models can enhance students' skills in critical thinking and analytical reasoning (topic #3). Group projects and discussions will help students' communication skills (topic #4). Finally, many GIS models and geographic research topics are dealing with global issues, such as ocean circulation models, earthquake locations, and world energy resources and consumption (topic #5).

SPATIAL LITERACY AND GIS&T

Spatial literacy is

> an ability to capture and communicate knowledge in the form of a map, understand and recognize the world as viewed from above, recognize and interpret patterns, know that geography is more than just a list of places on the earth's surface, see the value of geography as a basis for organizing and discovering information, and comprehend such basic concepts as scale and spatial resolution . . . a set of abilities related to working and reasoning in a spatial world and to making a picture truly worth a thousand words. (Goodchild 2006, 1)

As noted in the National Research Council (NRC) report, *Learning to Think Spatially* (2006, 1), "without explicit attention to spatial literacy, we cannot meet our responsibility for equipping the next generation of students for life and work in the 21st Century." Ultimately, spatial thinking is integral to the success of all students. Living things and their environments are situated **in** space, and human-environment interactions must be understood in terms of locations, distances, directions, shapes, and patterns (NRC 2006).

Geographic information science and technology is founded on the idea that technology can be used to study space and spatial interactions. There are two primary domains of geographic information science and technology (UCGIS 2006) (see Figure 1). One subdomain is geographic information science (GIScience). GIScience is multidisciplinary, addressing the nature of geographic information and the application of geospatial technologies to basic scientific questions (Goodchild 1992). GIScience draws on insights and methods from philosophy, psychology, mathematics, statistics, computer science, landscape architecture, and other fields. The second subdomain is geospatial technology (GST). GST is the specialized set of information technologies (such as aerial photography, remote sensing, surveying, and global positioning systems) that support a wide variety of uses, from data acquisition to data storage and manipulation to image analysis to geovisualization display and output.

GIS&T is a relatively new field of U.S. higher education. Although the early development of GIS in North America can be traced back to the 1960s with the creation of the Canada Geographic Information System (1962) and the Harvard Laboratory for Computer Graphics and Spatial Analysis (1964), most early GIS courses were created in the 1980s by individual teachers without content standards or GIS textbooks.

One early example of a GE-level mapping course was GEOG 1501, The Language of Maps, created in the 1980s by Dr. Phil Gersmehl at the University of Minnesota. This GE-level course satisfied the communications requirement for graduation at Minnesota, where it competed with algebra, rhetoric, journalism, and English. The five-credit course included three lecture sessions and two laboratories per week and routinely attracted about 280 students each semester. Invited guests from various disciplines and sectors described how they used maps to help their work, such as locating retail stores, how to fight mosquitoes, and how to prepare for floods, to name a few. Laboratory sessions were devoted to skill acquisition, discussions of the guest lectures, and a term project. GEOG 1501 has since been replaced with GEOG 1502: Maps, Visualization, and Geographical Reasoning (Mapping Our World). GEOG 1502 fulfills Minnesota's GE graduation requirement in Liberal Education: Mathematical Thinking. The new course concentrates on the "fundamental issues related to the acquisition, storage, manipulation, analysis, display, and interpretation of spatially referenced data. Emphasis is on mathematical analysis of these data and interpretation of cultural and physical patterns critical to the development of geographical reasoning" (http://www.geog.umn.edu/ugrad/courses.html #geog1502).

Earlier still, in the 1950s, John Sherman created a successful cartographic emphasis program at the University of Washington (Velikonja 1997). When Sherman retired in 1986, his cartographic training and research program was discontinued and replaced with a computer- mapping and GIS program. Today, the University of Washington offers sophomore-level and junior-level GE-level GIS courses; GEOG 258: Maps and GIS, which satisfies the Individual and Society requirement for graduation, and GEOG 360: Principle of GIS Mapping, which satisfies the Quantitative and Symbolic Reasoning requirement for graduation, as well as the Individual and Society requirement for graduation.

Another early example is GEOG 170: Map Reading and Interpretation at the University of Wisconsin–Madison. In 1973, Phil Muehrcke, a colleague of Sherman, developed GEOG 170 after leaving the University of Washington for the University of Wisconsin–Madison. Today, the course still is numbered GEOG 170 but has been retitled Our Digital Globe: An Overview of GIScience and its Technology. The course, which satisfies Wisconsin's Physical Science requirement, explores the geospatial information that surrounds us—maps, images, and location-specific data. The course examines the creation and use of maps and map-related products to answer spatial questions, and provides the tools students need to assess the strengths and limitations of map representations. It investigates the application of geospatial technologies like GPS, Google Earth, satellite imaging, and GIS to improve and enhance our ability to understand and convey spatial information (http://geography.wisc.edu/classes/catalogfall2010).

OBSTACLES TO A GE-LEVEL GIS OR GIS&T COURSE

The National Center for Geographic Information and Analysis (NCGIA) released its Core Curriculum in GIS in 1990 (Kemp and Goodchild 1991). Hundreds of universities and colleges worldwide adopted the Core Curriculum in concert with the advent of accessible GIS software and GPS units, and started to offer a comprehensive series of GIS courses (such as Introduction to GIS, Applications of GIS, and Advanced GIS) as part of their technology emphasis. The courses, designed for either the geography major or for the student interested in a career as a GIS professional, quickly became very popular for senior students and graduate students in many geography departments. However, during this time, most universities and colleges did not provide a fundamental GE-level GIS&T course for freshmen and sophomore students. Four obstacles stood in the way of such a class:

1. **The constraints of teaching facilities and GIS equipment.** Traditional GIS courses were designed for 25 to 30 students in a well-equipped computer laboratory with high-end GIS workstations. Most GE-level courses are expected to serve larger enrollments. Therefore, the large number of students generally exceeded the capacity of a regular GIS laboratory (DiBiase 1996).
2. **Skepticism among geography faculties.** Through the 1990s and beyond, GIS generally was conceived as an advanced technical specialty rather than as a topic with wider appeal. As debates about the nature of GIS as a "tool" or a "science" persisted (Wright et al. 1997), the relevance of the topic to the GE curriculum was only slowly recognized.
3. **The costs of collecting GIS data and remotely sensed imagery.** To design a GE-level GIS&T course for freshmen and nongeography-major students, instructors needed to collect a huge amount of local and global GIS datasets and imagery to demonstrate valuable GIS functions in real-world scenarios, but the cost of acquiring these datasets and this imagery was very expensive in the 1990s.
4. **Low public awareness of geospatial technology.** Before the advent of Google Earth and Google Maps in 2005, the general public and scientific communities were unfamiliar with GIS applications and did not recognize the importance of GIScience and geospatial technologies. Absent these constituencies, there was little motivation to propose GE GIS&T courses.

Those who did consider proposing and developing GE courses in GIS&T faced additional obstacles (DiBiase 1996):

1. **Difficulty of coordinating lecture content and laboratory exercises.** The principles of GIScience introduced in lectures may not be well connected to individual GIS laboratory exercises and software training.

2. **Complexity of commercial GIS packages** discouraged many students and may prevent nongeography majors from learning about the essential values of spatial analysis and GIS models from a novice user's perspective. A friendly, easy-to-use, intuitive GIS software is needed for GE-level courses.
3. **The costs of maintaining computing infrastructure** for enrolling large GE-level GIS laboratory sessions (100 to 200 students) is prohibitive.

EMPHASIZING SPATIAL LITERACY AND QUANTITATIVE REASONING: A PROMISING PATH FOR GIS&T IN GENERAL EDUCATION

In 1997, David DiBiase at Penn State University created a GE-level GIS&T course called GEOG 160: Mapping Our Changing World. The course tackled the first two developmental obstacles noted previously: (1) It incorporated a series of off-site homework assignments, thus lessening the need for a large computer laboratory, and (2) the course included a broader scope of GIS&T curriculum designed with the consensus of the geography faculty (in other words, the faculty was on board). GEOG 160 presently is part of the ten core courses in the geography department at Penn State under the university's Social and Behavioral Science GE category. GEOG 160 helps students begin to "develop the knowledge, skills, and dispositions that constitute geographic information literacy—the ability to recognize when information is needed and . . . to locate, evaluate, and use effectively the needed information" (www.geog.psu.edu/courses/geog160_in dex.html).

> The original design of Penn State's GE-level GIS&T course was to introduce essential spatial-thinking methods and geographic knowledge to nongeography majors.
>
> The objective of an introduction to GIScience should be more to attract students than to launch them. Its focus—in lectures and in laboratories—should be on helping students to understand the unique properties of geographic information, and on developing critical appreciation of the social context and implications of its production and use. (DiBiase 1996, 66)

GEOG 160 is one example of how GIS&T can be transformed into a core GE offering. It has served as a model course for other GE-level GIS&T courses at other institutions, including San Diego State University and Southwestern College (see below). By introducing GIScience and geospatial technologies, such as GPS, cartography, and remote sensing, GEOG 160 provides students with the technical and contextual knowledge of GIS&T from the perspective of an information "consumer" (www.geog.psu.edu/courses/geog160_index.html).

Today, advances in technology and evolving technological trends in GIS&T have minimized the instructional obstacles as noted by DiBiase. For example, the following four technological trends in GIS&T have made it easier for faculty to develop GE-level GIS&T courses:

1. **Web-mapping technology** provides easy access to local, national, and global geospatial information. With the establishment of geospatial cyberinfrastructure, such as the National Map and the National Atlas (NRC 2007), NASA Earth Science Gateway (Alameh et al. 2006), and Geospatial One Stop (Goodchild et al. 2007), GIS&T students are able to explore the whole world from both macro and micro scales, and to study various scientific and social subjects, such as volcano eruptions in Iceland and urban sprawl in Brazil. Web maps also facilitate scientific inquiries by integrating thematic maps, census data, and satellite images. Open-access 3D viewers such as Google Earth help students understand urban and rural environments, ocean currents, land uses, and spatial patterns in various subjects.
2. **Wireless mobile-mapping** applications in mobile devices bring geospatial technology from the real world into the classroom. Location-Based Services (LBS) in smart phones connects the study of GIS&T closely to students' daily lives. Today's students take for granted the power of GIS&T when they use their cellular phones to choose destinations, plot routes, track friends, and post their vacation photographs in Flickr with Google Maps. The popularity of mobile-mapping applications and LBS are beginning to increase the public awareness of GIS&T, thus removing an obstacle to GE-level GIS&T education.
3. **Crowdsourced information** (Howe 2006) and volunteered geographic information (VGI) (Goodchild 2007) enable students to develop a community-centered view in general education and to collaborate with others in a teamwork environment. The rise of Web 2.0 (Batty et al. 2010) enabled the development of dynamic Web-mapping services and mashups, which allow users to create and share their own geospatial data collaboratively. Volunteers can contribute their local knowledge and efforts to collect mapping information by using GPS, mobile sensors, and Web-mapping tools, such as OpenStreetMap project (Hakley and Weber 2008). For example, students in a GIS&T class can submit their own feedback on a mapping mashup regarding a local park renovation plan or ask their friends to discuss the potential problems of relocating the airport in the city. These collaborative decision-making experiences created in a GIS&T class set the stage for critical thinking and group cooperation.
4. **Desktop virtualization and cloud computing** (software as services) can provide students with access to fully functional high-end GIS&T software without local desktop GIS&T software installed. As noted in the previous discussion, an early obstacle to GIS&T as a GE course has been the lack of computer facilities and the high cost of GIS software and data. Web-based mapping services along with Web-based GIS&T tools are part of the solution. With desktop

virtualization, students are able to access and use, via the Internet, fully functional GIS and remote-sensing software and associated data housed on a server(s) (DiNoto 2010). The student is not required to load software, with the exception of a Web browser plug-in or a driver. With desktop virtualization, the world of high-end GIS&T tools can be made available (even on mobile devices such as the iPad) 24 hours a day and seven days a week to students in a GIS&T class.

Leveraging prior experience at other institutions as well as the social and technological trends as noted previously, San Diego State University (SDSU) created a GE-level GIS&T course in 2006, called GEOG 104: Geographic Information Science and Spatial Reasoning. The course utilizes Web-based GIS exercises, online lecture notes, and interactive Web forum discussions to provide a broad overview of geospatial technology and GIScience, including geographic information systems, global positioning systems, remote sensing, spatial statistics, and cartography. GEOG 104 is designed to provide a foundation of GIScience and geospatial technology, including map projections, coordinate systems, data processing, data formats, multimedia cartography, Internet GIS, GPS, location/allocation modeling, and image interpretation. Lectures synthesize these topics within the context of both natural environments and human activities. Web-based GIS exercises provide hands-on experiences for students to explore various "spatial" topics, such as wildfire spreading, San Diego watershed management, urban transportation systems, and epidemiology. The new GEOG 104 course was approved by the University Senate in 2006 as a lower-division class under the GE category of Mathematics/Quantitative Reasoning: Foundations of Natural Science and Quantitative Reasoning. The course is also a preparation course for the B.S. and B.A. major in geography.

The faculty of SDSU's geography department proposed to designate the GEOG 104 course as satisfing the university's Mathematics and Quantitative Reasoning requirement. The College Senate approved the designation. The proposal faced a few challenges, specifically from the mathematics department, whose faculty was concerned that an overlap existed with its statistics courses. The prevailing justification for GEOG 104 to satisfy Mathematics and Quantitative Reasoning was to highlight the need for information literacy and information technology in general education. Moreover, it was successfully argued that GIS&T emphasizes the computational aspect of geographic problems with spatial statistics methods and GIS modeling techniques. By using computers and mathematical algorithms, students learn both the concepts of spatial reasoning and the techniques of quantitative geocomputation. For example, students can utilize online mapping tools to analyze the socioeconomic impact of the recent BP oil spill in the Gulf of Mexico and calculate the total length of the coastline and the size of the impact area. The detailed course proposal and justification documents are available at the GeoTech Center Resource Repository (http://resources.geotechcenter.org/index.php ?P=Home).

Shortly after SDSU's GEOG 104 course was approved, Southwestern College (SWC), a public community college in San Diego County, adopted a similar course: GEOG 150: Geographic Information Science and Spatial Reasoning. GEOG 150 transfers to SDSU fulfilling the same GE categories for graduation at SDSU as does GEOG 104. In addition, the course fulfills a number of graduation requirements for an A.A. or A.S. degree at Southwestern College, including Computer Literacy and Language and Analytical Thinking. The course also is a core course for a Certificate in GIS&T, an A.A. in Geography, a Certificate in Community, Economic, and Urban Development, and a Certificate in Logistics and Transportation. Many community college students seek to transfer to four-year institutions. Many other community college students seek vocational and professional training. Therefore, SWC's GEOG 150 course serves two purposes: (1) as a GE-level course introducing students to quantitative reasoning and spatial literacy and (2) as an entry point to the core set of GIS&T courses at SWC.

All the contemporary GIS&T example courses profiled previously highlight spatial literacy and satisfy specific GE categories at their respective institutions. Characteristics of GE-level GIS&T classes at PSU, SDSU, and SWC are compared in Table 1.

A BLUEPRINT OF GIS&T IN GENERAL EDUCATION

"The [GIScience] education questions have changed over the past two decades, from how to educate an elite group of professional experts, to how to provide a basic level of understanding of GIScience principle to everyone" (Goodchild 2010, 15). Not only does a GE-level GIS&T course fulfill a general education need in quantitative thinking and spatial literacy, it also fulfills a societal need for GIScience education.

The main goal of a GE-level GIS&T course is not to provide vocational training for GIS professionals nor to recruit more geography majors. Rather, the main goal is to equip students with a spatial literacy foundation (including spatial awareness and spatial and quantitative reasoning methodologies) so students can discover the value of geographic knowledge and develop their ability to explore and visualize real-world, critical problems such as global climate change, natural disaster recovery and responses, and watershed conservation. A GE-level GIS&T course not only emphasizes geographical science (NRC 2010) but also embraces other disciplines that require the analysis of spatial characteristics (including, but not limited to, social science, geology, political science, criminology, philosophy, biology, anthropology, business, history, and environmental science). For a long time, general education has had a gap between its social science components and its quantitative-reasoning components. GIS&T can become an essential GE course to bridge this gap and to connect fundamental scientific theories to real-world experiences and scenarios.

A GE-level GIS&T course should focus on spatial literacy and problem solving. The course, while covering certain fundamental concepts of geographical science, would be a contextual

Table 1. The GE-level GIS&T Course Comparison Between SDSU, Penn State, and Southwestern College

	SDSU (2010) GEOG 104	PSU (2010) GEOG 160	SWC (2010) GEOG 150
Course Titles	Geographic Information Science and Spatial Reasoning	Mapping Our Changing World	Geographic Information Science and Spatial Reasoning
2010 General Education Statements (Cited from General Catalog)	General Education profoundly influences undergraduates by providing the breadth of knowledge necessary for meaningful work, lifelong learning, socially responsible citizenship, and intellectual development. This 49-unit program . . . places specialized disciplines into a wider world, enabling students to integrate knowledge and to make connections among fields of inquiry.	These skills include the ability to reason logically and quantitatively and to communicate effectively; an understanding of the sciences that makes sense of the natural environment; a familiarity with the cultural movements that have shaped societies and their values; and an appreciation for the enduring arts that express, inspire, and continually change these values.	The College believes that a comprehensive education introduces the student to the fundamentals of human experience and knowledge in the context of a global society. Such experience provides a common base of learning for all students and seeks to meet the needs of a student body diverse in social, cultural, and educational backgrounds.
The GIS&T Course in GE Distribution	Mathematics/Quantitative Reasoning	Social and Behavioral Sciences Courses (GS)	Computer Literacy Language and Analytical Thinking
Topics Outline	1. Overview of GIScience 2. Mapping the Earth 3. Network of Geographic Information 4. Georeferencing 5. GIS Software and Data Models 6. GPS, Mobile GIS, LBS 7. GIS Data Collection and Database Management 8. Internet and Web GIS 9. Introduction to Remote Sensing 10. Geospatial Visualization 11. Spatial Statistics 12. GIS and Society 13. The Future of Geospatial Technology	1. Data and Information 2. Scales and Transformations 3. Census Data and Thematic Maps 4. TIGER, Topology, and Geocoding 5. Land Surveying and GPS 6.-7. National Spatial Data Infrastructure I and II 8. Remotely Sensed Image Data 9. Integrating Geographic Data	1. Overview of GIS&T, Data, and Information 2. Scales and Transformations 3. Spatial Data (Data Sources and GPS) 4. Introduction to Remote Sensing 5. Spatial Data Modeling 6. Data Input and Editing 7. Data Analysis 8. Spatial Statistics 9. Analytical Modeling in GIS 10. Cartographic Display and Geospatial Visualization

class, which emphasizes the meaning of, reason for, and relevance of spatial thinking and geospatial technology. Students should leave the course with a fundamental understanding of how geospatial technology is helping to solve the most critical problems of our day (such as climate change, energy research and resources, famine studies, natural hazard monitoring/prediction, disease tracking and prevention, and global, cultural, and political analysis).

Based on the successful experiences of PSU's GEOG 160 course, SDSU's GEOG 104 course, and SWC's GEOG 150 course, we propose a conceptual education model of a GE-level GIS&T course (see Figure 2). The model is revised from DiBiase's education model (1996). The top layer includes the three major learning objectives of GIS&T that are supported by five major instructional/learning components.

Three learning objectives of GE GIS&T are:

1. The student will understand the fundamental concepts of geographical science (NRC 2010) and be aware of important current and emerging applications of geospatial technology.
2. The student will know how to visualize spatial datasets and spatial patterns in dynamic Web-based maps and start to explore scientific questions based on data visualization, such as climate change, famine studies, and natural hazard monitoring.
3. The student will operate simple (Web-based) GIS analysis tools to compute basic spatial relations and to make sense of geospatial data encountered in everyday life.

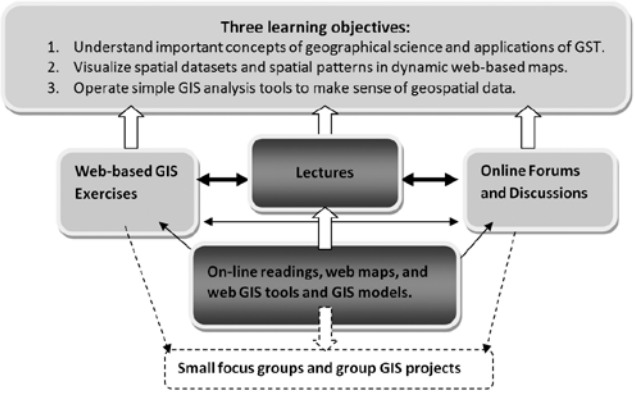

Figure 2. A conceptual education model of GIS&T in general education (adapted from DiBiase 1996)

We believe that the five major teaching components proposed in this education model support the learning objectives effectively and provide pedagogical guidelines for teaching GIS&T courses. Lectures are the core teaching element in the education model and have clear connections with Web-based GIS exercises and online forums. Under the three instructional components, online readings and Web resources help students gain a deeper understanding of lecture subjects. Student should read these online reading assignments before and after the lecture sessions. After each lecture session, students should work on Web-based GIS exercises and answer online forum questions. The Web-based environment is more flexible than other traditional GIS laboratory settings and students can finish these assignments at off-site locations.

Small focus group discussions (in class) and group projects are suggested as other major elements in GIS&T because they can facilitate critical thinking and collaborative teamwork. For example, the recent oil spill disaster in the Gulf of Mexico can be a good focus-group topic. One student group (three or four people) can play the role of BP and discuss how to clean up the oil spill by using GIS and remote sensing. Another group can play the role of the U.S. government and focus on the assessment of environmental impacts and compensation for the victims by using GIS models. The third group can play the role of residents in the coastal areas and discuss their alternative solution and compensation needs. These focus-group discussions may be extended to final group projects at the end of the semester for each focus group.

Open and easy access of lecture notes and Web-based GIS exercises are the key to a scalable and effective GIS&T GE course. A GIS&T course Web site should be created to host lecture notes, Web GIS exercises, online reading assignments, and discussion forums.

Figure 3. Southwestern College GEOG 150 virtual remote desktop access

The open-access nature of a GIS&T course such as the one at SDSU creates an opportunity to extend GIS&T to distance learning. A successful example of a GIS&T GE distance-learning course is Southwestern College's GEOG 150 course. The course itself follows the education model of Figure 2. The delivery of the course, however, is completely online and eight weeks in length. All lecture notes (PowerPoint), course documents, online learning modules, examinations, homework assignments, and online discussions are delivered via the BlackBoard system. In addition, the course textbook is online, free, and interactive (DiBiase 2010). Students are introduced to commercial grade GIS&T software via desktop virtual access (see Figure 3). By delivering the course online and in compressed, eight-week terms, Southwestern College is able to offer the course to the greatest number of students, returning students, and working professionals.

THE IMPACT OF GE-LEVEL GIS&T FOR CAREER AWARENESS AND ENROLLMENT DIVERSIFICATION

Geospatial technology is central to many applications (such as land-use planning, environmental management, emergency response, homeland security, and a multitude of other fields) (Brand 2005). Applications for this technology and demand for workers with geospatial technology (GST) skills have outpaced the development of its workforce across the United States. In fact, GST is experiencing a diffusion of innovation (Hanink 1997 and Wachter et al. 2006) similar to computing in the 1980s and 1990s when the technology moved from the arena of a select few to being a pervasive tool across the workforce in a wide spectrum of industries. There is little question that the geospatial information enterprise is large and growing. The American Society for Photogrammetry and Remote Sensing (ASPRS) survey of the "remote sensing and geospatial information industry" led it to estimate industry revenues in 2001 at $2.4 billion and to predict industry growth at more than $6 billion by 2012. In addition, the ASPRS estimates that about 175,000 people are employed in the "U.S. remote sensing and geospatial information industry" (Mondello et al. 2004). The belief that the need for geospatial workers far exceeds the available supply is widespread.

The core curriculum for most college students includes a large amount of GE coursework. In fact, most students will spend two years completing the majority of their GE coursework before taking major courses. Therefore, it makes sense to offer a GIS&T course that fulfills GE requirements. By doing so, geospatial curriculum inevitably will be taken by a large and diverse cohort of students seeking to fulfill their GE required course load. As a GE offering, a GIS&T course will not just be taken by students who know about "geospatial," but also by students who do not. So, although alerting students to career opportunities in the geospatial industry is not a primary objective of GE-level GIS&T courses, it may address this need indirectly by increasing public awareness.

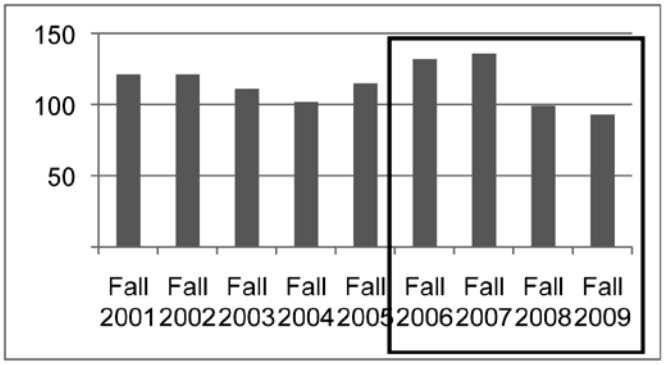

Figure 4. The geography major enrollment at San Diego State University (GEOG104 was implemented in 2006.)

Enrollment Trends

By collecting and comparing enrollment data of GIS&T courses from PSU, SDSU, and SWC, we found three informative enrollment patterns in a GE-level GIS&T course:

1. **Adding a (GE) course in GIS&T did not increase the total number of geography major students at any of the institutions.** For example, after the installation of GEOG 104 at SDSU in 1996, the enrollment of geography students at SDSU actually decreased from 132 students in the fall of 2006 to 93 students in the fall of 2009 (most likely because of economic recession impacts) (see Figure 4). A similar enrollment pattern was observed at Penn State between 2000 and 2009. Southwestern College traditionally has few geography majors. However, when Southwestern College adopted a GIS&T GE course, the typical cohort of students in the GIS&T class increased by more than 30 percent. In addition, although we did not see an increase in geography majors, we did see a large number of students who took the GEOG 150 course initially for GE requirements go on to complete the remaining courses for the GIS&T certificate.
2. **The majority of GE-level GIS&T students are nongeography majors.** At SDSU, in the fall of 2008 to 2009, only 20 percent of GIS&T students were geography majors. At Penn State, only 14 percent of the nearly 3,900 students who enrolled in GEOG 160 between 1997 and 2009 were geography majors. From the fall of 2008 to the spring of 2009, only three out of 90 Southwestern College GIS&T students were geography majors. The fact that GE courses in GIS&T attract students with diverse interests and goals suggests that such courses may be effective in promoting increased public awareness of the geospatial field.

Female student enrollment in GIS&T GE courses at SDSU and Southwestern College generally ranges from 35 percent to 60 percent of the total course enrollment. Females made up 36 percent of the enrollment in Penn State's GEOG 160 class between 1997 and 2009. According to a 2009 survey conducted by the National Geospatial Technology Center, female enrollment in non-GE GIS&T courses generally is 25 percent to 30 percent. This preliminary evidence suggests that GE-level GIS&T courses

may be more effective than upper-division GIS&T courses in attracting women to science and technology.

Table 2. Male Versus Female Enrollment for GIS&T GE Courses at SDSU and SWC

	Male Students	Female Students
SDSU 104 (Fall 2008)	21	20
SDSU 104 (Fall 2009)	21	16
SWC 150 (Fall 2008)	9	17
SWC 150 (Fall 2009)	22	15

CONCLUSION

This paper presents a rationale for creating more GE-level GIS&T courses at universities and colleges. With the new trends in technology, location-based services and applications, and content delivery, we predict that there will be a significant increase of GIS&T courses available in general education in the coming years. Larger enrollments attracted by these courses may contribute to increased public awareness of the geospatial field and of the value of spatial literacy. The challenges that confront GE-level GIS&T still exist. One challenge is to obtain administrative support from departments, colleges, and universities. At San Diego State University, we have strong departmental support because a portion of the department budget is based on full-time equivalent (FTE) and enrolled student numbers each semester. For departments whose annual budgets depend on student enrollments, creating a new GE course can increase the department funding directly. Furthermore, the use of Web-based exercises and desktop virtualization technologies may reduce costs associated with teaching assistants and on-campus GIS laboratories.

Like SDSU, Southwestern College enjoys strong departmental and administrative support, as well as the cooperation of other campus divisions and departments that have adopted GEOG 150 for their core curriculum. Any effort to develop successful courses and/or programs by faculty as it pertains to the overall mission of the college is encouraged by the administration. GEOG 150 is online and utilizes both Web-based curriculum and virtual desktop access. Students explore the world using Google Earth. They address spatial-analysis problems using Internet-based GIS sites. They review and research GIS&T concepts and applications using a Web-based interactive textbook and they explore high-end GIS and remote-sensing software via virtual desktop access.

GE-level GIS&T courses illuminate the tools and techniques needed to answer spatial questions logically and contextually. In addition, they address identified GE needs by science and technology, applied knowledge, critical thinking, communications, global issues, and quantitative reasoning (Hart Research Associates 2009, Bourke et al. 2009). We envision that the ascent of GIS&T in general education may herald a second quantitative "revolution" in scientific communities. In the wake of the first quantitative revolution in the 1970s and 1980s, statistical methods became a common component of GE curricula. GIS&T is perhaps becoming the new quantitative reasoning course for the 21st century. As appreciation for the power of spatial thinking spreads, GIS&T is poised to emerge as a key element in the GE curriculum of U.S. higher education.

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The New Geospatial Technology Competency Model: Bringing Workforce Needs into Focus

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Abstract: *This article recounts a decade-long quest to define the U.S. geospatial industry and its workforce. Its focus is a milestone reached in 2009–2010, when the U.S. Department of Labor issued descriptions of five new geospatial occupations, estimates of current and projected geospatial employment, and a new Geospatial Technology Competency Model (GTCM). The GTCM identifies the foundational, industry-wide, and industry sector–specific expertise that distinguishes, and binds together, successful geospatial professionals. It identifies 43 "core geospatial knowledge and abilities," as well as specialized competencies related to positioning and data acquisition, analysis and modeling, and software and application development. The paper describes the GTCM's content, the process by which it was developed, and its potential uses, including assessments of how higher-education curricula align with workforce needs.*

Just as nobody likes a wiseguy, nobody likes a definition.
—Michael Davis, *Profession, Code, and Ethics*

INTRODUCTION

At its best, higher education prepares students to make a living in a way that improves the quality of life. In the geospatial technology field, which provides so many opportunities in so many different fields and occupations, the responsibility is both exciting and challenging. The breadth and diversity of geospatial has made it difficult to reach consensus about what the field really entails, who geospatial professionals are, and what they should know and be able to do. This paper recounts a decade-long quest to define the U.S. geospatial industry and its workforce, as well as recent achievements that have brought these into sharper focus.

The term *geospatial* means different things to different people. For some stakeholders, it denotes a science. For others, it is a collection of tools used in various fields. Still others consider it a profession characterized by distinct standards of competence and codes of ethics. For the U.S. Department of Labor, as well as many educators, geospatial means a rapidly growing industry that generates employment opportunities for qualified workers. From this perspective, preparing U.S. workers to compete for opportunities in a global economy is an urgent challenge.

To this end, the Department of Labor's Employment and Training Administration (DOLETA) launched a High Growth Job Training Initiative in 2003 (DOLETA n. d.). "Geospatial technology" was one of 14 high-growth "sectors" it highlighted. Beginning in 2004, the DOLETA made $6.4 million of investments intended to identify workforce needs and to make the nation's "workforce training system" more "demand-driven" (DeRocco 2004). Among others, these investments led to two important outcomes: In late 2009 and 2010, the DOLETA issued definitions of six new geospatial occupations (National Center for O*NET Development 2009–2010) and a new Geospatial Technology Competency Model (DOLETA 2010). This paper describes these developments and discusses their meaning to the geospatial field and the professionals who work within it.

DEFINING THE INDUSTRY

From the outset of its engagement with the geospatial field, the DOLETA sought to clarify the opportunity:

> There is not yet an industry-wide definition of the scope of the disciplines or the training and credentials required to work in the industry. There is no single organization tracking all relevant jobs within the geospatial industry and there are no comprehensive job descriptions or salary information for all relevant job opportunities. . . . There is a lack of public awareness of the impact of geospatial technology applications on daily professional and personal activities. With greater understanding will come greater interest in entering the profession, as well as greater demand for geospatial capabilities and applications across a wide range of other sectors. (DOLETA 2005, 1)

The DOLETA's early conception of the field appears in a 2004 speech by former Assistant Secretary of Labor for Employment and Training Emily Stover DeRocco, who referred to the geospatial technology industry as "a cluster of commercial activities growing out of the Global Positioning System [GPS]." She went on to observe:

> This new and still undefined industry has a current worldwide market of about $5 billion, and is growing by 10 percent to 13 percent per year, a growth rate that is expected to continue throughout this decade. The market is projected to have annual revenues of $30 billion by 2005. A survey

of geospatial product and service providers revealed that 87 percent of respondents said they had difficulty filling positions requiring geospatial technology skills. (DeRocco 2004)

Emerging Consensus

Among the first grants awarded by the DOLETA in 2004 was $695,362 to the Spatial Technologies Information Association (STIA) for a project called Geospatial Industry Awareness and Opportunities. In partnership with a long list of workforce boards, community colleges, geospatial firms, and other organizations, the STIA promised to "develop standard definitions of the geospatial industry sector, vet the definitions through industry leaders, and disseminate results through the industry . . ." via an online workforce information clearinghouse, among other vehicles (DOLETA 2004). When the STIA disbanded, the grant went to the Geospatial Information Technology Association (GITA), in collaboration with the Association of American Geographers (AAG) and the Wharton School of Business at the University of Pennsylvania.

The new project partners assembled groups of "thought leaders" representing industry, government agencies, and academia for two roundtable discussions in October of 2005 and January of 2006. The leadership roundtables included discussions and polls about industry definitions. Following the roundtables and subsequent input from stakeholders, the project recommended that the DOLETA adopt the following broad and inclusive definition:

> The geospatial industry acquires, integrates, manages, analyzes, maps, distributes, and uses geographic, temporal, and spatial information and knowledge. The industry includes basic and applied research, technology development, education, and applications to address the planning, decision-making, and operational needs of people and organizations of all types. (GITA and AAG 2006, 8)

The New Geospatial Occupations

Industry observers long have complained that the Department of Labor, the Bureau of Labor Statistics, and the U.S. Census were not doing enough to identify and track geospatial employment (Marble 2006, Estaville 2010). In addition to its recommended industry definition, the GITA and the AAG recommended that the Department of Labor establish two new occupational titles immediately: GIS/Geospatial Analyst and GIS/Geospatial Technician (GITA and AAG 2006, 18). Following these recommendations and with input from other stakeholders, the DOLETA established six new occupations in late 2009.

Table 1 lists the ten geospatial occupations now found in DOLETA's O*NET database, which includes information on hundreds of standardized occupations (National Center for O*NET Development 2010). Remarkably, DOLETA analysts estimate a total 2008 geospatial workforce of 857,000 individuals, not including geospatial software programmers and application developers. To put this figure into context, the U.S. Bureau of Labor Statistics estimates that 1,571,900 engineers (all specialties); 961,200 computer network, systems, and database administrators; and 22,600 statisticians were employed in the United States in 2008 (BLS 2010–2011). Even more remarkable is its estimate that nearly 340,000 additional workers will be needed over the next ten years.

VALIDATING WORKFORCE ESTIMATES

Because the geospatial field is diverse, expanding, and ill-defined, the size and composition of its workforce is hard to determine (Ohio State University 2002). Among the relatively few reliable labor market studies, the American Society for Photogrammetry and Remote Sensing (ASPRS) estimated that

> 175,000 people are employed in the U.S. remote-sensing and geospatial information industry, which includes those commercial firms, not-for-profit organizations, government agencies, and academic institutions involved in the capture, production, distribution, and application of remotely sensed geospatial data and information, primarily for the civilian sector. (Mondello, Hepner, and Williamson 2004, 11)

To bring the ASPRS's 2004 estimates up-to-date with the DOLETA's for 2008, we considered the periodic studies prepared by the market research firm Daratech, Inc. Daratech began tracking revenues of the GIS-related firms in 1989. Responding to the evolution and increasing integration of the industry, Daratech reframed its object of study in 2004 as "geospatial." Consistent with the expansive DOLETA definition recommended by the GITA and the AAG, Daratech defined geospatial technologies as a superset of technologies that includes:

- traditional GIS as the data storage, retrieval, and analysis mechanism;
- data-capture technologies, both as input and to serve as the basis for location-specific information served out to a client—so including many types of sensors, photogrammetry, and other types of imagery as input and the combination of GPS and location-based services (LBS) for later service;
- geocapable engineering technologies that combine the design element of a CAD tool with the underlying GIS layer for location-specific intelligence;
- technologies that serve the data and any analytical results to the end-consumer—whether that is within a traditional client/server environment or through a thin Web client; and
- related services to tie together disparate systems within the public or private enterprise (Daratech 2006, 2)

Across four industry sectors—software, data, services, and hardware—Daratech estimated an increase in industry revenues from about $2.4 billion in 2004 to $4.3 billion in 2008, a compound annual growth rate of 12.6 percent. Assuming that the geospatial workforce grew roughly in proportion to revenue increases during that period, the ASPRS 2004 estimate of the geospatial workforce extrapolates to about 315,000 in 2008.

Table 1. Geospatial Occupations Defined by the U.S. Department of Labor Employment and Training Administration

Occupation	Estimated Employment (2008)	Projected Growth (2008–2018)	Projected Growth Rate (2008–2018)
Geospatial Information Scientists and Technologists*	209,000	72,600	Average (7% to 13%)
Geographic Information Systems Technicians*	209,000	72,600	Average (7% to 13%)
Remote sensing Scientists and Technologists*	27,000	10,100	Average (7% to 13%)
Remote sensing Technicians*	65,000	36,400	Average (7% to 13%)
Precision Agriculture Technicians*	65,000	36,400	Average (7% to 13%)
Geodetic Surveyors*	58,000	23,300	Faster than average (14% to 19%)
Surveyors	58,000	23,300	Faster than average (14% to 19%)
Surveying Technicians	77,000	29,400	Much faster than average (≥ 20%)
Mapping Technicians	77,000	29,400	Much faster than average (≥ 20%)
Cartographers and Photogrammetrists	12,000	6,400	Much faster than average (≥ 20%)
Totals	**857,000**	**339,9000**	

*New occupations established late 2009.
Note: Employment and growth estimates do not include geospatial software programmers and application developers.
Source: U.S. Department of Labor Employment and Training Administration, O*NET Online, http://online.onetcenter.org/, September 6, 2010

This rough estimate suggests that the DOLETA's employment estimates may be high, perhaps by as much as a factor of three, but not by an order of magnitude. However, given that both the ASPRS industry definition is more narrowly focused than the GITA/AAG definition adopted by the DOLETA and Daratech, it seems reasonable to conclude that the ASPRS initial estimate was conservative, that the DOLETA estimates are not extravagant, and that workforce estimates depend highly on how the geospatial industry is defined.

Some industry observers believe that available market research may considerably underestimate the geospatial industry. Recent studies pointing to $6 to $12 billion economic impact in Australia (Curtin University and Victoria University 2008) and a $5.3 billion market in China in 2006 (Zhong and Liu 2008) suggest that Daratech's worldwide revenue estimates are low. Carl Reed, Chief Technology Officer of the Open Geospatial Consortium (2010), suggests that substantial revenues generated by advertising and click-throughs at online mapping and earth browser applications are likely to be overlooked in traditional market estimates, because proprietary information of this type often is not disclosed. Observing that "geospatial analysis and data management are not relegated to just a few software companies anymore," Directions Media Editor in Chief Joe Francica (2009) concludes, "We are at the threshold of a new business environment, both economically and technologically, that requires new ways to measure the growth of the [geospatial] market."

Despite the challenges in estimating the geospatial industry's revenues or workforce, the DOLETA's recognition of six new geospatial occupations is an important milestone. Now that the Department of Labor is tracking a more complete array of geospatial occupations, observers can expect more reliable workforce estimates in years to come. And whether the 2008 geospatial workforce numbered 315,000, 857,000, or somewhere in between, no one disputes the need to prepare many additional workers in the years to come.

From the perspective of employment and training, the most expansive conceptions of the geospatial industry encompass many occupations beyond the ones listed in Table 1, including engineers, marketing professionals, and many others. Individuals in various walks of life will benefit from increased awareness and understanding of geospatial technology and applications. In part, this need will be addressed by innovative general education offerings as described by Tsou and Yanow (2010) elsewhere in this issue. However, the DOLETA's overriding concern, like those of many U.S. higher education institutions and the industry itself, is how to increase the capacity and the effectiveness of the U.S. geospatial education infrastructure to help realize the additional employment opportunities that the geospatial industry is expected to offer.

THE FIRST GEOSPATIAL TECHNOLOGY COMPETENCY MODEL

The widely cited prediction of a $30 billion geospatial technology industry seems to have originated with the U.S. National Aeronautics and Space Administration (NASA). In 1997, NASA launched a National Workforce Development Education and Training Initiative to address an expected "serious shortfall of professionals and trained specialists who can utilize geospatial technologies in their jobs" (Gaudet, Annulis, and Carr 2003, 21). As part of that initiative, NASA mobilized a team of workforce development specialists at the University of Southern Mississippi to identify key competencies of geospatial professionals. The University of Southern Mississippi's Geospatial Workforce Development Center (later reorganized as the Workplace Learning and Performance Institute) used focus-group and group-systems methodologies to help representatives of 16 leading businesses, government agencies, and professional societies identify the key competencies that geospatial workers need to master.

The result was the first Geospatial Technology Competency Model (GTCM), a matrix that associates 39 competencies with each of 12 worker roles (Gaudet, Annulis and Carr 2001). A key insight of this pioneering study was the observation that:

> For geospatial technology professionals to be successful in today's marketplace, it is critical to understand that the knowledge, skills, and abilities required for their jobs include a blend of technical, business, analytical, and interpersonal competencies. (Gaudet, Annulis, and Carr 2003, 25)

The University of Southern Mississippi's GTCM was ahead of its time. Not until 2006 did the University Consortium for Geographic Information Science (UCGIS) complete the first edition of the *Geographic Information Science and Technology Body of Knowledge,* an inventory of 1,660 educational objectives representing that breadth of technical expertise in the geospatial knowledge domain. Absent that inventory, the original GTCM fell short in its attempt to identify technical competencies. The shortcoming became apparent during the study that the GITA and the AAG conducted for the DOLETA. Of the industry roundtable participants and other stakeholders who responded to an online survey, 62 percent agreed that the 12 technical competencies identified in the GTCM were inadequate. The project's Phase I Report (GITA and AAG 2006, 30) concluded that the GTCM "should be refined and updated." This effort would resume in 2008 as part of the DOLETA's in-house competency modeling initiative.

THE DOLETA COMPETENCY MODELING INITIATIVE

The DOLETA commenced its Industry Competency Initiative in 2005. Goals included promoting the development of industry-driven competency models in high-growth, high-demand industries. The contractors that developed the DOLETA's competency modeling framework proposed that *competency* be defined as "the capability to apply or use a set of related knowledge, skills, and abilities required to successfully perform 'critical work functions' or tasks in a defined work setting" (Ennis 2008, 5). They defined *competency model* as "a collection of competencies that together define successful performance in a particular work setting" (4). Uses of competency models include guiding individual professional development, helping people in moving up or over in an organization or industry, helping educators and trainers develop curricula that address workforce needs, and informing development of interview protocols, requirements for professional certification, and criteria for academic program accreditation and articulation (PDRI and Aguirre International 2005).

The DOLETA's competency model framework consists of nine tiers (see Table 2). Although the tiers are illustrated in pyramid form (shown in Figure 1), the content of each DOLETA competency model is a list of competencies corresponding to the first five tiers of the framework. The DOLETA pyramid graphic resembles the illustration used by Marble (1998) in appearance but differs entirely in meaning. Marble's pyramid represented levels of knowledge and abilities possessed by different practitioner groups, ranging from a large group of low-level practitioners who use basic GIS tools in routine ways to a small group of experts engaged in research and development at the top of the pyramid. In contrast, the tiers of the DOLETA pyramid progress from general to specific, rather than from elementary to advanced. Tiers 1 through 3, called Foundation Competencies, specify general workplace behaviors and knowledge that successful workers in most industries exhibit. Tiers 4 and 5 include the distinctive technical competencies that characterize a given industry and its sectors. Tiers 6 to 8 include occupation-specific competencies and requirements that are specified in the occupation descriptions published at O*NET Online. Tier 9 represents management competencies associated with one or more occupations. Because of the number of occupational specialties in a given industry, Tiers 6 to 9 are linked to, but not included in, the DOLETA's industry competency models at its online Competency Model Clearinghouse.

Table 2. Tiers of the DOLETA Competency Model Framework

Tier 9: Management Competencies
Tier 8: Occupation-specific Requirements
Tier 7: Occupation-specific Technical Requirements
Tier 6: Occupation-specific Knowledge Areas
Tier 5: Industry-specific Technical Competencies
Tier 4: Industry-wide Technical Competencies
Tier 3: Workplace Competencies
Tier 2: Academic Competencies
Tier 1: Personal Effectiveness Competencies

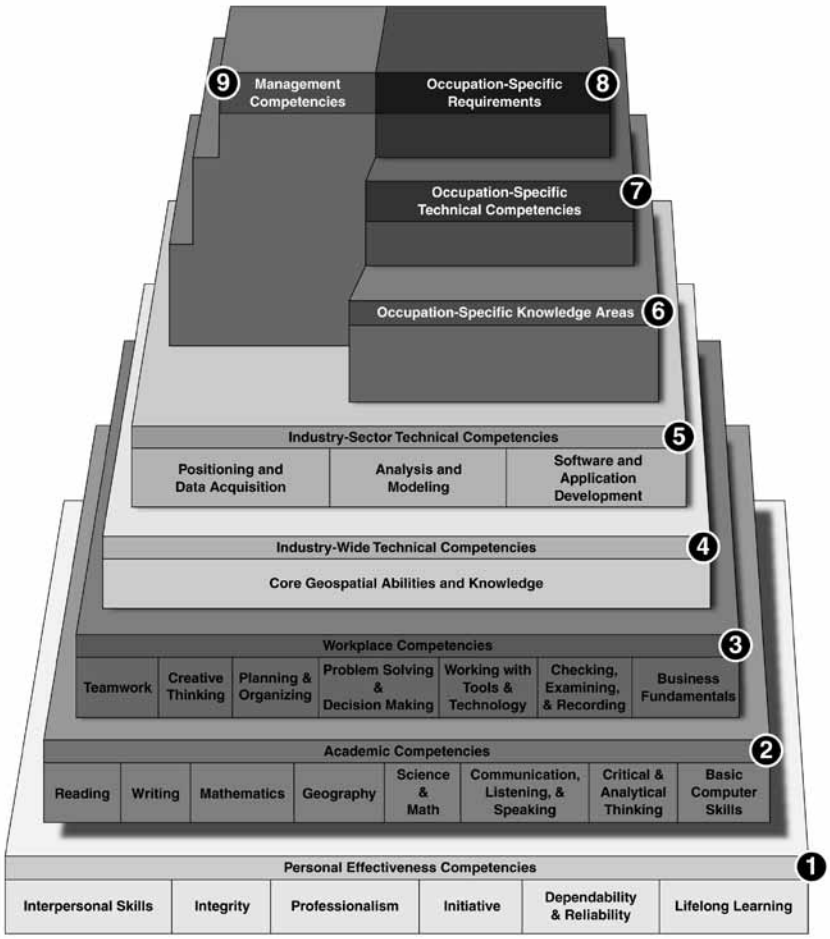


Figure 1. Pyramid graphic depicting tiers of the Geospatial Technology Competency Model (GTCM). The complete model is available at the DOLETA's Competency Model Clearinghouse, http://www.careeonestop.org/competency model/.

Table 3. Tier 1 Personal Effectiveness Competencies of Building Blocks

Interpersonal Skills
Integrity
Professionalism
Initiative
Dependability
Lifelong Learning

Table 4. Example of a Tier 1 Personal Effectiveness Competency Cluster

Initiative: Demonstrating gumption at work.
• Take initiative in seeking out new responsibilities and work challenges
• Pursue work with energy, drive, and effort to accomplish tasks
• Persist at a task despite interruptions, obstacles, or setbacks
• Establish and maintain personally challenging but realistic work goals
• Strive to exceed standards and expectations

THE NEW GEOSPATIAL TECHNOLOGY COMPETENCY MODEL

The pyramid graphic that illustrates the DOLETA's Geospatial Technology Competency Model (GTCM) appears in Figure 1. It shows that most tiers consist of several building blocks, each of which represents a competency cluster. The complete GTCM includes lists of competencies associated with each block. Following the graphic is a series of tables that present sample blocks for Tiers 1 to 3 and complete lists for Tier 5.

The DOLETA's graphic depicts Tier 1—the Personal Effectiveness Competencies—as hovering below the pyramid. Included in Tier 1 are the personal attributes or "soft skills" that are essential for most life roles and that generally are learned in the home or community and reinforced at school and in the workplace.

Table 3 lists the six Personal Effectiveness Competency building blocks included in the GTCM. Highlighted is one example block, Initiative. Competencies listed in this block appear in Table 4.

Tier 2, the Academic Competencies, include knowledge and

Table 5. Tier 2 Academic Competencies Building Blocks

Reading
Writing
Mathematics
Geography
Science & Engineering
Communication
Critical & Analytical Thinking
Basic Computer Skills

Table 7. Tier 3 Workplace Competencies Building Blocks

Teamwork
Creative Thinking
Planning & Organization
Problem Solving & Decision Making
Working with Tools & Technology
Checking, Examining, & Recording
Business Fundamentals

Table 6. Example of a Tier 2 Academic Competency Cluster

Geography: Understanding the science of place and space. Knowing how to ask and discover where things are located on the surface of the earth, why they are located where they are, how places differ from one another, and how people interact with the environment.

Subject-specific Geographic Knowledge

Human–Environment Interaction: Know and apply geographic information about relationships between nature and society (e.g., pollution from industrial development, economic effects of drought)

Regional Geography: Know and apply knowledge of the physical and human geography of a specific country or world region

Physical Geography: Know and apply geographic information about the processes that shape physical landscapes; weather, climate and atmospheric processes; ecosystems and ecological processes; and natural hazards

Cultural Geography: Know and apply geographic information about culture and cultural processes, including religion, language, ethnicity, diffusion, meaning of landscapes, cultural significance of place

Geographic Skills

Geographic Information Systems (GIS): Use GIS to acquire, manage, display, and analyze spatial data in digital form

Cartography: Producing, creating, and designing paper or digital maps

Field Methods: Use interviews, questionnaires, observations, photography, maps, GPS, GIS, and other techniques to measure geographic information in the field

Spatial Statistics: Use quantitative methods to process spatial data for the purpose of making calculations, models, and inferences about space, spatial patterns, and spatial relationships

Geographic Perspectives

Spatial Thinking: Identify, explain, and find meaning in spatial patterns and relationships, such as site conditions, how places are similar and different, the influence of a land feature on its neighbors, the nature of transitions between places, how places are linked at local, regional, and/or global scales

Global Perspective: Possess and apply knowledge of how people, places, and regions are linked by global networks and processes (e.g., globalization, international trade, immigration, Internet technology, global climate system)

Interdisciplinary Perspective: Draw on and synthesize the information, concepts, and methods of the natural and social sciences for geographic research and applications

Table 8. Example of a Tier 3 Workplace Competency Cluster

Business Fundamentals: Knowledge of basic business principles, trends, and economics.

Economic/Business/Financial Principles

- Characteristics of Markets
- Cost and Pricing of Products
- Economic Terminology
- Fundamentals of Accounting
- Profit and Loss
- Supply/Demand

Economic System as a Framework for Decision-making

- Quantify the costs and benefits of an information technology solution for a given organization
- Assess patterns of technologies by examining their effects on parts of an organization, as well as the effects on the organization's interactions with customers, suppliers, distributors, and workers
- Explain the relationship between individual performance and the success of the organization

Business Ethics—Act in the best interests of the company, your coworkers, your community, other stakeholders, and the environment

Legal/Financial

- Comply with the letter and spirit of applicable laws
- Use company property legitimately, minimizing loss and waste; report loss, waste, or theft of company property to appropriate personnel
- Maintain privacy and confidentiality of company information, as well as that of customers and coworkers
- Comply with intellectual property laws
- Protect trade secrets

Environmental/Health/Safety

- Hold paramount the safety, health, and welfare of the public
- Maintain a healthful and safe environment and report any violations/discrepancies
- Ensure equipment and systems are designed to be environmentally friendly and strive to continually minimize the resulting carbon footprint
- Practice sustainability by using processes that are nonpolluting, conserving of energy and natural resources, economically efficient, that use local materials, and are safe for workers, communities, and consumers

Social

- Emphasize quality, customer satisfaction, and fair pricing
- Deal with customers in good faith; no bribes, kickbacks, or excessive hospitality
- Recognize and resist temptations to compete unfairly

Marketing

- Demonstrate an understanding of market trends, company's position in the marketplace, and defined market segments
- Understand position of product/service in relation to market demand
- Uphold the company and product brand through building and maintaining customer relations
- Integrate internal and external customer demands and needs into the product

Entrepreneurship

- Explain the entrepreneurial process, including discovery, concept development, resourcing, actualization, harvesting
- Demonstrate skills in leadership and team building, including enlisting others to work toward a shared vision
- Discuss strategies for managing growth, including using replicable processes to create enterprises that are sustainable

Geospatial Business Fundamentals

- Discuss the historical origins of geospatial technology
- Demonstrate awareness of the various professions, agencies, and firms that make up the geospatial technology industry
- Understand the respective roles of the private sector, universities, nonprofit organizations, and government agencies in the geospatial market
- Make a business case for a given organization's investment in geospatial technology, including value added and risks minimized
- Recognize ethical implications of bidding and other business practices in geospatial business contexts and make reasoned decisions about appropriate actions

abilities learned primarily in a school setting. These cognitive functions and thinking styles apply to most industries and occupations.

Table 5 lists the eight Academic Competency building blocks included in the GTCM. Highlighted is one example block, Geography. The GTCM is the first DOLETA competency model to include Geography as a core academic competency area. Competencies listed in this block appear in Table 6.

The Workplace Competencies specified in Tier 3 represent motives and traits, as well as interpersonal and self-management styles honed in the workplace. They tend to apply to many industries and occupations.

Table 7 lists the seven Workplace Competency building blocks included in the GTCM. Highlighted is one example block, Business Fundamentals. Competencies listed in this block appear in Table 8. Although Business Fundamentals are included in Tier 3 of many industry competency models, some of the knowledge and abilities listed in Table 8 reflect the distinctive character of geospatial business practice.

Tier 4, the Industry-wide Technical Competencies, includes 43 examples of Critical Work Functions that many geospatial professionals will be expected to perform during their careers. In addition to the work functions, Tier 4 also identifies Technical Content Areas—the background knowledge on which skills and abilities are based. These are referenced to the *GIS&T Body of Knowledge* (UCGIS 2006, DiBiase et al. 2007). The Core Geospatial Abilities and Knowledge specified in Tier 4 are exemplary, not exhaustive; geospatial professionals are called on to demonstrate other abilities and knowledge depending on their particular roles and positions. Furthermore, few if any workers are responsible for every Critical Work Function in any one job. Thus, the examples cited represent both the core competencies of the geospatial field and the diversity of professional practice within it (DOLETA 2010, 15). By preparing workers to successfully traverse opportunities in different parts of an organization or even in different organizations, these crosscutting industry-wide technical competencies foster an agile geospatial workforce.

Table 9. Tier 4 Industry-wide Technical Competencies Building Block

Core Geospatial Abilities and Knowledge

Table 9 shows that Tier 4 consists of a single building block that includes the core competencies that distinguish the geospatial field. The 43 Critical Work Functions that make up the core are listed in Table 10. Although the competencies are organized under headings, they are intentionally not separated into blocks that might suggest compartmentalization.

Tier 5, the Industry Sector Technical Competencies, includes Critical Work Functions and Technical Content Areas required for worker success in each of three industry sectors: (1) Positioning and Geospatial Data Acquisition, (2) Analysis and Modeling, and (3) Software and Application Development. The sectors represent clusters of worker competencies associated with three major categories of geospatial industry products and services. The Critical Work Functions listed for each sector are exemplary rather than exhaustive, representing the diversity of professional practice in the geospatial field. The responsibilities of many individual geospatial professionals span two or even three sectors. However, few if any workers are responsible for every work function listed in a given sector. A few Critical Work Functions are restricted in some circumstances by U.S. state law to professionals who are licensed to perform such tasks (DOLETA 2010, 19).

Table 11. Tier 5 Industry-sector Technical Competencies Building Blocks

Positioning and Data Acquisition
Analysis and Modeling
Software and Applications Development

Table 11 shows the three building blocks that make up Tier 5, the Industry-sector Technical Competencies. All three blocks are highlighted; the work functions that make up each block appear in Tables 12 to 14.

POSITIONING AND DATA ACQUISITION

Sales of geospatial data account for more than one-third of the total geospatial industry revenues. In the United States, federal, state, and local government agencies are major consumers, but utilities, telecommunications firms, and other geographically extensive organizations also rely on up-to-date geospatial data for their business operations. Workers in this sector are expert in the unique geometric and thematic properties of geospatial data and are especially knowledgeable about the factors that affect data quality. They know how various data production technologies work—including the Global Navigation Satellite System (GNSS) and its component technologies such as GPS, airborne and satellite-based sensors, photogrammetric instruments, surveying instruments, real-time GPS/GIS mapping systems, and other field data collection devices—and know how to deploy them to meet project requirements. Others are expert in field data collection, qualitative survey methods, administrative records and databases, and other data capture methods and technologies used to collect georeferenced observations and measurements. In addition to traditional modes of capturing data through remote sensing, surveying, and other field-based methods, this sector includes newer modes that incorporate the positioning capabilities of mobile phones and in-car navigation systems, as well as volunteered geospatial data gathered from social media and Internet technologies. Despite many laypersons' assumption that the world already has been mapped, the efforts of a substantial portion of the geospatial workforce continue to be devoted to the production of georeferenced data (DOLETA 2010, 18).

Table 10. Tier 4: **Core Geospatial Abilities and Knowledge** (DOLETA 2010)

Critical Work Functions:

Earth Geometry and Geodesy

1. Discuss the roles of several geometric approximations of the earth's shape, such as geoids, ellipsoids, and spheres
2. Describe characteristics and appropriate uses of common geospatial coordinate systems, such as geographic (latitude and longitude), UTM and State Plane coordinates
3. Explain the relationship of horizontal datums, such as North American Datum of 1983 (NAD 83) or the World Geodetic System of 1984 (WGS 84), to coordinate system grids and geometric approximations of the earth's shape
4. Describe characteristics and appropriate uses of common map projections, such as Transverse Mercator, Lambert Conformal Conic, Albers Conic Equal Area, Azimuthal Equidistant, and Polar Stereographic

Data Quality

5. Discuss the elements of geospatial data quality, including geometric accuracy, thematic accuracy, resolution, precision, and fitness for use
6. In the context of a given geospatial project, explain the difference between quality control and quality assurance
7. Identify data quality and integration problems likely to be associated with geospatial and attribute data acquired with legacy systems and processes
8. Calculate and interpret statistical measures of the accuracy of a digital data set, such as root mean square error (RMSE)

Satellite Positioning and Other Measurement Systems

9. Describe the basic components and operations of the Global Navigation Satellite System (GNSS), including the Global Positioning System and similar systems
10. Explain the distinction between GNSS data post-processing (such as U.S. National Geodetic Survey's Online Positioning User Service) and real-time processing (such as Real-Time Kinematic)
11. Collect and integrate GNSS/GPS positions and associated attribute data with other geospatial data sets
12. Compare differential GNSS and autonomous GNSS
13. Plan a GNSS data-acquisition mission that optimizes efficiency and data quality
14. Identify and describe characteristics of inertial measurement systems and other geospatial measurement systems

Remote Sensing and Photogrammetry

15. Use the concept of the "electromagnetic spectrum" to explain the difference between optical sensors, microwave sensors, multispectral and hyperspectral sensors
16. Differentiate the several types of resolution that characterize remotely sensed imagery, including spatial, spectral, radiometric, temporal, and extent
17. Explain the difference between active and passive remote sensing, citing examples of each
18. Acquire information needed to compare the capabilities and limitations of various sensor types in the context of project requirements
19. Explain the use of sampling ground-truth data for quality assurance in remote sensing
20. Define "orthoimagery" in terms of terrain correction and georeferencing

Cartography

21. Employ cartographic design principles to create and edit visual representations of geospatial data, including maps, graphs, and diagrams
22. Demonstrate how the selection of data classification and/or symbolization techniques affects the message of the thematic map
23. Critique the design of a given map in light of its intended audience and purpose

Table 10. Tier 4: Continued

Geographic Information Systems

24. Demonstrate understanding of the conceptual foundations on which geographic information systems (GIS) are based, including the problem of representing change over time and the imprecision and uncertainty that characterizes all geographic information
25. Use geospatial hardware and software tools to digitize and georeference a paper map or plat
26. Acquire and integrate a variety of field data, image data, vector data, and attribute data to create, update, and maintain GIS databases
27. Specify uses of standard nonspatial data models, specifically the relational data model and its extensions
28. Compare advantages and disadvantages of standard spatial data models, including the nature of vector, raster, and object-oriented models, in the context of spatial data used in the workplace
29. Describe examples of geospatial data analysis in which spatial relationships such as distance, direction, and topologic relationships (e.g., adjacency, connectivity, and overlap) are particularly relevant
30. Use geospatial software tools to perform basic GIS analysis functions, including spatial measurement, data query and retrieval, vector overlay, and raster map algebra
31. Demonstrate a working knowledge of GIS hardware and software capabilities, including real-time GPS/GIS mapping systems

Programming, application development, and geospatial information technology

32. Demonstrate understanding of common geospatial algorithms, such as geocoding or drive-time analysis, by writing or interpreting pseudo code
33. Recognize GIS tasks that are amenable to automation, such as route generation, incident response, and land-use change analysis
34. Identify alternatives for customization and automation, such as APIs, SDKs, scripting languages
35. Identify the information technology components of a GIS, such as databases, software programs, application servers, data servers, SAN devices, workstations, switches, routers, and firewalls
36. Compare benefits and shortcomings of desktop, server, enterprise, and hosted (cloud) software applications
37. Discuss trends in geospatial technology and applications
38. Compare the capabilities and limitations of different types of geospatial software, such as CAD, GIS, image processing
39. Recognize opportunities to leverage positioning technology to create mobile end-user applications

Professionalism

40. Identify allied fields that rely on geospatial technology and that employ geospatial professionals
41. Participate in scientific and professional organizations and coordinating organizations
42. Demonstrate familiarity with codes of professional ethics and rules of conduct for geospatial professionals
43. Identify legal, ethical, and business considerations that affect an organization's decision to share geospatial data

Table 12. Tier 5: Industry-sector Technical Competencies. Sector 1: **Positioning and Data Acquisition.** (DOLETA 2010)

Critical Work Functions:

1. Use specialized geospatial software to transform ellipsoid, datum, and/or map projection to georegister one set of geospatial data to another
2. Geocode a list of address-referenced locations to map data encoded with geographic coordinates and attributed with address ranges
3. Discuss examples of systematic and unsystematic land-partitioning systems in the United States and their implications for land records
4. Compare how land records are administrated in the United States in comparison with other developed and developing countries
5. Explain the distinction between a property boundary and its representations, such as deed lines, lines on imagery, boundary depictions in cadastral (land-records) databases
6. Plot a legal boundary description from a deed or plat
7. Design an integrated measurement system solution for acquiring and processing geospatial data
8. Identify sampling strategies for field-data collection, including systematic, random, and stratified random sampling, and describe circumstances favorable to each
9. Explain how spatial autocorrelation influences sampling strategies and statistics
10. Perform requirements analysis for remotely sensed data acquisition using resolution concepts
11. Explain the concept of "bit depth" and its implications for remotely sensed image data
12. Plan a remotely sensed data-acquisition mission, including specifying an appropriate sensor and platform combination suited for particular project requirements
13. Illustrate the differences between ellipsoidal (or geodetic) heights, geoidal heights, and orthometric elevation in relation to GNSS
14. Make and justify a choice between Real-time Standard Positioning Service (SPS) and Real-time Precise Positioning Service (PPS) for a given objective
15. Perform GNSS data postprocessing (such as National Geodetic Survey's Online Positioning User Service) and real time (such as Real Time Kinematic)
16. Collect and integrate carrier-phase (survey-grade) GNSS positions and associated attribute data with other geospatial data sets.
17. Explain GNSS data-quality issues, such as multipath, PDOP, and signal-to-noise ratio
18. Explain major GNSS error sources, such as ionospheric delay, clock error, ephemerides, and satellite health
19. Produce an orthoimage data product with geometric accuracy suitable for project requirements
20. Describe the components and operation of an aerotriangulation system
21. Produce a metadata document that conforms to a geospatial metadata standard
22. Design a questionnaire and interview protocol for acquiring georeferenced socioeconomic data
23. Diagram the sequence of functions involved in producing georeferenced textual information harvested from social media sites and the World Wide Web
24. Explain how an online real estate site acquires and integrates public information about nearly 100 million property parcels in the United States

ANALYSIS AND MODELING

This sector encompasses the professional end-users of geospatial data and software, many of whom are employed in geospatial occupations within allied industries. Successful practitioners in this sector know when and how to employ analytical functions of geospatial software tools to render valid and reliable information from geospatial data. Many are fluent with both data-driven "exploratory" analyses as well as model-driven analyses for hypothesis testing and prediction. Some analysts specialize in designing and implementing geospatial databases that enable efficient analyses. Others specialize in processing remotely sensed image data. Still others are licensed by state governments to perform legal analyses of land records (DOLETA 2010, 21).

SOFTWARE AND APPLICATION DEVELOPMENT

Market research indicates that this sector accounts for the largest share of sales revenue earned in the geospatial industry (Daratech 2006). Geospatial software products vary from full-featured GIS software products to specialized applications targeted to the needs of particular user communities to component tool kits used by developers to create specialized end-user applications. Software products also include applications for processing, analysis, or adding value to remotely sensed data. In addition to workers employed by commercial software-development firms, many geospatial professionals in diverse settings create specialized software applications to automate routine tasks and to customize end-user interfaces. Increasingly common are customized map mashups based on online mapping systems that expose Application Programming Interfaces (APIs). Open APIs and related Web technologies allow amateurs as well as professionals in many fields, not just geospatial professionals, to create mapping applications. However, the work functions outlined in Table 14 apply specifically to geospatial professionals whose primary work roles include software and application development (DOLETA 2010, 23).

Beyond the scope of this paper are the occupation-specific competencies and requirements associated with Tiers 6 through 9 of the GTCM. As noted previously, descriptions of the ten geospatial occupations can be found through O*NET OnLine (http://online.onetcenter.org/). Other occupational specifications include an ongoing series of DACUM (Developing A CurriculUM, a technique for identifying occupation-specific duties and tasks, http://www.dacum.org/) occupational analyses performed by the GeoTech Center (Johnson 2010, elsewhere in this issue). Requirements for licensure and certification of Professional Surveyors, Professional Photogrammetrists, and GIS Professionals, are published by the National Council of Examiners for Engineering and Surveying (NCEES) (http://www.ncees.org/), the ASPRS (http://www.asprs.org), and the GIS Certification Institute (http://www.gisci.org).

Table 13. Tier 5: Industry-sector Technical Competencies. Sector 2: **Analysis and Modeling** (DOLETA 2010)

Critical Work Functions:

1. Describe an example of a useful application of a buffer operation in GIS software
2. Perform a site-suitability analysis using intersection and overlay functions of GIS software
3. Use GIS software to identify an optimal route that accounts for visibility, slope, and specified land uses
4. Perform dynamic segmentation on transportation network data encoded in a linear reference system
5. Explain how leading online routing systems work, and account for common geocoding errors
6. Use location-allocation software functions to locate service facilities that satisfy given constraints
7. Develop conceptual, logical, and physical models of a geospatial database designed in response to user requirements
8. Explain the modifiable areal unit problem in relation to the "ecological fallacy"
9. Compare characteristics and appropriate uses of geospatial modeling techniques, such as neural networks, cellular automata, heuristics, agent-based models, and simulation models such as Monte Carlo simulation
10. Assess the current state of the art in coupling predictive models and simulations with GIS software
11. Employ cartographic techniques to represent different kinds of uncertainty, including uncertain boundary locations, transitional boundaries, and ambiguity of attributes
12. Establish, reestablish, and/or monument property boundaries; represent such boundaries in plats, records, and descriptions, all under personal and professional liability as stipulated in legal statute and precedent
13. Define the sampling theorem in relation to the concept of spatial resolution of remotely sensed imagery
14. Determine appropriate image-data and image-analysis techniques needed to fulfill project requirements
15. Outline workflows that identify the sequence of procedures involved in geometric correction, radiometric correction, and mosaicking of remotely sensed data
16. Explain how to quantify the thematic accuracy of a land-use/land-cover map derived from remotely sensed imagery
17. Evaluate the thematic accuracy of a data product derived from aerial-image interpretation, such as a soils map, using ground-verification methods
18. Explain the difference between pixel-based and object-based image classification
19. Perform object-oriented image classification using specialized software tools

Table 14. Tier 5: Industry-sector Technical Competencies. Sector 3: **Software and Application Development.** (DOLETA 2010)

Critical Work Functions:

1. Develop use cases for user-centered requirements analyses
2. Perform a feasibility study and cost/benefit analysis
3. Design a geospatial system architecture that responds to user needs, including desktop, server, and mobile applications
4. Communicate effectively with end-users to ensure that software applications meet user needs
5. Optimize geospatial system performance
6. Identify appropriate software development tools for particular end uses
7. Create geospatial software programs using programming languages such as C, C++, and Java
8. Ensure that the software code complies with industry standards, such as those promulgated by the Open Geospatial Consortium (OGC)
9. Identify the factors that affect the interoperability of geospatial software applications
10. Automate geospatial analysis methods such as transformations, raster analysis, and geometric operations
11. Use scripting languages such as Python and others to automate repetitive tasks in desktop geospatial software
12. Customize geospatial software using proprietary and open-source software components, such as ESRI's ArcObjects, Intergraph's GeoMedia software suite, and the GeoTools open-source project
13. Use scripting languages such as JavaScript, PHP, and KML to create Web-mapping applications
14. Employ query languages such as SQL to interrogate spatial databases
15. Work effectively in teams to plan and coordinate software and application development
16. Stay informed about trends and best practices in information technology and software engineering, such as unit testing, version control, and continuous integration
17. Evaluate open-source software components for reuse and potential return contributions
18. Realize opportunities to leverage positioning technology to create mobile end-user applications
19. Explain how geospatial software in large enterprises fits into SOA (Service-Oriented Architecture) and SaaS (Software as a Service)
20. Be able to leverage new architectural opportunities such as cloud computing

THE DOLETA COMPETENCY MODELING PROCESS

The six-step process by which the GTCM and other industry competency models were developed is explained in PDRI and Aguirre International (2005).

Step 1. Gather industry information. The DOLETA's geospatial competency modeling effort began in 2008. Workforce analysts compiled national and state skills standards, technical curricula, syllabi and open course materials, job descriptions, certification standards, and other relevant resources. Many resources had been identified earlier, during a 2003 "industry scan" conducted at the formative stage of the High Growth Job Training Initiative. Prominent among these resources was the University of Southern Mississippi's original GTCM.

Step 2. Develop draft competency model. At this stage, analysts began to merge workforce needs identified in Step 1 into the DOLETA's competency model framework. The initial draft of the DOLETA GTCM (April 28, 2008) included Foundational Competencies (Tiers 1 to 3) and 27 industry-wide Critical Work Functions (Tier 4) under six headings: "Principles of Geospatial Technologies," "Geographic Information Systems," "Cartography," "Remote Sensing and Photogrammetry," Surveying and Global Positioning System (GPS)," and "Computer Programming and Database Management." The initial draft included no industry-sector technical competencies (Tier 5), because analysts found no consensus among stakeholders about the sectors of the geospatial technology industry. As explained previously, no occupation-specific knowledge areas, technical competencies, requirements, or management competencies (Tiers 6 to 9) were included.

Step 3. Gather Information from industry representatives. Information gathering predated the DOLETA's competency initiative. As part of the High Growth Job Training Initiative, the DOLETA convened meetings with geospatial industry representatives in April of 2003, July of 2003, and March of 2005 to learn about workforce challenges. In all, the DOLETA consulted "more than 182 individuals representing 111 geospatial technology sector organizations from 19 states and the District of Columbia, including members of industry (40 percent), education (21 percent), user groups (15 percent), associations and organizations, workforce professionals (3 percent), and government at all levels (21 percent)" (DOLETA 2005, 2). The 2006 report by the GITA and the AAG also provided extensive industry intelligence and recommendations gleaned from two industry roundtables and a subsequent public comment period.

Then, in June of 2006, the DOLETA's quest for a consensus industry definition suffered a setback at a meeting of industry leaders it hosted to discuss the GITA/AAG project. At that meeting, the Management Association for Private Photogrammetric Surveyors (MAPPS) challenged the proposed industry definition,

and even the assertion that geospatial activities constitute an "industry" per se. Instead, the MAPPS insisted that geospatial be defined as a "profession" and an "Architecture-Engineering discipline" (MAPPS 2006). Following the meeting, in response to the DOLETA's request for comment, the GITA contested what it saw as the MAPPS's attempt to "describe geospatial as a profession limited to the discipline of architecture and engineering (A&E) as defined by federal regulations, rather than a crosscutting industry falling within many fields" (Samborski 2006a, 3). The unfortunate result of this debate was that the DOLETA could not affirm that the industry definition proposed by the GITA/AAG team reflected a true consensus in the field. This setback weakened momentum and delayed completion of the DOLETA's GTCM.

Prospects improved in March of 2009, when representatives of the National Geospatial Technology Center of Excellence (GeoTech Center) approached the DOLETA to offer assistance in its competency modeling effort. Established in 2008 by a grant from the National Science Foundation's Advanced Technology Education program, the GeoTech Center is a consortium of educators and higher education institutions dedicated to improving the capacity and quality of geospatial education and training within the nation's nearly 1,200 two-year colleges. Among the Center's highest priority objectives were to assess geospatial workforce needs and identify core competencies (Sullivan, Brase and Johnson 2008). Following the DOLETA's initial briefing about the status of its GTCM project, GeoTech Center representatives recommended in July of 2009 an approach to complete and validate the model. The Center proposed to facilitate a workshop involving a panel of 12 professionals representing a cross section of expertise in the geospatial industry. The panel's primary objectives would be to (1) identify industry sectors and key sector-specific competencies (Tier 5); (2) refine and validate draft industry-wide competencies (Tier 4); and (3) refine and validate draft foundational competencies (Tiers 1 to 3). The DOLETA agreed to the Center's proposed plan and panelists by October of 2009 (panelists and their affiliations are identified in Table 15). Panelists were recruited and oriented to the project by February of 2010. Orientation activities included packets delivered by ground mail that contained copies of the draft GTCM, related resources including the original Southern Mississippi GTCM, the *GIS&T Body of Knowledge,* and the Professional Geography Competency Model (described in a following section), as well as market research reports by the ASPRS and Daratech. Orientation also included an hour-long Webinar in which the DOLETA and GeoTech Center representatives explained the project background, objectives, and workshop agenda.

In March of 2009, panelists met for one and a half days in Scottsdale, Arizona. During the morning of the first day, the panel reached a first milestone when it affirmed the need to differentiate between sector-specific and industry-wide or "crosscutting" competencies. A careful review of the Critical Work Functions included in Tier 4 of the draft GTCM followed. One by one, each of 27 draft work functions was either validated as crosscutting (typically with refined wording), set aside for later consideration

Table 15. Invited Participants in the March of 2010 GTCM Validation Workshop

Panelist	Affiliations
Tripp Corbin	Associate Vice President GIS-IT, Keck & Wood; GISP; CFM; President GA URISA; At-large Board Member GITA SE Chapter
David DiBiase (facilitator)	Manager, Penn State Online GIS programs; GISP; CMS-GIS; URISA and GISCI Boards
Thomas Fox	GeoIntel Analyst, Booz Allen Hamilton
Joe Francica	Editor in Chief, Directions Media; formerly USGS EROS Data Center, Intergraph Corporation
Kass Green	President, Kass Green & Associates; Past President ASPRS; numerous Boards
Janet Jackson	GIS Consultant, Intersect; former President GITA Carolina Chapter; Professional Surveyor columnist
Gary Jeffress	Director, Conrad Blucher Institute, Texas A&M Corpus Christi; RPLS; former President GLIS; GeoTech National Visiting Committee
Brian Jones	JBS International, contractor support for the U.S. Department of Labor Employment and Training Administration
Brent Jones	Survey/Cadastre/Engineering Manager, ESRI; GITA past President
Jeremy Mennis	Associate Professor of Geography, Temple University; Chairperson, GIS Specialty Group, AAG
Karen Schuckman	Senior Lecturer, Penn State; consultant to URS Corp., formerly with EarthData; ASPRS past President; RPLS, CP
Cy Smith	GIO, State of Oregon; COGO Chairperson; NSGIC past President; URISA President Elect; GISP
Jan Van Sickle	Van Sickle LLC, Denver; RPLS, ACSM, ASPRS

as a sector-specific competency to be included in Tier 5, demoted to a lower foundational tier, or discarded. During this process, new industry-wide work functions were suggested, discussed, and accepted or set aside for later consideration. Every one of the 43 crosscutting work functions that appear in the final version of the GTCM was included by consensus of the panel.

The panel reached another crucial but unanticipated milestone when it agreed that industry-wide competencies should be aggregated into a single block spanning the entire Tier 4, rather than segregated into separate blocks associated with subdisciplines or professions (e.g., GIS, cartography, land surveying, remote sensing, and photogrammetry). The panel reasoned that if selected Critical Work Functions are indeed relevant to every geospatial professional, then they should not be depicted in a way that suggests otherwise. Thus, Tier 4 of the GTCM pyramid diagram consists of a single block labeled "Core Geospatial Abilities and Knowledge" (see Figure 1).

Another milestone was harder to reach. The panelists and facilitator struggled to identify a set of industry sectors for Tier 5. The panel first attempted to define sectors a priori, expecting that the Tier 5 competencies could readily be sorted by sector thereafter. When it became apparent that this "top-down" approach would not lead to consensus, the panel instead began identifying specialized work functions with the expectation that clusters of competencies eventually would become apparent, and that these clusters would in turn suggest industry sectors. This "bottom-up" approach proved more fruitful. Starting with critical but specialized work functions identified during the earlier review of Tier 4, panelists soon identified many more work functions that were of critical importance to some but not all geospatial professionals. Near the end of the workshop, when numerous specialized work functions had been listed, panelists began to propose sector names. They assuredly rejected suggestions based on disciplines, or professions, and especially regulated versus unregulated practices (i.e., work functions performed by state licensed practitioners versus voluntarily certified or uncredentialed practitioners). Instead, panelists agreed on a functional classification of geospatial expertise that, coincidentally, resembles the industry sectors identified by the market research firm Daratech, Inc., and, more approximately, to those identified in the ASPRS's 10-Year Industry Forecast. The panel's consensus implies that most geospatial workers, and the agencies and firms that employ them, cannot be segregated neatly into exclusive sectors. The nature of geospatial projects, the panel concluded, requires most workers and employers to engage in a range of activities that requires expertise spanning two or more competency clusters. Geospatial professionals, agencies, and firms are, and must be, versatile.

Step 4. Refine the model. After the workshop, the facilitator distributed a revised draft GTMC to participants for review (March 15, 2010). Discussion and suggestions led to a revision dated April 1, 2010, which was distributed for public review.

Step 5. Validate the model. Leaders of 16 professional and scientific associations and firms with interests in the geospatial field were invited to comment on the April 1 draft. Posts in leading online trade publications also solicited public comment. Lively discussion followed.

The topic that generated the most discussion was the definition of Geography competencies in Tier 2. The Professional Geography Competency Model was the key resource for that building block. It also played an important role in validating the Foundation Competencies in Tiers 1 to 3.

PROFESSIONAL GEOGRAPHY COMPETENCY MODEL

In 2005, a team of education researchers and advisers affiliated with the AAG conducted a series of focus groups and surveys intended to illuminate workforce needs in fields that hire individuals with geography degrees. The Geography competencies identified in Tier 2 of the DOLETA GTCM are drawn directly from this research (Solem, Cheung and Schempler 2008).

Equally important, a crosswalk of the two competency models reveals close correspondence between the Foundation Competencies and the AAG's "general" skill areas. Of the 21 competency blocks in Tiers 1 to 3, 76 percent correspond to one or more of the AAG's 29 "general" skill areas. Conversely, 83 percent of the AAG's general skill areas have close counterparts in the GTCM's Foundation Competencies. The two models diverge most in respect to Tier 1, the Personal Effectiveness competencies, some of which (e.g., Initiative, Dependability, and Reliability) may be too elementary to have attracted the notice of the AAG project's respondents. Even so, the primary importance of general workplace skills revealed in the AAG study validates the new GTCM's emphasis on foundational competencies.

Following the first round of public review, a new draft GTCM, dated May 14, 2010, was prepared and distributed to all 15 respondents. Additional discussion led to a final draft dated June 1, 2010. In all, the validation stage yielded 49 pages of critique, suggestions, and responses from the facilitator and other panelists—nearly twice the length of the new GTCM itself.

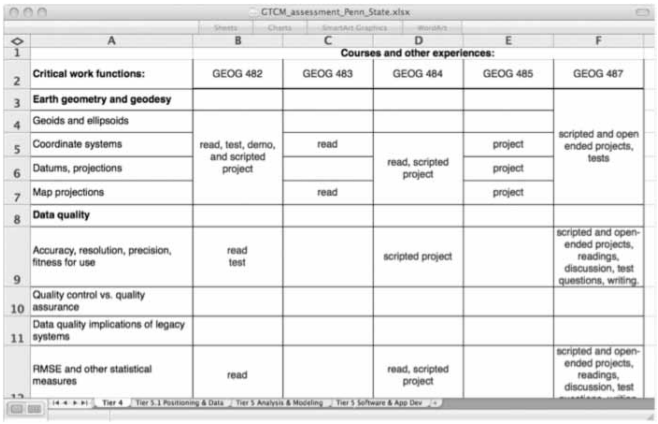
Step 6. Finalize the model. In parallel with the public review, the DOLETA conducted its own internal review of the GTCM. Following successful conclusion of both processes and approval from Assistant Secretary of Employment and Training Jane Oates, the DOLETA published the GTCM at its Competency Model Clearinghouse on June 18, 2010. The DOLETA announced the launch with a press release describing the value of the model and the importance of the achievement. "Competency models offer workers an opportunity to learn what it takes to enter a particular field," wrote Secretary of Labor Hilda L. Solis. "The geospatial model serves as a guide for those who want to both find a good job and map out a long-term career pathway in any of several geospatial technology fields including surveying and mapping, computer science and information science" (DOLETA 2010b).

USING THE NEW GTCM FOR CURRICULUM ASSESSMENT

Academic departments not accountable to subject-specific accreditation offer most of the geospatial courses and programs in U.S. higher education (DiBiase 2003). Accreditation is a formal peer-review process for assuring the qualifications and effectiveness of educational programs (Hamm 1997). Absent accreditation, many geospatial education and training programs lack a mechanism for periodic self-assessment and peer review of curricula, faculty qualifications, and student achievement, among other things. In this context, one of the most important potential uses of the new GTCM may be to self-assess how education and training curricula align with workforce needs.

Shown in Figure 2 is a portion of a prototype self-assessment instrument based on the new GTCM. The prototype is a simple spreadsheet that consists of multiple worksheets. Each worksheet consists of a matrix corresponding to one of the new GTCM's five tiers. Matrix rows list key competencies and critical work functions identified by workforce analysts and geospatial professionals. Columns represent the array of courses and other formal educational experiences included in a curriculum. Shown in this example are self-assessments conducted by instructors of five core classes in Penn State University's online Certificate Program in GIS. In each applicable matrix cell, instructors note the ways in which a particular course addresses a particular competency. Specifically, instructors note student assignments that yield tangible evidence of mastery. For example, educators may note that a course provides lectures pertaining to a particular competency, readings, discussion, demonstrations, writing assignments, scripted practical project assignments, open-ended project assignments, and/or test questions or problems.

The self-assessment process is efficient. Instructors who contributed to the example shown in Figure 2 report that self-assessments took only one to two hours per course. Although the prototype assessment instrument is just a simple spreadsheet, the GeoTech Center plans to develop and support more sophisticated implementations of this and related instruments in response to user feedback about the prototype instrument.



	A	B	C	D	E	F
1		Courses and other experiences:				
2	**Critical work functions:**	GEOG 482	GEOG 483	GEOG 484	GEOG 485	GEOG 487
3	**Earth geometry and geodesy**					scripted and open ended projects, tests
4	Geoids and ellipsoids	read, test, demo, and scripted project		read, scripted project		
5	Coordinate systems		read		project	
6	Datums, projections				project	
7	Map projections		read		project	
8	**Data quality**					
9	Accuracy, resolution, precision, fitness for use	read test		scripted project		scripted and open-ended projects, readings, discussion, test questions, writing.
10	Quality control vs. quality assurance					
11	Data quality implications of legacy systems					
	RMSE and other statistical measures	read		read, scripted project		scripted and open-ended projects, readings, discussion, test

Figure 2. Prototype curriculum self-assessment instrument based on the Geospatial Technology Competency Model (GTCM). This and related resources are freely available at the GeoTech Center Resource Repository, http://resources.geotechcenter.org.

DISCUSSION

In the orientation Webinar conducted prior to the GTCM validation workshop, DOLETA representatives urged panelists to keep the "80 percent rule" in mind. This meant that the group should not expect 100 percent agreement on any point but should define consensus as 80 percent agreement. The same advice guided the team's response to critiques received during the public review period. While many suggestions were incorporated into the final GTCM, some were rebutted and set aside. A few of these overruled objections deserve attention here.

One reviewer objected to the "inconsistent granularity" of the competencies and the Critical Work Functions. Examples cited were "compile data required for map production" and "explain the implications of the term 'authoritative measurements' as specified . . ." (Both of these draft work functions were ultimately omitted from the GTCM.) Instead of a range of broad and focused competencies, the reviewer suggested that work functions be consistently broad. That approach would allow for comprehensive coverage without excessive length. On behalf of workshop participants, the facilitator (who also served as lead editor of the GTCM's final revisions) replied that uniform granularity is not necessarily a virtue. In practice, the work functions that geospatial professionals are called on to perform do vary in granularity, from the nebulous to specific. Furthermore, the draft competency cited as a "specific" example ("Explain the implications of the term 'authoritative measurements' as specified . . .") actually implies a great deal of contextual knowledge about the contested territories of professionalism in the geospatial realm. In general, the panel concluded that uniform granularity was not a worthy objective.

The same insightful reviewer commented on the "competenciness" (sic) of the Critical Work Functions in the draft GTCM. The reviewer correctly pointed out that a Critical Work Function is "something the person would actually do on the job, phrased in a way that someone could judge whether they are doing it well/correctly." Contrary to that goal, the reviewer pointed out that many competencies and work functions are so conceptual that mastery can only be demonstrated by discussion or explanation. In contrast, another reviewer argued that competencies should emphasize "understanding (hence, 'explain') . . . and not the standard of doing it." A workshop participant observed that action verbs such as "discuss" and "describe" should be minimized for "they do not describe what the worker actually 'does.' Rather, they describe how a student proves what he/she has learned." Although panelists understood this distinction, they often crafted competencies that require workers to explain concepts and applications. They agreed that the ability to communicate knowledge effectively to clients, peers, supervisors, and employees often epitomizes expertise in the geospatial workplace.

Other reviewers disapproved of the three industry sectors adopted for Tier 5. One reviewer argued that work functions

are specific to occupations or professions not to industry sectors. However, panelists agreed that sorting work functions by sector is distinctly advantageous. Instead of segregating the geospatial industry into exclusive constituencies, the GTCM seeks to unveil its coherence by showing that the goals, activities, and expertise of the various geospatial professions overlap and complement one another. The reviewer's constructive comment resulted in an expanded preface to Tier 5 that explains this rationale.

CONCLUSION

The most fundamental critiques of the GTCM may be that it (and related efforts to define the geospatial field) is futile at best, and hegemonic at worst, insofar as it privileges one way of knowing and thinking about the field over others. As Davis (2002) says, "[N]obody likes a definition." However, he also points out, "Definitions are to writing what benchmarks are to surveying, shared points of reference" (1). The definitions of the geospatial technology industry, of geospatial workforce needs, of occupations and the employment estimates described previously should be useful points of reference for educators, current and aspiring professionals, employers, and the public. Without such reference points, it will be hard to gauge the success of the geospatial education infrastructure.

This paper mentioned several uses of competency models such as the GTCM, including individual professional development, curriculum planning and assessment, informing development of interview protocols, requirements for professional certification, and criteria for academic program accreditation and articulation. Highlighted here was the GTCM's potential for assessing the alignment of academic program curricula with geospatial workforce needs. In the long run, the GTCM's usefulness will depend on frequent updates that account for the continuing evolution of the field.

Encouragingly, the GTCM demonstrates that a diverse group of geospatial professionals can reach consensus on fundamental questions concerning the identity of the geospatial field and the nature of expertise within it. Reflecting on the debate about industry definitions, GITA Executive Director Bob Samborski observed, "This exercise has revealed the potential for the various elements of the geospatial industry to achieve a far more constructive, unifying purpose" (2006b, 3). The GTCM is another hopeful sign that the field can achieve greater clarity in the public realm, greater understanding and synergy among geospatial professionals, and greater educational effectiveness.

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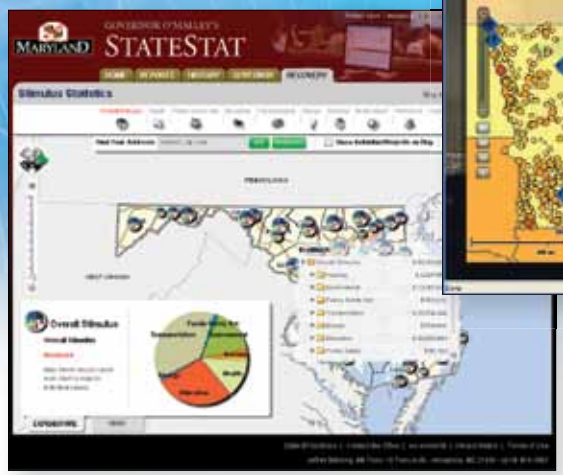

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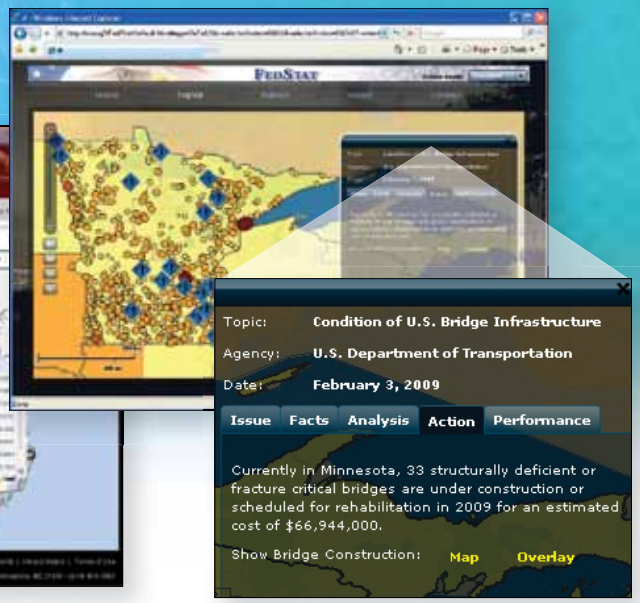

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