

Why is a GIS&T Body of Knowledge Needed?

Workforce needs

Size of the geospatial enterprise: There is little question that the geospatial information enterprise is large and growing. Absent a standard industry definition, however, estimates of the size of the enterprise have varied. Technology market research firm Daratech (2004) estimated that worldwide sales of GIS software, services, data, and hardware totaled \$1.84 billion in 2003. Daratech predicted that total revenues increased nearly 10 percent in 2004. The American Society for Photogrammetry and Remote Sensing's (ASPRS) survey of the "remote sensing and geospatial information industry" led it to estimate 2001 industry revenues at \$2.4 billion, and to predict growth to more than \$6 billion by 2012 (Mondello, Hepner, & Williamson, 2004). The National Aeronautics and Space Administration (NASA), in consultation with the Geospatial Workforce Development Center at the University of Southern Mississippi, estimated that the U.S. "geospatial technology" market would generate \$30 billion a year by 2005—\$20 billion for remote sensing, \$10 billion for geographic information services (Gaudet, Annulis, & Carr, 2003). This most optimistic prediction, based on an expansive conception of the geospatial information industry that includes remote sensing, GIS, and global positioning system technologies, has since been adopted by the U.S. Department of Labor (U.S. Department of Labor, n.d.).

Size of the geospatial workforce: Because of the varied definitions, broad scope, and rapid evolution of the geospatial enterprise, reliable information about the size and composition of the geospatial workforce is difficult to obtain (Ohio State University, 2002). A few telling estimates do exist, however. ASPRS estimates that about 175,000 people are employed in the "U.S. remote sensing and geospatial information industry" (Mondello, Hepner, and Williamson, 2004). Environmental Systems Research Institute (ESRI), which along with Intergraph accounts for nearly half of the worldwide GIS software market, estimated in 2000 that 500,000 individuals in the U.S. use its software products as part of their jobs, and that some 50,000 individuals work as full-time GIS specialists (Phoenix, 2000). Longley and colleagues

estimate that there are some four million GIS users worldwide, working at some two million sites (Longley, Goodchild, Maguire, & Rhind, 2005). Whatever the actual size of the geospatial information workforce, everyone seems to agree that there are too few qualified workers available to support the industry's growth.

Inadequate supply of geospatial professionals: NASA launched a National Workforce Development Education and Training Initiative in 1997 to address the “serious shortfall of professionals and trained specialists who can utilize geospatial technologies in their jobs” (Gaudet, Annulis, & Carr, 2003, p. 21). ESRI Higher Education Marketing Manager Michael Phoenix estimates that “the shortfall in producing individuals with an advanced level of GIS education is around 3,000 to 4,000 [annually] in the U.S. alone” (Phoenix, 2000, p. 13). The Assistant Secretary for Labor and Training of the U.S. Department of Labor has pointed to survey data indicating that “87 percent of geospatial product and service providers ... had difficulty filling positions requiring geospatial technology skills” (DeRocco, 2004, p. 2). So bullish is the U.S. Department of Labor (DoL) about prospects for growth in “geospatial-related occupations” (Table 1) that it identified geospatial technologies as one of twelve “high-growth” industries. Citing “an immediate and anticipated need to fill tens of thousands of positions,” DoL launched the “President’s High Growth Job Training Initiative” in 2003 (Department of Labor, n.d.). Seeking “alternatives to the traditional pipeline” of four-year degree programs, DoL’s Education and Training Administration is investing up to \$250 million to develop training programs at community colleges (Department of Labor, n.d.). While industry insiders may consider the Department of Labor’s conception of the geospatial industry far too inclusive (e.g., Sietzen, 2004), no one is likely to contest DoL’s analysis that workforce issues have become urgent.

Occupation	2000-2010 Growth (projected)
Cartographers and Photogrammetrists	18.5%
Surveyors	08.1%
Surveying and Mapping Technicians	25.3%
Architectural and Civil Drafters	20.8%
Civil Engineering Technicians	11.9%
Mechanical Drafters	15.4%
Electrical Drafters	23.3%
Electrical and Electronic Engineers	10.8%
Mechanical Engineering Technicians	13.9%
Industrial Engineering Technicians	10.1%
Environmental Engineering Technicians	29.1%
Geoscientists	18.1%

Table 1: U.S. Department of Labor “Geospatial Jobs Outlook” (Department of Labor, n.d.).

Inadequate preparation for high tech roles: Concerns about the preparedness of those who enter the workforce through the “traditional pipeline” of four-year degree programs are less frequently expressed than worries about the quantity of such workers. Such concerns do exist, however. Respondents to the ASPRS industry survey complained not only about the “shortage of trained workers emerging from educational programs,” but also about “the lack of the required skill sets among many of the graduates” (Mondello, Hepner, & Williamson, 2004, p. 13). Since education degree and certificate programs that

specialize in GIS&T are not specifically accredited, it is difficult to judge objectively the educational effectiveness of the traditional pipeline. Even so, a brief review of two critiques is instructive.

1. **Unregulated academic certificate programs:** Ironically, one set of concerns follows from the attempts of higher education institutions to respond to the increasing demand for specialized geospatial education and training opportunities. Some 120 U.S. higher education institutions have developed academic certificate programs that promise to help students to develop GIS-related knowledge and skills and to earn credentials that will help them compete for jobs or advance their careers in the geospatial industry. The proliferation of academic certificate programs is not unique to GIS, of course. The U.S. Department of Education lists over 2,000 post-graduate certificate programs that serve as many as 40-45 million people in the U.S. (Irby, 1999). Wikle (1998) points out that academic certification programs in GIS vary widely in scope, focus, and rigor. Ted Marchese (1999, p. 4), long-time vice president of the American Association for Higher Education, has observed that "...developments in the postsecondary marketplace are quickly outrunning the capacity of existing quality assurance mechanisms to assure fair practice." This "can make it difficult for students and employers to assess the value of these programs" (Lapidus, 2000, p. 7). The lack of standards and accountability for academic certificate programs led veteran GIS practitioner and educator William Huxhold to complain that "today anybody can teach anything and call it GIS education. ... Who knows whether the skills being taught in these programs are needed to become a GIS professional?" (Huxhold, 2000a, p. 25)
2. **Insufficiently rigorous undergraduate programs:** In 1998, Duane Marble published an influential critique of the "low-level, non-technical" character of GIS education in undergraduate degree programs (Marble, 1998, p. 28). "Existing GIS education," Marble claimed, "fails to provide the background in GIScience that is necessary to meet the needs either of the users of GIScience technology or of the scientific community engaged in basic GIScience research and development" (Marble, 1999, p. 31). Unlike students in the early days of GIS education, when the primitive state of the technology necessitated programming skills, Marble pointed out that latter day students and some instructors believe that all one has to do to become a GIS professional is to master the standard functions of commercial off-the-shelf (COTS) software. Thus, graduates are no longer prepared "to make substantial contributions to the ongoing development of GIS technology" (Marble, 1998, p. 1). Advanced knowledge and skills in computer and information sciences are needed more than ever, he argued, to realize the full potential of GIS&T.

Marble identified a "pyramid" of six competency levels that undergraduate degree programs should prepare students to achieve (Figure 2). Public awareness of geospatial technologies constitutes the base of the pyramid. One level above the base is the relatively large number of workers who need to be prepared for careers involving "routine use" of COTS software and related geospatial technologies. A somewhat smaller number of graduates needed to work with "higher level modeling applications" within COTS software must possess knowledge and skills in spatial analysis, computer programming, and database man-

agement systems. More demanding and fewer still are “application design and development” roles that require workers to create software applications rather than to simply use them. Specialists responsible for “system design” require advanced analytical as well as technical skills, including system analysis, database design and development, user interface design, and programming. Finally, the peak of the pyramid represents the relatively small number (perhaps 10,000 or more worldwide) of individuals whose sophisticated understanding of geography, spatial analysis, and computer and information sciences prepares them to lead “research and software development” teams within software companies, government agencies, and in universities. Marble (1998) argued that the base of the pyramid is expanding “at explosive rate while the upper levels have been permitted to crumble” (p. 29).

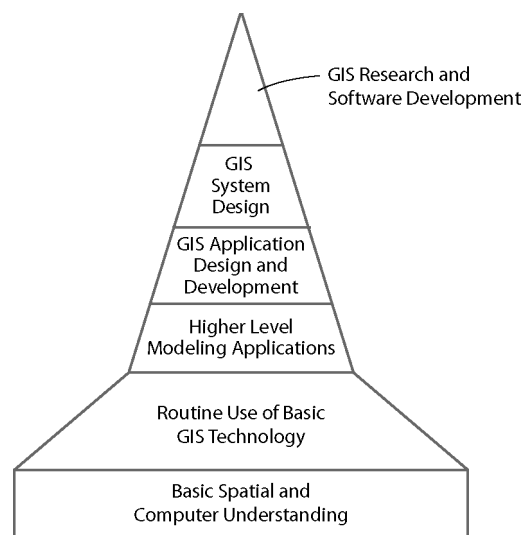


Figure 2: “Pyramid” of roles played by GIS&T professionals. Fewer, but more highly skilled, personnel are needed at the upper levels of the pyramid. (Marble, 1998).

To counteract what he viewed as a failing undergraduate education system, Marble (1998) argued for a “full-fledged examination of the entire spectrum of courses required to support an adequate education at each level of the pyramid” (p. 29). His critique and prescription resonated within the GIS software industry, which subsequently supported efforts to define a new undergraduate curriculum that “immediately reestablish[es] the strong role of computer science education within GIS” (Marble, 1998, p. 29) The resulting Model Curricula initiative, as well as other related efforts, is reviewed in the section on how the *Body of Knowledge* relates to other curriculum efforts.

NASA Geospatial Workforce Development Initiative: Participants in a 2001 “research definition” workshop at the Ohio State University noted that the “nearly complete lack of supply and demand data ... is severely hampering GIS&T development and application in this country ... The Workshop strongly recommends that statistical and other studies of the overall GIS&T workforce ... be undertaken as soon as possible” (Ohio State University, 2002, p. 19). Independently, and motivated primarily by concern

about the U.S. remote sensing industry workforce, in 2001 NASA mobilized a team of workforce development specialists at the University of Southern Mississippi to carry out a study to identify key competencies of geospatial professionals. The Geospatial Workforce Development Center (later reorganized as the Workplace Learning and Performance Institute) convened workshops involving representatives of sixteen leading businesses, government agencies, and professional societies in the geospatial arena. Using focus group and group systems methodologies, researchers asked representatives to identify the key competencies and roles that their employees or constituents were expected to play. The twelve roles identified in the study appear in Table 2.

Applications Development	Identify and develop tools and instruments to satisfy customer needs
Data Acquisition	Collect geospatial and related data
Coordination	Interorganizational facilitation and communication
Data Analysis and Interpretation	Process data and extract information to create products, drive conclusions, and inform decision-making reports
Data Management	Catalog, archive, retrieve, and distribute geospatial data
Management	Efficiently and effectively apply the company's mission using financial, technical, and intellectual skills and resources to optimize the end products
Marketing	Identify customer requirements and needs, and effectively communicate those needs and requirements to the organization, as well as promote geospatial solutions
Project Management	Effectively oversee activity requirements to produce the desired outcomes on time and within budget
Systems Analysis	Assess requirements to produce the desired outcomes on time and within budget
Systems Management	Integrate resources and develop additional resources to support spatial and temporal user requirements
Training	Analyze, design, and develop instructional and non-instructional interventions to provide transfer of knowledge and evaluation for performance enhancement
Visualization	Render data and information into visual geospatial representations

Table 2: Twelve roles played by geospatial technology professionals (Gaudet, Annulis, & Carr, 2003).

Roles were defined as subsets of thirty-nine particular competencies. Competencies rated as “important” by at least 50 percent of role experts were deemed “core competencies.” Competencies appear in Table 3, clustered into four categories. Authors of the study conclude 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, & Carr, 2003, p. 25).

TECHNICAL COMPETENCIES**Ability to Assess Relationships Among****Geospatial Technologies**

Cartography

Computer Programming Skills

Environmental Applications

GIS Theory and Applications

Geological Applications

Geospatial Data Processing Tools

Photogrammetry

Remote Sensing Theory and Applications

Spatial Information Processing

Technical Writing**Technological Literacy**

Topology

ANALYTICAL COMPETENCIES**Creative Thinking**

Knowledge Management

Model Building Skills

Problem-Solving Skills

Research Skill

Systems Thinking

BUSINESS COMPETENCIES**Ability to See the “Big Picture”**

Business Understanding

Buy-in/Advocacy

Change Management**Cost Benefit Analysis/ROI**

Ethics Modeling

Industry Understanding

Legal Understanding

Organizational Understanding

Performance Analysis and Evaluation

Visioning**INTERPERSONAL COMPETENCIES**

Coaching

Communication

Conflict Management

Feedback Skills

Group Process Understanding

Leadership Skills

Questioning

Relationship Building Skills**Self-Knowledge/Self-Management**

Table 3: Thirty-nine competencies required for success in the geospatial technology profession. Each of the roles outlined in Table 2 above requires a subset of the technical, analytical, business, and interpersonal competencies in Table 3. Boldface type indicates core competencies (Gaudet, Annulis, & Carr, 2003).

The Workplace Learning and Performance Institute’s (WLPI) compilation of geospatial roles and competencies does not align neatly with real job descriptions posted by actual employers. Following earlier studies (e.g., Huxhold, 1991; Dramovicz 1997), the Urban and Regional Information Systems Association’s (URISA) Model Job Descriptions for GIS Professionals (Huxhold, 2000b) identifies six generic job titles for GIS professionals: managers, coordinators, specialists, programmers, analysts, and technicians. Like the roles represented in Marble’s pyramid, these six job titles constitute a ranked list in which each role subsumes most of the knowledge and skills of the roles below it. By contrast, the WLPI’s twelve roles represent unranked, nominal categories. This follows in part from WLPI’s conception of the “geospatial industry,” which is much broader, and thus more diverse, than the conceptions of most practitioners and educators who work in the GIS&T field. More fundamentally, workforce development specialists argue that “today’s fast-changing workplace requires that the basis for recruiting, selecting, and compensating individuals is their competence and skills, rather than a job title. The best approach to develop a workforce is to focus less on specific tasks and duties and more on identifying work-related competencies” (Gaudet, Annulis, & Carr, 2003, p. 22). This first edition of the *Body of Knowledge* adopts the pyramid representation of geospatial workforce roles that is most familiar to practitioners and educators. The units, topics, and objectives that make up the ten knowledge areas presented in section V of this document provide a list of the technical, analytical, and business competencies that are particular to the GIS&T field that is more representative, more detailed, and more useful than the list suggested

by WLPI. Cultivation of generic technical, analytical, business, and interpersonal skills is considered in the following section on the GIS&T education infrastructure.

Many public and private organizations are involved in helping individuals master the knowledge, skills, and credentials needed to contribute to, and advance within, the GIS&T enterprise. Collectively, this constellation of organizations may be conceived of as an “educational infrastructure.” The following section describes this infrastructure, and argues that fostering synergies among its various components is a key objective for national-scale curriculum development efforts.

The GIS&T education infrastructure

As Longley et al. (2000) argue, a diversity of education and training approaches is needed to prepare practitioners in a wide range of fields to realize the potential of geospatial technologies to improve the quality of life. A constellation of public and private organizations provide formal and informal educational opportunities to current and future GIS&T professionals throughout their lifetimes. These organizations include not only educational institutions, but professional societies, private firms, government agencies, and public and private media. In addition to planning, implementing, and assessing curricula, these organizations are concerned with the mobility of students’ academic achievement among institutions (ensured through articulation agreements), accreditation of academic programs, certification of the qualifications of individual practitioners, selection and continuing professional development of employees, and promotion of basic awareness of GIS&T. A body of knowledge produced as a result of the collective effort of a community of researchers, educators, and practitioners has the potential to provide an authoritative basis for increasing the coherence of these activities. Realizing synergies among these organizations and their activities is, the editors believe, key to improving their effectiveness in addressing workforce needs.

Because the field is demanding intellectually as well as technically, and because it is evolving rapidly, educational opportunities in GIS&T must span a lifetime of learning. Opportunities to learn about, and learn with, geospatial technologies are available in many (though certainly not most) primary and secondary classrooms in the U.S., in two-year colleges, and in training sessions provided by for-profit businesses. For learners whose locations or personal situations prevent them from participating in traditional classes, educational opportunities are increasingly available through asynchronous online delivery as well as self-study texts. Furthermore, exposure to geospatial technologies gained through commercial and educational television programming, museum exhibits, geocaching clubs, and other popular media and organizations are indispensable vehicles for fostering geospatial literacy and interest in geospatial careers among the general public. Together, this constellation of educational opportunities constitute what has been called an “educational infrastructure”—an “interwoven network of educational, social and cultural resources” that supports the cumulative process by which individuals learn throughout their lifetimes (St. John and Perry, 1993, p. 60). A description of the informal and formal sectors of the infrastructure follows.

Informal education: The solution to the problem of recruiting, preparing, and retaining competent geospatial technology workers begins with a public understanding of GIS&T and its contributions to society. This challenge is related to the more general problem of recruiting the new generation of scientists, mathematicians, and engineers needed to ensure the nation's economic security. Public understanding of science is also needed to ensure the informed citizenry upon which representative democracy depends. Informal science education fosters public understanding of science both by providing opportunities for learning beyond the classroom and by mitigating the loss of knowledge that most of us experience after completing our formal education (Crane, 1994).

The informal or "free choice" component of the educational infrastructure is "the public's primary source of information about science" (Falk, 2001, p. 10). Experts on informal science education argue that investments should be directed toward increasing the capacity of the educational infrastructure and fostering synergies among its components (e.g., Falk, 2001; St. John, 1998). Specifically, Bybee (2001) claims that, "if the nation is going to achieve science literacy, it will need to recognize the importance of a combined effort of both the formal and free-choice education communities" (p. 47).

Bybee's argument holds for the special case of geographic information science literacy as well. For the same reasons that undergraduate degree programs in Forensic Science are emerging in response to the popularity of the various *Crime Scene Investigation (CSI)* series on primetime network television, applications of geospatial technologies in television programs such as those seen recently in *The District* and *Numb3rs* may prompt young people to imagine geospatial technology careers. With \$1 million of support from the U.S. Department of Labor, a venture called Kidz Online is developing a series of digital video and other resources intended to raise awareness about career opportunities in GIS&T. Geocaching clubs and Google "mashups" engage thousands of enthusiasts nationwide. How might this keen interest in geospatial technology be leveraged to attract future GIScientists? How often are the outcomes of geospatial research and applications highlighted in museum exhibits, or in programs on the National Geographic and Discovery channels? The National Science Foundation's Informal Science Education program supports such projects on a limited and highly competitive basis. Informal education remains the most neglected sector of the geospatial education infrastructure, however. Synergies among formal and informal education are needed to expand public understanding of geographic information science and to recruit talented young people to geographic information studies and geospatial careers.

Formal education: Figure 3 depicts the formal aspect of the GIS&T education infrastructure in matrix form. Four sectors of formal education are represented with columns labeled Primary and Secondary, Undergraduate, Graduate, and Postbaccalaureate and Professional. Six rows represent the levels of expertise that make up Marble's pyramid. A partial inventory of the components of the infrastructure populates the matrix cells. Discussion of the technical, analytical, business, and interpersonal competencies cultivated by the various components at each stage follows.

	Primary and secondary education	Undergraduate education	Graduate education	Postbaccalaureate and Professional education
Research and Development				
System Design			Research universities Government agencies	
Application Design		Four-year institutions Two-year institutions	Software companies Publishers	Four-year institutions Two-year institutions Software companies Professional societies
Modeling		Software companies Publishers		Academic publishers Government agencies
Routine Use		Software companies Publishers		
Basic Understanding	K-12 schools Software companies Government agencies Publishers	Government agencies		

Figure 3: The GIS&T education infrastructure. Columns represent sectors of formal education that span a lifetime of learning. Rows correspond to the roles played by geospatial professionals as represented in Marble's pyramid. Informal education spans the learner's lifetime in parallel with formal education.

Formal education at primary and secondary levels: Geospatial technologies can be effective tools for supporting active and inquiry-based learning in K-12 education (Audet & Ludwig, 2000). Although many exciting innovations at individual schools can be identified, in general the rate of adoption of GIS and related technologies in U.S. primary and secondary schools has been slow (Bednarz, Downs, & Vender, 2002). Teachers' concerns about access to technology, data, training, and curricular materials, combined with the absence of institutional support and professional incentives, conspire to hinder adoptions. Ironically these disincentives persist even as hardware costs decline, educational software licensing is liberalized, free or low-cost curricular materials developed by software vendors, private firms, and government agencies proliferate, and Internet connectivity expands. Federal government emphasis on high-stakes testing associated with No Child Left Behind (NCLB) legislation, combined with lack of funding for geography initiatives under NCLB, also conspire to discourage teacher innovation. The National Research Council's 2006 publication *Learning to Think Spatially* may inspire a new wave of adoptions and innovation. The K-12 sector, combined with informal science education, remains a crucial but under-performing sector for promoting public awareness of geospatial technologies.

Formal education at the undergraduate level—Two-year institutions: According to the National Center for Education Statistics, 42 percent of the 16.5 million U.S. undergraduates in 1999-2000 were enrolled in over 2,000 two-year institutions (in some cases known as "community colleges") (Horn, Peter, & Rooney, 2002). Undergraduates enrolled at public two-year colleges tend to be older, and are more

likely to study part-time, than students at four-year institutions. They are also more likely to seek associate's degrees and vocational certificates.

The success of two-year institutions, and their faculties, is judged primarily by the quantity of enrollments they attract. Thus two-year colleges have a strong incentive to respond to the demand for individuals properly trained for entry-level positions in the geospatial technology industry. One of the most attractive characteristics of community colleges—their low tuition rates—pose challenges for institutions that wish to respond to the demand for geospatial technology education and training, however. Long-established certificate and associate degree programs in geospatial technology at Houston Area Community College, Lansing Area Community College, and Mesa Community College, among others, demonstrate the ability of community-based institutions to overcome such obstacles. Support for development of new programs is available on a competitive basis through the National Science Foundation's Advanced Technology Education program, and, more recently, through the Department of Labor's High Growth Technology Jobs initiative. Institutions that prefer not to develop curricular materials on their own can use licensed materials from commercial vendors (e.g., Digital Quest's SPACESTARS) and from some higher education institutions (e.g., the University of Mississippi's Institute for Advanced Education in Geospatial Sciences). Workforce development goals and programming planning and implementation strategies for two-year institutions are discussed in the report of a workshop sponsored by NSF and the National Council for Geographic Education (Allen, Brand, Beck, Johnson, & Johnson, 2006).

Two-year institutions are well-positioned to prepare students for entry-level positions that involve routine use of geospatial technologies. In terms of the geospatial technology roles identified by WLPI, two-year curricula leading to associates degrees or certificates ought to prepare students for duties including data acquisition, rudimentary data analysis and interpretation, training, and visualization. The institutional incentives and funding streams needed to substantially increase capacity in this sector are in place. However, associate and certificate programs are likely to lack the breadth and depth needed to prepare students for leadership roles in the geospatial industry. One- or two-year programs that emphasize development of technical competencies may necessarily neglect the analytical, interpersonal, and business competencies required for success in geospatial technology roles. While investments in the two-year sector may succeed in expanding the pool of qualified entry-level workers, they are unlikely to “rebuild the top of the pyramid” in the way that Marble and others argue is urgently needed. Innovative baccalaureate, graduate, and postbaccalaureate education and training are needed to answer that challenge.

Formal education at the undergraduate level—Four-year institutions: Very few higher education institutions offer baccalaureate degree programs focused specifically upon GIS, GIScience, or geospatial technologies *per se*. Berdusco (2003) identified about 425 higher education institutions worldwide (about 260 U.S.) that offer formal certificate, diploma, and degree programs in GIS and GIScience. Of the 28 U.S. universities listed as offering undergraduate degree programs in GIS, all but four in fact offer B.A. and B.S. degrees in geography (nineteen programs), Earth science, environmental science, natural resources, or forestry, with concentrations, specializations, tracks, or undergraduate certificates in GIS,

GIScience, cartography, and related topics. For the same reasons that the geospatial workforce is diffused among many industries in every employment sector, geospatial activities tend to be widely dispersed and poorly coordinated on four-year college campuses. Within academic programs, courses involving geospatial technologies are often positioned as intermediate or advanced technical specialties with prerequisites and class size limits that pose barriers to enrollment.

Four-year baccalaureate degree programs provide opportunities to teach and learn subjects at greater depth than in two-year programs. Graduates who excel in rigorous baccalaureate degree programs with specializations in geospatial technology should be well prepared for entry-level positions that involve routine use of geospatial technologies and to apply spatial analysis techniques to address reasonably sophisticated problems in a variety of fields. In addition, graduates of four-year programs should have at least begun to develop the business and interpersonal competencies required for advancement in government agencies and private businesses. In practice, however, too many students who were not exposed to geospatial technologies in primary and secondary schools discover it too late in their college careers to study it in much depth as undergraduates. Some talented undergraduates may master the technical and analytical skills required to develop customized software applications, but few are likely to have had the opportunity to master the array of competencies needed to excel in system design or project management. So long as the geospatial educational infrastructure remains weak at the K-12 level, and geospatial technology expertise remains diffused on college campuses, it is probably unrealistic to expect many undergraduates to progress to the upper levels of Marble's pyramid.

Formal education at the graduate level: Berdusco (2003) identifies 76 graduate degree programs in GIS or GIScience worldwide, 30 of which are U.S.-based. This is certainly an undercount, but it is the right order of magnitude. The University Consortium for Geographic Information Science (UCGIS) represents more than seventy U.S. higher education institutions that have demonstrated a "critical mass of resources to make a significant contribution to the mission of the UCGIS," which includes advancing multidisciplinary research and education in GIScience (UCGIS, 2005). Most of these institutions offer one or more M.A., M.Sc., and Ph.D. degree programs with emphases in GIS or GIScience. Not many more than ten institutions offer specialized professional master's degree programs (discussed in the following section).

Geographic information science is a research enterprise. GIScientists lead research and development efforts at GIS software firms, government agencies, and in universities. Academic GIScientists are also responsible for recruiting, training, and mentoring the next generation of researchers who will advance the capabilities of geospatial technologies in the future. Research-based, multidisciplinary graduate education in GIScience prepares students to master the technical, analytical, business, and interpersonal competencies needed to play leading roles in research and development, system analysis and design, and application development (Saalfeld, 1997). Graduate education can also promote adoption of spatial analysis and geographic modeling among the various disciplines that employ geospatial technologies.

Leading academic graduate programs with emphases in GIScience rely upon the sponsorship of government agencies and industry to provide the tuition and stipends needed to attract and retain the most promising young scholars. UCGIS's key objectives are to identify research priorities and to advocate increased and sustained support for multidisciplinary university research. This objective aligns with NSF's goal to recruit the next generation of scientists, engineers, and mathematicians that is needed to ensure U.S. industrial competitiveness through the twenty-first century. The success of programs including the Department of Geography at the University at Buffalo in attracting NSF IGERT (Integrative Graduate Education and Research Training) grants attests to the relevance and value of graduate education in GIScience. Increased support for programs like IGERT, and for sponsored university research in general, is needed to increase the capacity of research-based graduate education, which in turn is needed to "rebuild the top of the pyramid."

Formal education beyond the undergraduate and graduate levels: For many workers, formal education is no longer a prelude to a career; it is a lifelong endeavor. While their parents might have expected to work for one employer throughout their careers, a more realistic expectation for graduates entering the workforce today is a succession of careers with different employers. Workforce development experts refer to the phenomenon as "job churning." They estimate that "one-third of all [U.S.] jobs are in flux each year, meaning that they have recently been created or soon will be eliminated from the economy" (Kohl, 2000, p. 13). As the U.S. population as a whole has aged, so has its workforce. By 2006, the cohort aged 35 to 64 is expected to account for nearly two-thirds of all workers. The combination of demographic trends and job churning has led to an older clientele for higher education. Between 1970 and 2000, the proportion of college students aged eighteen to 21 years declined 24 percent, from 58.4 percent to 44.2 percent (U.S. Census Bureau, 2001). Today's "typical" graduate student "is female, in her thirties, married with dependents, and takes classes on a part-time basis while also holding a full-time job" (Kohl, 2000, p. 18).

Higher education has been criticized for its tentative responses to these changes. Kohl (2000), for example, argues that "universities' preoccupation with traditional college-age students, coupled with their typically fragmented organizational structure, often makes it difficult to focus attention on the learning demands of postbaccalaureate students" (p. 20). The same might be said of the GIS&T higher education community, which has devoted a perhaps inordinate share of attention to baccalaureate curricula. The higher education community is not oblivious to the post-graduate sector, however. Acknowledging the public's frustration with universities' perceived unresponsiveness to such changes, members of the Kellogg Commission on the Future of State and Land-Grant Universities (1999) has argued that "With a more diverse and older student population, we need a more diversified set of educational offerings. As people mature and move through successive careers, we need to be there to help them retool and retread, with special courses available at their convenience" (p. 8). The specialized academic certification programs discussed above represent one response to needs of lifelong learners in the geospatial arena. Another response is the development of distance education programs in GIS and GIScience

(Wright & DiBiase, 2005). Such programs are particularly well suited to adult learners who lack access to nighttime and weekend offerings at nearby campuses and who are highly motivated to earn credentials that will advance their careers.

- **Academic certificate programs:** Certification is the process by which organizations award credentials to individuals who demonstrate certain qualifications and/or competencies. Accredited educational institutions confer academic certificates; professional societies and businesses operate professional certification programs (these are considered later in this document). Wikle (1999) points out that academic certificate programs “differ from degree programs mostly in terms of their focus and duration. In contrast to degree programs that include general education courses, certificates are narrowly focused and require less time to complete” (p. 54). Academic certificates can be awarded as a stand-alone credential, as part of a baccalaureate degree, or as part as a graduate degree. When part of a degree program, the certificate emphasizes education and training distinct from the degree earned. For example, a degree conferred in biology earned with a GIS certificate would carry expertise in both biology and GIS.

Phoenix (personal communication, June 14, 2005) estimates that in 2005, close to 10,000 students worldwide were pursuing some sort of academic certificate of achievement that involves GIS. Certainly several thousands are pursuing such credentials in the U.S. One institution alone, the Pennsylvania State University, has conferred over 700 certificates of achievement in GIS since 1999, and now attracts new students at an annual rate of nearly 400. In 2000, Phoenix estimated that there were over 200 academic GIS certification programs in the U.S. At last count, ESRI’s online database of academic GIS programs (Environmental Systems Research Institute, 2005) listed 246 two-year and four-year institutions that claim to offer GIS certificates, of which 120 were located in the United States. Twenty-four U.S. institutions claimed to deliver certificate programs by distance learning.

- **Professional masters degrees:** Every year, some 400,000 U.S. students earn master’s degrees in hundreds of different specialties. Eighty-five percent of U.S. master’s degree programs “are what have come to be called practice-oriented, or professional, degrees” (LaPidus, 2000, p. 6). In comparison with academic degree programs, professional programs are more “specialized in terms of focus, applied in terms of content, ... and depersonalized in that they often seek to shape students according to a predefined template of professional competencies” (LaPidus, 2000, p. 6). Such programs are tailored to adult professionals and may employ practitioners as faculty. The best professional programs “transcend professional competency and foster professional leadership” (LaPidus, 2000, p. 6).

The GIS&T education infrastructure includes relatively few professional master’s degree programs. Kemp (2005) counts only 20 U.S. higher education institutions that offer master’s programs in GIS and GIScience. Three are distance learning programs. Worldwide, Phoenix (2004) estimates that only about 500 students are pursuing master’s degrees in GIS or GIScience.

Referring to both professional and academic programs, Phoenix (2000) has stressed that “the few graduate programs now in place cannot meet the needs of the marketplace” (p. 13). The shortage of advanced, practice-oriented master’s programs tailored to the needs of continuing adult professionals is one of the most serious weaknesses of the U.S. GIS&T education infrastructure. The *Body of Knowledge* should be a useful resource for institutions that are planning such programs.

- **Education and training by non-accredited institutions:** In terms of the numbers of learners served, GIS software companies may be the primary training providers in the GIS&T field. ESRI alone enrolls some 20,000 students annually in many offerings of over 40 instructor-led, classroom-based training courses at nearly 50 U.S. locations. Most courses span a few days. Intergraph also offers some 24 different short courses at its Huntsville, Alabama headquarters, at clients’ sites, and at six other Intergraph offices around the world.

ESRI attracts nearly 12,000 participants each year to its International Users Conference; training sessions and briefings about ESRI software product developments occupy most of the conference agenda. Intergraph’s annual GeoSpatial World conference includes “certificate programs” that consist of series of technical sessions and workshops on several different themes.

Both Intergraph and ESRI provide online instruction as well. Intergraph offers a ten-week, instructor-led “Introduction to GIS” course using WebBoard discussion forum software. Students enrolled in a M.Sc. program offered by member institutions of the UNIGIS International consortium can earn academic credit for the Intergraph course. ESRI’s “Virtual Campus” offers a variety of online education and training products, including self-paced, non-instructor-led course modules, digital video and audio recordings of software demonstrations and workshops, and instructor-led “virtual classrooms” in which students access ArcGIS software via a Citrix application server and interact with an ESRI instructor by telephone and Microsoft LiveMeeting collaboration software. Launched in 1997, the Virtual Campus is the best known online training source in the geospatial education infrastructure. By 2004 over 230,000 members in 189 countries had at least registered to view a free sample module or seminar (Johnson & Boyd, 2005). ESRI’s educational site licenses include no-cost access to many Virtual Campus modules by students and faculty. ESRI Press has become one of the leading publishers of GIS-related textbooks.

Postbaccalaureate and professional education is the most diverse and fastest-growing sector of the geospatial education infrastructure. Academic certificate programs abound. Professional master’s degree programs are relatively few, perhaps because the GIS&T enterprise has not yet consolidated as a distinct profession. Yet, since many of the few now in operation were established in the last five years, it seems reasonable to expect that more such programs will appear by the end of the decade. Commercial software companies serve many thousands of learners every year with a variety of product-oriented, non-credit offerings. Because postbaccalaureate students tend to be older, more motivated, and more experienced than their counterparts in undergraduate and graduate education, distance learn-

ing methods hold the promise of extending access to learners who are not free to participate in place-bound offerings. The capacity of accredited higher education institutions may be limited by cultural factors that value selectivity over capacity. Academic leadership—and perhaps financial incentives—will be needed to inspire faculty acceptance for innovative professional programs that involve practitioners as faculty. The capacity of commercial initiatives will continue to respond to demand and ability to pay; although software companies diligently seek to avoid competition with higher education institutions, such competition seems inevitable in the future. Efforts to increase the quantity and quality of outputs from the geospatial education infrastructure should include realizing synergies between the commercial and non-commercial components of the post-baccalaureate and professional sector. The following section outlines potential uses of the *Body of Knowledge* that will strengthen, and foster synergies among, these and other components of the education infrastructure.

Applications of the *GIS&T Body of Knowledge*

As explained above, the GIS&T education infrastructure includes a variety of actors including professional societies, commercial software and service providers, government agencies, and academic publishers, as well as accredited education institutions. A successful *GIS&T Body of Knowledge* will be useful to many of these actors, and will foster synergies among them. This section outlines several uses of the *Body of Knowledge* that have the potential to strengthen the education infrastructure.

Curriculum planning: As demand for new academic certificate and degree programs increases, program planners look for resources to guide curriculum choices. Successful curriculum planning involves a series of “critical events,” including identifying the needs of the profession, specifying job performance measures, and determining educational objectives, among others (Nadler and Nadler, 1998; see also Dacum.org, 2005). The *Body of Knowledge* specifies core and elective units made up of topics that are defined in terms of formal educational objectives. Educators charged with planning new GIS&T certificate or degree programs can use the *Body of Knowledge* to outline the minimum course content needed to ensure that students develop core competencies. They can design activities that cultivate knowledge and skills at targeted levels of competence, because most topics are defined as ranges of objectives (usually, from fundamental to advanced). They can readily convert objectives into assessment instruments that gauge students’ mastery. Most important, the granularity of units and topics in the *Body of Knowledge* is fine enough to be adaptable to the unique constraints and opportunities afforded by particular institutional settings.

Program accreditation: Accreditation is the process by which organizations attest to the qualifications and effectiveness of educational institutions and programs. Eight regional commissions accredit most of the approximately 4,000 degree-granting higher education institutions in the U.S. (Hamm, 1997; Cook, 2001). More than 60 commissions accredit a variety of professional degree programs, including computer science, engineering, landscape architecture, and planning. The traditional model of accreditation involves a periodic institutional self-study, followed by a site visit by a panel of reviewers, and finally an