friendliness, and cost. Map librarians and libraries will have to analyze their needs to choose the system that best meets the local requirements. Additional work needs to be done to evaluate the capabilities of specific geographic information systems and their suitability for library settings. Alternatively, librarians should work with GIS vendors to help them develop systems that will meet the requirements of libraries or create interfaces that could be used in libraries on existing geographic information systems.

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What You'll Need To Know To Use GIS in 2001*

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A student who enters a college or university in 1998 will, in the normal course of events, graduate, and, one hopes, seek gainful employment in 2001. Many students who major in geography will specialize in geographic information systems (GIS) and related skills because of their interest in life after college. GIS is currently a fifteen billion dollar industry that barely noticed the recent recession and that gives every promise of continued rapid growth over the next decade.

Training to use geographic information systems varies greatly at the moment. Although most college and university geography programs offer GIS instruction, it is also provided in departments of agronomy, computer science, electrical engineering, forestry, geology, landscape architecture, planning, and surveying engineering, among others. Some progress toward standardization of GIS curricula has begun under the leadership of the National Center for Geographic Information and Analysis (NCGIA), but variations in GIS curricula will and should continue to exist. Geographic information systems are supple tools, and different applications will continue to demand different curricula.

I will, therefore, suggest what geography students should be taught beginning in 1998. There will doubtless be considerable commonality between what I will suggest and what a forester or a planner might propose. Less overlap would be evident between the curriculum a computer scientist would prefer and my specifications. Because 1998 and 2001 are a long way off in industry and technological terms, I will focus primarily on general classes of attributes rather than on specific skills.

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CURRENT CURRICULA

A recent, comprehensive survey of GIS instruction (Morgan and Fleury 1993) reveals that the typical GIS curriculum consists of but one GIS course that is offered at both the undergraduate and graduate levels. The course is generally offered only once a year and it does not have prerequisites. The modal course trains students to use GIS software, usually one of the commercially available packages designed for microcomputers. Student projects involve entering data via manual digitizing and translation from other data formats, and manipulating the data in various ways. Few colleges currently offer the three courses recommended in the NCGIA curriculum (Goodchild and Kemp 1990). A typical sequence of topics in the single course is: Introduction, Data Acquisition, Spatial Data Bases, Vector Views of GIS, Coordinate Systems and Geocoding, Raster Data Structures, and Applications.

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This curriculum and syllabus betoken a young specialty. As recently as five years ago, there was no journal devoted to GIS, nor was there a textbook. As the specialty continues to develop, we can expect a proliferation of courses and approaches, and eventually the development of a cumulative and sequential curriculum, in which introductory courses will be prerequisite to intermediate and advanced courses. We should also expect a gradual abandonment of instruction based on proprietary software packages in favor of technical training in the commonalities among individual software systems. We can also reasonably expect a migration of curricular focus up the hierarchy of tasks. Inordinate amounts of time and energy are now devoted to data capture and input, in GIS applications as well as in GIS instruction. In eight years time, one hopes to see more focus on manipulation of spatial data, analysis, display, and decision-making than is currently evident in GIS teaching and applications.

DESIDERATA

Let us assume those hopes will be realized, that in major outline, the evolution of geographic information systems will parallel that of the computers on which the technology is based. Let us assume, therefore, that by 2001 GIS users who wish to do so will be able to focus almost exclusively on the descriptive, analytical, and managerial tasks geographic information systems facilitate, rather than on the internal operations of GIS software. On that basis, I will spell out my desiderata for the baccalaureate graduate of 2001 who I would like to apply for a job using GIS if I had such a position to fill.

Too much effort is now devoted to training students to use GIS software; too little attention is given to its pitfalls and to the purposes to which it can legitimately and usefully be put.

Above all, I'd want more education and less training. Too much effort is now devoted to training students to use GIS software; too little attention is given to its pitfalls and to the purposes to which it can legitimately and usefully be put. That desideratum implies several specifics.

One is greater sensitivity to the shortcomings and misuses of GIS. GIS is a powerful tool for many purposes, but it is not panacea for all the world's ills, and it can be the basis for frightful errors. A half billion dollar GIS did not prevent a United States warship from shooting down a civilian airline over the Persian Gulf some years ago, and disasters of similar magnitude await those who rely uncritically upon analysis based on careless or inappropriate uses of GIS.

Another specific is more education in the principles of sound map design and less making of maps simply because we now have software and hardware that can generate them cheaply and quickly. One good map is worth dozens of mediocre maps and hundreds of poor maps. One really bad map is much worse than no maps at all.

What I'm suggesting is that however widespread it becomes, GIS is no substitute for the substance of the specialties that employ it. On the

contrary, because it is a powerful tool, GIS must be used with increasing caution. The geography students of the next millennium will need more and better education in the fundamentals of geography, not less.

That geography will be somewhat different from today's discipline. It will stress synthesis as much as analysis, and GIS will be quite helpful in that respect. Much attention has focused heretofore on the analytical capacities of geographic information systems. I am equally or more excited about their capacities for integrating diverse kinds of information in ways that are difficult or impossible with paper maps. Therefore I hope that current requirements that students take a course in analytic techniques will soon be matched by a required course in synthetic techniques.

Geographers now focus primarily on mapping existing phenomena. As geographic information software evolves and becomes more adroit at incorporating change and time, emphasis will shift toward simulation of future states of places and regions. Geographers will, accordingly, need to hone their forecasting skills. I don't know if geographers will ever forecast changes is land use the way meteorologists now forecast the weather, but I think the trend will be in that direction.

Geographic research is still largely a solitary enterprise. Cooperative effort between two scholars is infrequent, and among more than two rare. Geography and GIS research is–with few exceptions–a refugee from the industrial revolution that has occurred in research in the medical and natural sciences. Large research projects that achieve economies of scale based on division of labor are the wave of the future, and colleges preparing students to work in the next millennium will shortchange their charges if they do not teach them how to work as members of research and management teams.

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New concepts and skills will be required that are not common elements of current GIS instruction. If I were tsar of the national GIS curriculum I would mandate at least one course in ethics. One course will not enable anyone to resolve the ethical dilemmas GIS practitioners and theoreticians will face in the future, but it would sensitize them to the issues with which they will grapple, and it would help them avoid some of the most egregious snares they will encounter.

I would also mandate formal instruction in decision science or some similar specialty that examines how and why people decide among alternatives. I would insist that a component of such instruction be attempts to understand how people perceive risks and how they make decisions among alternatives carrying known and unknown risks. Many applications of GIS will involve risk assessment and decision making under conditions of considerable uncertainty.

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More generally, I would require a broad exposure to another GIS, geographic information science. Too many geographic information system experts are still at the Alexander Graham Bell stage of thinking. Bell never conceived of his contraption as the basis for a network; he thought largely or only of pairwise connections. Similarly, most current specialists think of geographic information systems as stand alone entities, when it is becoming increasingly obvious that GISs are much more powerful when they are interconnected than they can ever be in isolation.

Internet, and the vision of telescience that underlay its establishment, will create a new world in which new wayfinding skills will be needed. Neophyte geographers were once tutored in the use of tools such as compasses, sextants, and transits so they could navigate the worlds they hoped to explore. In the future, they will have to navigate global information networks using tools such as Gopher, WAIS, World-Wide Web, Archie, Veronica, and Jughead (Pool 1993). Without the command of such

tools, they will be lost in the vast seas of data they will encounter in the future.

Finally, I would demand explicit and detailed exposure to questions of research design. The definition of data and the relationships between data and theory, of which too many GIS specialists are wholly innocent, would be a good starting point, but my course(s) would embrace simulation as a research technique, and strategies for community research. I'd try to devise GIS versions of the *collaboratories* William Wulf (1993) has proposed, dispersed but virtual facilities devoted to the telecartography and telegeography that will be vital parts of the geography of the future.

ENVOI

How successful GIS specialists will be in restructuring curricula to incorporate the desiderata I have here identified remains to be seen. I know from discussions with numerous GIS specialists and industry leaders that they are sensitive to the needs I have identified. But formalizing such needs, and more to the point, shepherding them through the curriculum committees and the other pettifoggery that infest United States University campuses within the next four years, will be difficult. I do not know if those preparing GIS specialists will be able to meet the goals I have specified this afternoon. I do know that they will shirk their obligations to their students if they do not.

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