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

David DiBiase, Tripp Corbin, Thomas Fox, Joe Francica, Kass Green, Janet Jackson, Gary Jeffress, Brian Jones, Brent Jones, Jeremy Mennis, Karen Schuckman, Cy Smith, and Jan Van Sickle

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

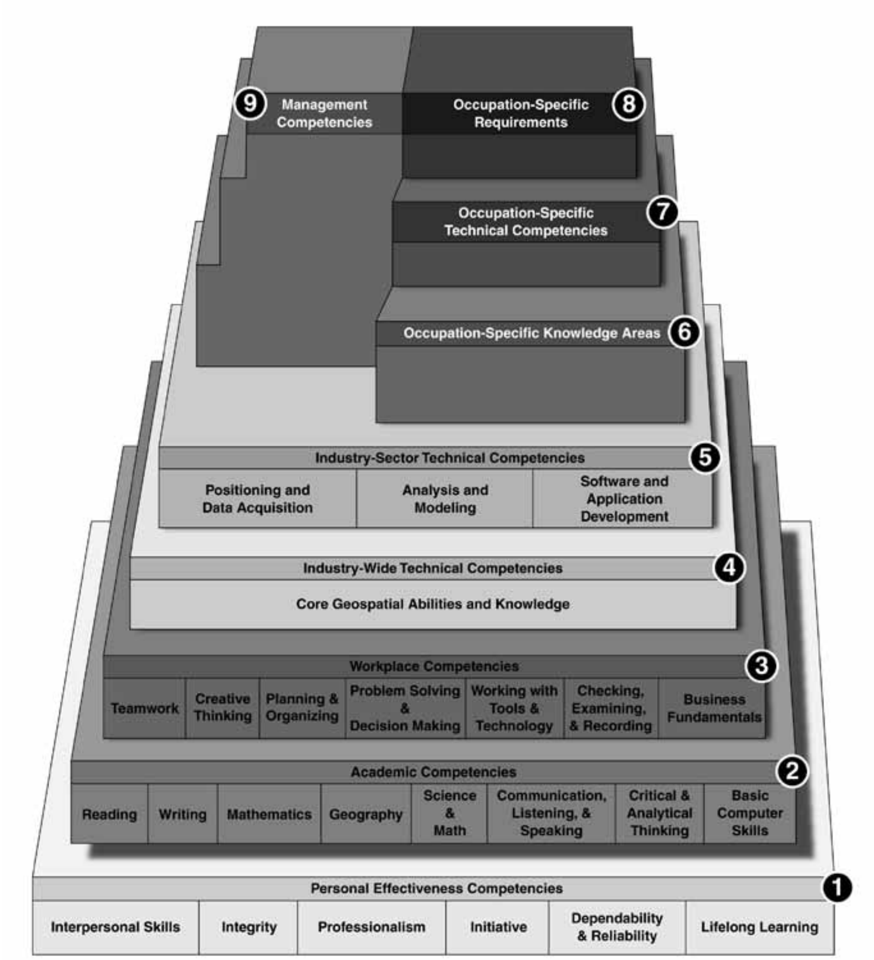


Figure 1. Pyramid graphic depicting tiers of the Geospatial Technology Competency Model (GTCM). The complete model is available at the DOLETA's Competency Model Clearinghouse, http://www.careeonestop.org/competency model/.

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 CurricuIUM, 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.

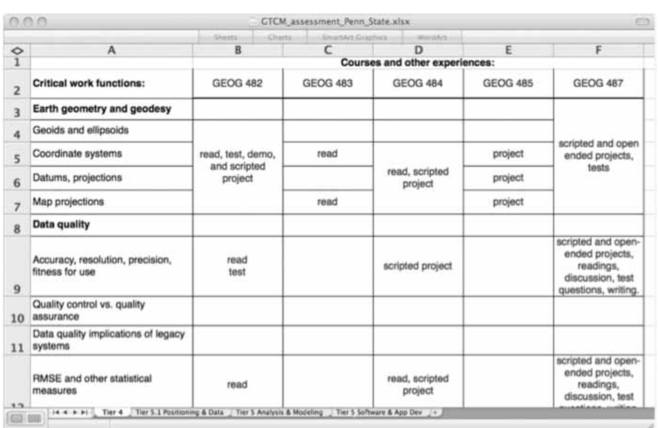
Step 6. Finalize the model. In parallel with the public review, the DOLETA conducted its own internal review of the GTCM. Following successful conclusion of both processes and approval from Assistant Secretary of Employment and Training Jane Oates, the DOLETA published the GTCM at its Competency Model 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



	Courses and other experiences:				
Critical work functions:	GEOG 482	GEOG 483	GEOG 484	GEOG 485	GEOG 487
Earth geometry and geodesy					
Geoids and ellipsoids	read, test, demo, and scripted project		read, scripted project		scripted and open ended projects, tests
Coordinate systems		read		project	
Datums, projections				project	
Map projections		read		project	
Data quality					
Accuracy, resolution, precision, fitness for use	read test		scripted project		scripted and open-ended projects, readings, discussion, test questions, writing.
Quality control vs. quality assurance					
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.

GeoTech Center plans to develop and support more sophisticated implementations of this and related instruments in response to user feedback about the prototype instrument.

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.

Acknowledgments

Substantial portions of this paper were adapted from the U.S. Department of Labor's Geospatial Technology Competency Model, much of which the authors helped to write. The National Science Foundation's Advanced Technology Education Program supported this project through its National Geospatial Technology Center of Excellence (Award DUE #0801893). Authors' opinions are not necessarily shared by the NSF. The GeoTech Center and the authors thank DOLETA staff members Pam Frugoli, Jennifer Troke, and Brad Wiggins, as well as JBS International staff members Barbara Derwart and Brian Jones, who encouraged and facilitated our work. Thanks also to reviewers for challenging us to deliver a worthy product. Special thanks to James Detwiler and Frank Hardisty of Pennsylvania State University, on whom the authors relied to ensure that the GTCM's treatment of programming and application development accurately reflects the current state of the art.

About the Author

David DiBiase heads the Penn State Online Certificate and Master of GIS degree programs. As a senior researcher with the GeoTech Center, he directed the effort to complete the U.S. Department of Labor's Geospatial Technology Competency Model in 2010. As chairperson of the UCGIS Education Committee from 2004 to 2006, he led the editorial team that completed the *GIS&T Body of Knowledge*. From 1999 to 2003, as a member of URISA's Certification Committee, he helped design the criteria by which the GIS Certification Institute (GISCI) awarded its GIS Professional credential to more than 4,500 practitioners. He currently serves as GISCI President and member of the URISA Board of Directors.

Corresponding Address:
John A. Dutton e-Education Institute
Penn State University
2217 Earth-Engineering Sciences Building
University Park, PA 16802
(814) 863-1790
dibiase@psu.edu

References

BLS 2010. Occupational outlook handbook. Http://www.bls.gov/OCO.

Curtin University and Victoria University 2008. Trends in the development of the Australian spatial information industry (October 2008). Www.crcsi.com.au/UPLOADS/PUBLICATIONS/PUBLICATION_366.pdf.

Daratech, Inc. 2006. GIS/Geospatial markets and opportunities. Cambridge, MA: Daratech, Inc.

Davis, M. 2002. Profession, code, and ethics. Burlington, VT: Ashgate.

DeRocco, E. S. 2004. Speech at AACC & ACCT National Legislative Summit, February 10, Washington, DC.

DiBiase, D. 2003. On accreditation and the peer review of geographic information science education. URISA Journal 15(1): 7-14, Http:// www.urisa.org/files/Dibiasevol15no1.pdf.

DiBiase, D., M. DeMers, A. Johnson, K. Kemp, A. Luck, B. Plewe, and E. Wentz, Eds. 2007. Introducing the first edition of the GIS&T body of knowledge. Cartography and Geographic Information Science 34 (2): 113-20.
DOLETA. The President's High Growth Job Training Initiative (no date). Http://www.doleta.gov/business/PDF/1%20-%20HGJTI%20overview.pdf.
DOLETA Geospatial industry awareness and opportunities. The President's High Growth Job Training Initiative, September 28, 2004, www.doleta.gov/brg/pdf/geospatial_gita.pdf.
DOLETA. Identifying and addressing workforce challenges in American's geospatial technology sector, November 2, 2005. Www.doleta.gov/Brg/pdf/Geospatial%20Final%20Report_08212007.pdf.
DOLETA. Geospatial technology competency model, July 2010. Http://www.careeronestop.org/ competencymodel/pyramid.aspx?GEO=Y.
DOLETA. U.S. Department of Labor announces release of geospatial technology competency model. News release, July 8, 2010b. Http://www.dol.gov/opa/media/press/eta/eta20100950.htm.
Ennis, M. R. 2008. Competency models: A review of the literature and the role of the employment and training administration (ETA). Www.careeronestop.org/COMPETENCYMODEL/info_documents/OPDRLiteratureReview.pdf.
Estaville, L. E. 2010. Geospatial workforce trends in the United States. International Journal of Applied Geospatial Research 1 (1): 57-66.
Francica, J. Does traditional market research miss the real numbers for geospatial technology growth? Directions Magazine (September 17, 2009). Http://www.directionsmag.com/articles/does-traditional-market-research-miss-the-real-numbers-for-geospatial-techn/122483.
Gaudet, C., H. Annulis, and J. Carr. 2001. Workforce development models for geospatial technology. University of Southern Mississippi: GeoSpatial Workforce Development Center.
Gaudet, C., H. Annulis, and J. Carr. 2003. Building the geospatial workforce. URISA Journal 15 (1): 21-30. Http://www.urisa.org/files/Gaudetvol15no1.pdf.
GITA and AAG. 2006. Defining and communicating geospatial industry workforce demand: Phase I report.
Hamm, M. S. 1997. The fundamentals of accreditation. Washington, DC: American Society of Association Executives.
Johnson, J. 2010. What GIS technicians do: A synthesis of DACUM job analyses. URISA Journal 22 (2): 31-40.
MAPPS. 2006. The geospatial profession: An architecture-engineering discipline. Presentation to the Department of Labor, June 19, 2006.
Marble, D. F. 1998. Rebuilding the top of the pyramid. ArcNews 20 (1): 1, 28-29.
Marble, D. F. 2006. Defining the components of the geospatial workforce—who are we? ArcNews 27 (4): 1, 6-9.
Mondello, C., G. F. Hepner, and R. A. Williamson. 2004. 10-year industry forecast, phases I-III, study documentation. Photogrammetric Engineering and Remote Sensing (January): 7-58, http://www.asprs.org/news/forecast/10-year-ind-forecast.pdf.
National Center for O*NET Development. O*NET online. Http://online.onetcenter.org/2009-10.
Ohio State University. 2002. Geographic information science and technology in a changing society: A research definition workshop. Columbus, OH: Center for Mapping and School of Natural Resources.
PDRI, Inc., and Aguirre International. 2005. Technical assistance guide for development and using competency models—one solution for a demand-driven workforce system. Http://www.careeronestop.org/competencymodel/Info_Documents/TAG.pdf.
Reed, C. Personal communication. August 13, 2010.
Samborski, R. 2006a. A rose by any other name. . . . GITA Newsletter. Http://www.gita.org/members_only/newsletter/2006/samborski_julyAug06.pdf.
Samborski, R. 2006b. After the dog days. Www.gita.org/gita-in-action/samborski0906.pdf.
Solem, M., I. Cheung, and B. Schlemper. 2008. Skills in professional geography: An assessment of workforce needs and expectations. Professional Geographer 60(3): 356-73.
Sullivan, D., T. Brase, and A. B. Johnson, 2008. A plan for the national coordination of geospatial technology education from a community college perspective. Monterey, CA: MATE Center, Monterey Peninsula College.
Tsou, M.-H., and K. Yanow. 2010, Enhancing general education with geographic information science and spatial reasoning. URISA Journal 22 (2): xx-xx.
UCGIS. 2006. Geographic information science and technology body of knowledge. Washington, DC: Association of American Geographers.
Zhong, E., and L. Liu. 2008. A study on geospatial industry size in China. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XXXVII (B4), Beijing, China.