Enhancing General Education with Geographic Information Science and Spatial Literacy

Ming-Hsiang Tsou and Ken Yanow

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

GENERAL EDUCATION: THE CONSCIENCE OF HIGHER EDUCATION

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

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

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

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

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

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

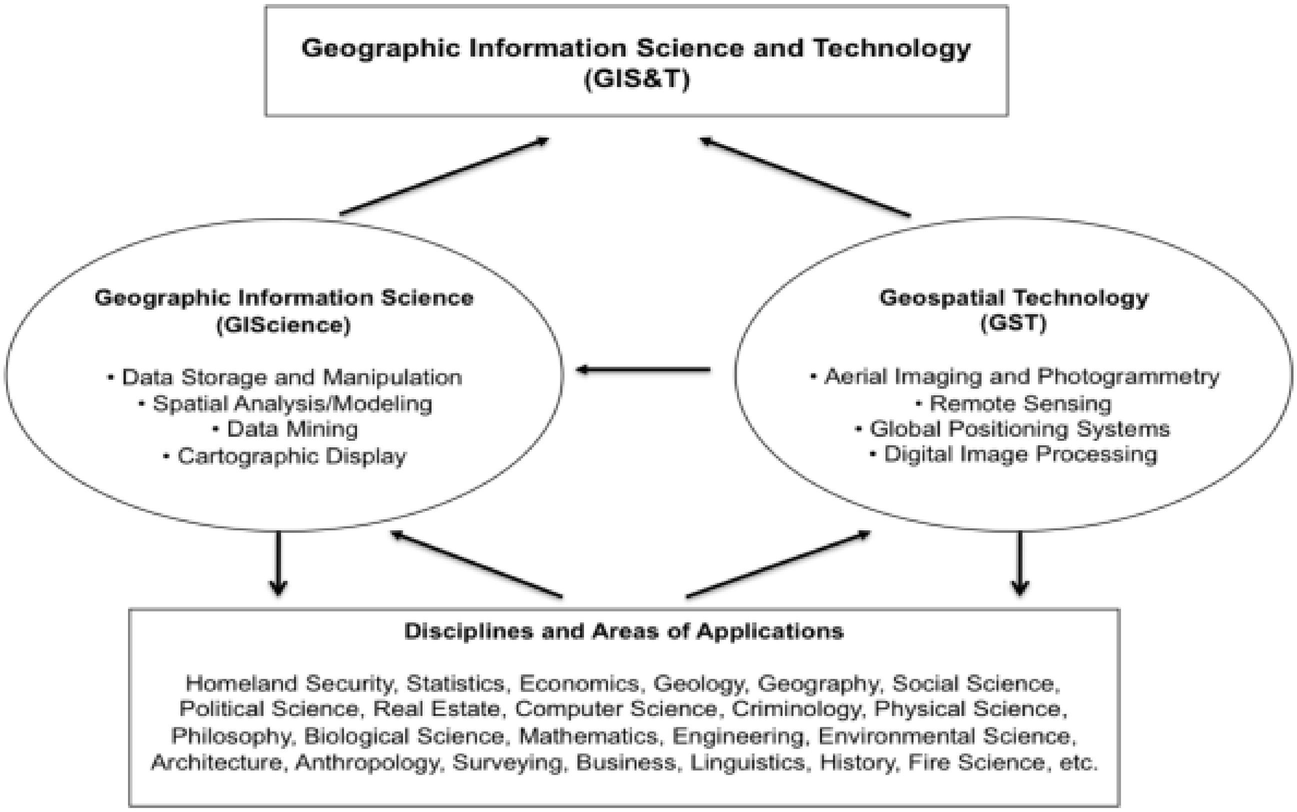

Figure 1. Geographic information science and technology

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

SPATIAL LITERACY AND GIS&T

Spatial literacy is

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

A BLUEPRINT OF GIS&T IN GENERAL EDUCATION

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

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

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

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

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

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

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

Three learning objectives of GE GIS&T are:

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

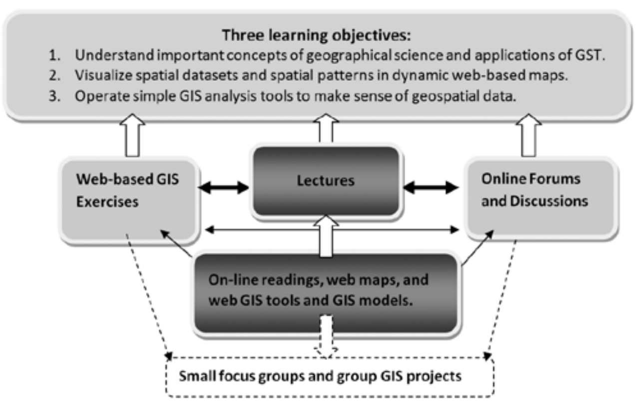

Figure 2. A conceptual education model of GIS&T in general education (adapted from DiBiase 1996)

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

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

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

Figure 3. Southwestern College GEOG 150 virtual remote desktop access

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

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

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

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

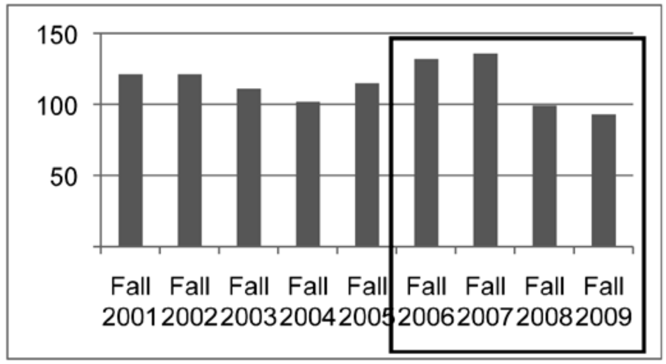

Figure 4. The geography major enrollment at San Diego State University (GEOG104 was implemented in 2006.)

Enrollment Trends

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

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

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

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

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

CONCLUSION

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

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

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

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About the Authors

Ming-Hsiang (Ming) Tsou is an associate professor in the Department of Geography, San Diego State University. He received a B.S. from National Taiwan University in 1991, an M.A. from the State University of New York at Buffalo in 1996, and a Ph.D. from the University of Colorado at Boulder in 2001, all in geography. His research interests are in Internet GIS and Web-mapping applications, wireless mobile GIS, GIS education, and geospatial cyberinfrastructure. He received the 2004 and 2010 Outstanding Faculty Awards at San Diego State University.

San Diego State University
5500 Campanile Drive
San Diego, CA 92182-4493
mtsou@mail.sdsu.edu
http://geography.sdsu.edu/People/Pages/tsou/index.html

Ken Yanow is a professor of geographical sciences at Southwestern College. He holds a B.A. in physics (UC Santa Barbara), an M.S. in astronomy (SDSU), and an M.A. in geography (SDSU). He is a Co-PI for the NSF-funded National GeoTech Center of Excellence. His research interests include recruitment and retention of underserved and underrepresented student populations into geospatial technology programs and courses, geospatial technology as general education, virtual desktop remote access, and using GIS&T to study solar energy distribution.

900 Otay Lakes Road
Chula Vista, CA 91910
kyanow@swccd.edu
http://www.swccd.edu/~gis

References

Alameh, N. S., M. J. Bambacus, J. D. Evans, and S. R. Marley. 2006. NASA's Earth Science Gateway: A platform for interoperable services in support of the GEOSS vision. Proceedings of IGARSS, July 28 to August 4, 2006, Denver, Colorado, 2477-80.

Batty, M., A. Hudson-Smith, R. Milton, and A. Crooks. 2010. Map mashups, Web 2.0 and the GIS revolution. Annals of GIS 16 (1): 1-13.

Bloomington faculty approve general education requirements. 2006. Http://newsinfo.iu.edu/news/page/normal/4154.html.

Bourke, B., N. J. Bray, C. C. Horton. 2009. Approaches to the core curriculum: An exploratory analysis of top liberal arts and doctoral-granting institutions. The Journal of General Education 58 (4): 219-40.

Brand, O., Ed. 2005. National Science Foundation (NSF) workshop: Integrating geospatial information systems and remote sensing for technical workforce training at two-year colleges. Http://www.ncge.org/publications.

Clark, J. V. 1999. Minorities in science and math. Educational Resources Information

Center, Office of Educational Research and Improvement, U.S. Department of Education. Http://www.ericse.org/digests/dsc99-02.html.

Danielson, T., Moderator. 2009. Opening panel remarks by Joseph Berry, principal, BASIS and Keck Scholar in the Geosciences, University of Denver, GeoWorld Editorial Board Industry Outlook, GeoTec 2009.

DiBiase, D. 1996. Rethinking laboratory education for an introductory course on geographic information. Cartographica 33 (4): 61-72.

DiBiase, D. 2010. Nature of geographic information: An open geospatial textbook. College of Earth and Mineral Sciences Open Educational Resources Initiative, The Pennsylvania State University. Http://natureofgeoinfo.org.

DiNoto, V. 2010. Virtualizing the GIS application desktop through remote connect technology. Http://www.geotechcenter.org.

Gaudet, C., H. Annulis, and J. Carr. 2003. Building the geospatial workforce. URISA Journal 15 (1): 21-30.

Geospatial Industry Workforce Information System. 2005. Defining and communicating geospatial industry workforce demand. August 15, 2007, http://www.aag.org/gwis/phaseone/phase-one-report-v3-5-31-06.pdf.

Goodchild, M. 2007. Citizens as sensors: The world of volunteered geography. GeoJournal 69: 211-21.

Goodchild, M., P. Fu, and P. Rich. 2007. Sharing geographic information: An assessment of the geospatial one-stop. Annals of the Association of American Geographers 97: 250-66.

Goodchild, M. 2006. The fourth R? Rethinking GIS education. ArcNews Fall 2006: 1-5.

Goodchild, M. 2010. Twenty years of progress: GIScience in 2010. Journal of Spatial Information Science 1 (2010): 3-20.

Goodchild, M. 1992. Geographical information science. International Journal of Geographical Information Systems 6 (1): 31-45.

Haklay, M. M., and P. Weber. 2008. OpenStreetMap: User-generated street maps. IEEE Pervasive Computing 7 (4): 12-18.

Hanink, D. M. 1997. Principles and applications of economic geography. New York: John Wiley & Sons, Inc.

Harper, Robert A. 1982. Geography in general education: The need to focus on the geography of the field. Journal of Geography 81 (4): 122-39.

Hart Research Associates. 2009. Trends and emerging practices in general education, based on a survey among members of the Association of American Colleges and Universities, conducted November 19, 2008, to February 16, 2009.

Howe, J. 2006. The rise of crowdsourcing. Wired Magazine 14 (6): 161-65.

Kemp, K. K., and M. F. Goodchild. 1991. Developing a curriculum in geographic information systems: The National Center for Geographic Information and Analysis core curriculum project. Journal of Geography in Higher Education 15 (2): 121-32.

Kennedy, G., Ed. 1952. Education for democracy: The debate over the report of the President's Commission on Higher Education. Boston: D. C. Heath.

Land of plenty—diversity as America's competitive edge in science, engineering, and technology. Summary of the Report on the Congressional Commission of the Advancement of Women and Minorities in Science, Engineering, and Technology Development, July 2000. Http://www.nsf.gov/od/cawmset.

Miller, G. 1988. The meaning of general education: The emergence of a curriculum paradigm. New York: Teachers College Press Publications.

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

National Research Council (NRC). 2010. Understanding the changing planet: Strategic directions for the geographical sciences. Washington, DC: The National Academies Press.

National Research Council (NRC). 2007. A research agenda for geographic information science at United States Geological Survey. Washington, DC: The National Academies Press.

National Research Council (NRC). 2006. Learning to think spatially: GIS as a support system in the K-12 curriculum. Washington, DC: The National Academies Press.

Velikonja, J. 1997. John C. Sherman, May 3, 1916—October 21, 1996. Http://faculty.washington.edu/krumme/faculty/sherman.html.

University Consortium for Geographic Information Science. 2006. Geographic information science and technology body of knowledge. Washington, DC: Association of American Geographers.

Wachter, S., L. Hirschorn, and H. Sokoloff. 2006. The geospatial industry: A perspective on technology diffusion. July 5, 2007, http://www.geospatialonline.com/geospatialsolutions/article/articleDetail.jsp?id=101550.