INT. J. GEOGRAPHICAL INFORMATION SYSTEMS, 1992, VOL. 6, NO. 4, 309–320

NCGIA education activities: the core curriculum and beyond

MICHAEL F. GOODCHILD and KAREN K. KEMP

National Center for Geographic Information and Analysis (NCGIA),
University of California, Santa Barbara, CA 93106, U.S.A.

Abstract. Education has been part of the NCGIA's mission from the earliest discussions of the concept of the Center at the National Science Foundation. To respond to the need for short-term solutions to the shortage of adequately trained personnel in GIS, the Center developed a set of teaching materials or core curriculum. The steps in its development are described and an analysis of initial distribution statistics is presented. Current efforts to develop a framework for laboratory materials are outlined. The paper ends with an assessment of the project and comparison with other disciplines.

1. Introduction

In a much cited paper on automated geography published in 1983, Dobson (1983) argued that hardware and software had already made it possible to analyse detailed geographical patterns over large areas and to do so on affordable and powerful personal computing platforms. Of course, developments over the past decade have strengthened his arguments dramatically, as desktop processing power has improved by roughly two orders of magnitude with little increase in cost, and as software capabilities have advanced by leaps and bounds.

Dobson (1983) argued that by the 1990s 'developments in hardware and software should converge to provide analytical overkill for most geographical applications... but who would be doing this work?... Our success will depend largely on the extent to which college departments adapt to automation in the remaining years of this decade... to training new students and retraining themselves and other graduates in the techniques of automated geography'.

This fear that the technical capabilities of GIS and related technologies would be wasted because of a lack of people trained to make effective use of them recurs frequently in the literature of the 1980s. Morrison (1983) wrote in a commentary on Dobson's article: 'I do not see academic geography at this time... in a firm position to take positive steps to respond to Dobson's challenge... It is true that public school children of today are ready to engage in automated geography but that presents academic geography with perhaps our greatest challenge. Can the current geography faculties (ill trained in computers) avoid stifling that receptivity in our children? Who will be their teachers? Who will retrain our college faculty?'

Although one might argue that the discipline of geography presents a uniquely difficult case, it is certainly true that academe is slow to respond to new technologies. University budgets are often inadequate to pay for new equipment, faculties are often deeply conservative, and curricula are often difficult to change. So it is not surprising that concern for education and training surfaced frequently in early discussions about the possible functions of a National Center for Geographic Information and Analysis (NCGIA). The need for properly trained scientists, engineers, scholars and practitioners was stressed both as an issue specific to geographical information systems (GIS)

0269–3798/92 $3·00

and as a general concern of any centre supported by the National Science Foundation (NSF, the major sponsor of NCGIA) (Abler 1986, unpublished work). Dangermond is quoted as arguing that 'The shortage of trained people is the most immediate and pressing need NCGIA should address (Abler 1986, unpublished work). When the final solicitation document was issued in 1987 (NSF 1987), one of the four goals of NCGIA was 'to augment the nation's supply of experts in GIS and geographic analysis in participating disciplines'.

How can a comparatively tiny organization such as NCGIA (base funding from NSF amounts to $1·1 million per year) have a significant impact on education and training in GIS? Courses offered at NCGIA sites or by NCGIA staff might be effective at disseminating information on specific topics, including research results, but would have minimal impact on the field as a whole in the short term. On the other hand teaching materials could be distributed rapidly and, if effective, might succeed in influencing the quality and availability of GIS courses on a broad scale, and in many disciplines. In fact a 1986 prospectus for NCGIA had listed 'Instructional materials for classroom use' as one of the series of possible NCGIA products and services. Moreover, there seemed to be some acceptance of the notion that, because of its novelty, GIS was hampered by a lack of good textbooks and accessible literature: instructional materials might provide a bandaid solution until a more mature literature could develop.

2. NCGIA core curriculum

In its proposal submitted to NSF in early 1988, the Santa Barbara–Buffalo–Maine consortium (University of California, Santa Barbara; State University of New York at Buffalo; University of Maine) described the development and dissemination of a one-year course sequence in basic concepts and applications as its primary effort in meeting the Center's goals in education. The distributed materials would include lecture outlines and notes, graphics, exercises and assignments, reading lists, catalogues of hardware and software, instructional data sets and recommendations on software. The materials would be designed and distributed for maximum short-term impact on GIS courses in higher education.

Discussions of curricula in higher education are usually approached on the assumption that the instructor is paramount in the classroom. Moreover, GIS is fundamentally multidisciplinary, spanning many academic subcultures, each with their own classroom styles. In short, it would be foolish to try to prescribe either the content or the structure of GIS courses. The term 'core' was adopted rather than 'model' for precisely this reason, and the curriculum materials were designed to allow the instructor maximum flexibility, while providing the pieces from which he or she could quickly put together an effective programme on the fundamentals of GIS, adapted to the unique circumstances of every institution.

The development and testing of the NCGIA core curriculum has been described in detail in two papers (Kemp and Goodchild 1991, 1992). In autumn 1988 a detailed outline for a three-course sequence of 75 one-hour units was developed and distributed for comment, and presented at several conferences. The three courses, of 25 units each, were titled 'Introduction to GIS', 'Technical issues in GIS' and 'Application issues in GIS', on the assumption that the first would provide the foundation, whereas the second and third would accommodate different specialized interests. However, it is possible to imagine an almost infinite number of possible arrangements using different sequences and subsets of the materials. Each unit was designed to be as free-standing as

Table 1. The 75 units of the NCGIA core curriculum (revised version).

Introduction to GIS

- A. Introduction
    - 1. What is GIS?
    - 2. Maps and map analysis
    - 3. Introduction to computers
- B. A first view of GIS
    - 4. Raster GIS
    - 5. Raster GIS capabilities
- C. Data acquisition
    - 6. Sampling the world
    - 7. Data input
    - 8. Socio-economic data
    - 9. Environmental data
- D. Spatial databases
    - 10. Models of reality
    - 11. Spatial objects and database models
    - 12. Relationships among spatial objects
- E. Vector view of GIS
    - 13. Vector GIS
    - 14. Vector GIS capabilities
- F. Using the GIS
    - 15. Spatial analysis
    - 16. Output
    - 17. Graphic output design issues
    - 18. Modes of user/GIS interaction
    - 19. Generating complex products
    - 20. GIS for archives
- G. Past, present and future
    - 21. Raster/vector debate
    - 22. Object/layer debate
    - 23. History of GIS
    - 24. GIS marketplace
    - 25. Trends in GIS

Technical issues in GIS

- H. Coordinate systems and geocoding
    - 26. Common coordinate systems
    - 27. Map projections
    - 28. Affine and curvilinear transformations
    - 29. Discrete georeferencing
- I. Vector data structures and algorithms
    - 30. Storage of complex spatial objects
    - 31. Storage of lines: chain code
    - 32. Simple algorithms I—line intersection
    - 33. Simple algorithms II—polygons
    - 34. Polygon overlay operation
- J. Raster data structures and algorithms
    - 35. Raster storage
    - 36. Hierarchical data structures
    - 37. Quadtree algorithms and spatial indexes
- K. Data structures and algorithms for surfaces, volumes and time
    - 38. Digital elevation models
    - 39. TIN data model
    - 40. Spatial interpolation I
    - 41. Spatial interpolation II
    - 42. Temporal and 3D databases

Table 1. *continued:*

- L. Databases for GIS
  - 43. Database concepts I
  - 44. Database concepts II
- M. Error modelling and data uncertainty
  - 45. Accuracy of spatial databases
  - 46. Managing error
  - 47. Fractals
  - 48. Line generalization
- N. Visualization of spatial data
  - 50. Colour theory

Application issues in GIS

- O. GIS application areas
  - 51. GIS application areas
  - 52. Resource management applications
  - 53. Urban planning and management
  - 54. Cadastral records and LIS
  - 55. Facilities management
  - 56. Demographic and network applications
- P. Decision-making in a GIS context
  - 57. Multiple criteria methods
  - 58. Location-allocation on networks
  - 59. Spatial decision support systems
- Q. System planning
  - 60. System planning overview
  - 61. Functional requirements analysis
  - 62. System evaluation
  - 63. Benchmarking
  - 64. Pilot project
  - 65. Costs and benefits
- R. System implementation
  - 66. Database creation
  - 67. Implementation issues
  - 68. Implementation strategies for large organizations
- S. Other issues
  - 69. GIS standards
  - 70. Legal issues
  - 71. Development of a national GIS policy
  - 72. GIS and global science
  - 73. GIS and spatial cognition
  - 74. Knowledge based techniques
  - 75. The future of GIS

possible, and the units are arranged in a three-level hierarchy for easier adaptability: within each course, units are grouped into lettered modules (table 1).

GIS technology has been criticized for being a technology in search of applications, for the naivety of some of its analyses and assumptions, for the inaccuracies of its databases, and for the frequent failure of its practitioners to understand the limitations of its results. For these reasons, the topics in the core curriculum were chosen not only to introduce students to the technology, but more importantly to stress the issues surrounding its use, and the concepts underlying its applications. Considerable emphasis is placed on the relationships between database contents and the real geographical variation being represented.

Early in 1989, invitations were issued to about 50 GIS professionals to contribute initial drafts of the instruction units. The responses were edited during the spring and summer of 1989, and draft versions of the courses were distributed beginning in late July. Earlier, the Center had begun soliciting instructors and departments willing to act as test sites for the draft version, and to provide comments and feedback. By July 75 test sites had been identified, and the total number of copies of the draft version distributed eventually rose to over 100. Those at each test site agreed to teach sections or all of the three-course sequence, and to return questionnaires from the instructor and students at various stages. The test programme and its results have been described in detail by Kemp and Goodchild (1992).

By the end of the test programme in spring 1990 a large number of useful comments and criticisms had been received. These were analysed and incorporated into a complete revision of the materials. The first and third courses (units 1–25 and 51–75) were extensively reorganized, and all units received corrections, additions and rewording of difficult sections. The revised core curriculum was released in late July 1990, with the outline shown in table 1.

3. Distribution

3.1. *Demand*

Advertising the final version of the curriculum began in earnest in the early part of 1990. Advertisement was mainly by word of mouth and presentations by the editors at conferences and meetings, although a number of newsletters and association bulletins included short notices about the curriculum. By the end of 1991 over 750 copies had been distributed by NCGIA. A review of the distribution statistics reveals few surprising details and confirms much that we anticipated about the demand for these materials.

Tables 2–5 summarize some of the characteristics of the organizations that have purchased the curriculum. Of the first 736 copies distibuted, only 58% have gone to educational institutions, a group which includes universities, polytechnics and colleges. We have been surprised at this rather lower than expected proportion. Table 2 shows that commercial organizations, including GIS vendors and consultants, have obtained 16 per cent. Conversations with individuals in these organizations indicate that the curriculum addresses their needs to be knowledgeable in the GIS field and to be aware of the important elements being included in formal GIS education. Many commercial trainers are incorporating part of the materials into their own training programmes. It is interesting to note that a quarterly breakdown of the orders shows a steady decrease in the proportion of sales to educational institutions, while sales to other sectors have remained relatively constant.

Table 2. Distribution of the core curriculum to December 1991 by type of organization.

Type of organization	Number	Per cent
Educational institutions	428	58
Commercial organizations	119	16
Government agencies	94	13
Other[a]	95	13
Total	736	

[a] 'Other' included individuals, libraries, research institutes, bookstores and publishers.

In addition to the commercial organizations, many government agencies (federal, state, county and local) have also decided to obtain the curriculum. A remaining 13 per cent have been distributed to private individuals, libraries, bookstores, publishers and others.

3.2. *National differences*

Table 3 provides some insight into possible national differences in how the curriculum is being received around the world. There are currently 49 countries on our distribution list. North American purchases account for 60 per cent of all orders, with European organizations making up 23 per cent. A breakdown by country shows that apart from the United States (U.S.) and Canada, the United Kingdom (U.K.), The Netherlands, Germany and Australia are the largest national groups represented. It is interesting to note that European purchasers are largely educational institutions, with

Table 3. Distribution of the core curriculum to December 1991 by continent and by country.

Continent/country	Education	Commercial	Government	Other	Total	Per cent
North America	237	97	66	45	445	60
Europe	118	15	4	35	172	23
Asia	26	5	10	6	47	6
Oceania	30	1	9	2	42	6
Africa	14	1	5	2	22	3
South America	3	0	0	5	8	1
Total	428	119	94	95	736	
Per cent	58	16	13	13		
U.S.A.	197	86	49	43	375	51
Canada	39	11	17	2	69	9
U.K.	48	2	1	3	54	7
Australia	22	1	8	1	32	4
The Netherlands	18	3	0	5	26	4
Germany	11	2	0	8	21	3
Spain	5	4	1	4	14	2
South Africa	8	1	3	0	12	2
New Zealand	8	0	1	1	10	1
India	2	0	7	1	10	1
France	2	0	0	6	8	1
Malaysia	4	2	1	0	7	1
Switzerland	6	0	0	1	7	1
Hong Kong	6	0	0	1	7	1
Austria	6	0	0	1	7	1
Japan	3	2	0	1	6	1
Finland	4	0	1	0	5	1
Ireland	4	0	0	0	4	1
Italy	2	0	0	2	4	1
Korea	3	0	0	1	4	1
Greece	2	0	1	1	4	1
Belgium	1	2	0	1	4	1

Countries receiving 1, 2 or 3 copies are: Argentina, Belgium, Botswana, Brazil, Chile, China, Colombia, Czechoslovakia, Denmark, Egypt, Hungary, Indonesia, Israel, Kenya, Mauritius, Morocco, Mozambique, Nepal, Norway, Philippines, Portugal, Qatar, Singapore, Sweden, Taiwan, Thailand, Trinidad and Yugoslavia.

Table 4. Distribution of the core curriculum to December 1991 to educational institutions by discipline or department.

Department	Number	Per cent
Geography	154	36
Geodesy	46	11
Engineering	33	8
Planning	25	6
Environmental science	24	6
Surveying	22	5
Geology	15	4
Forestry	14	3
Natural resources	14	3
Library	13	3
Remote sensing	9	2
Urban studies	9	2
Computer science	8	2
Cartography	8	2
Anthropology	8	2
Earth science	7	2
Landscape architecture	5	1
Social science	4	1
Geoscience	4	1
Photogrammetry	3	1
Biology	3	1
Total	428	

Notes: (1) lists only the major discipline groups, (2) multidisciplinary departments are counted once for each affiliation (i.e. Department of Geography and Geology is counted as both a geography and a geology department).

Table 5. Distribution of the core curriculum to December 1991 by type of government agency.

Government agency	Number	Per cent
Federal resource agency	26	28
GIS or land information centre	17	18
Other resource management	13	14
Public utilities and transportation	12	13
Planning	12	13
Remote sensing	5	5
Land survey and mapping	5	5
Census bureaux	4	4
Total government agencies	94	

Note: does not include copies distributed to the National Science Foundation.

few government agencies. This may be explained by the fact that until late 1991 the curriculum was available only in English. However, the same trend for few governmental purchasers is also evident in numbers in the U.K. On the other hand, compared with proportions in the U.S. and Europe, Australia and Canada have proportionately larger numbers of government copies. Given the similar language and cultural backgrounds of Canada, Australia and the U.K., this difference is likely to reflect the different roles played by government agencies in the three countries.

There is no apparent difference in the dates of purchase between the continents or major national groups. This reflects the strongly international character of the GIS business: this is not an innovation creeping slowly across the globe. With the possible surprising exception of the Japanese, who were comparatively late in obtaining a first copy, all major world economic players were included early in the distribition.

3.3. *Educational institutions*

There has been considerable discussion regarding the need for GIS to be taught widely within the edcuational system. Our distribution list tends to confirm this sentiment with only 36 per cent of the educational institutions indicating a departmental affiliation to geography. Table 4 shows the types of departments included in the distribution list. Although it is difficult to categorize simply by the names that have been assigned to them, especially when this is done on an international basis, it does appear that the areas of engineering, surveying, planning, earth and environmental science and forestry are also important disciplinary homes for GIS education.

3.4. *Government agencies*

Table 5 lists categories of government departments included in our distribution list. GIS centres represent 18 per cent of the 94 agencies which have purchased the curriculum. As GIS centres often have an educational role, their interest is easily recognized. Resource management agencies also feature strongly, with 39 copies sent to forestry and other natural resource management agencies at different levels of government. Public utility and planning agencies are also strongly represented.

3.5. *Conclusions and suggestions*

A number of new directions for the NCGIA are suggested by this analysis of the distribution of the core curriculum. As GIS technology is already an international activity, it is important to ensure that GIS education is equally available in all parts of the world. The NCGIA has begun a number of initiatives aimed at encouraging the international exchange of ideas about GIS education. Translation of the curriculum is being encouraged and promoted. We have devised a programme to assist universities in Eastern Europe and the less developed countries to obtain and distribute copies. In addition, as the curriculum is now so widely distributed, we have recognized the need to identify the North American bias in the materials and to encourage the development of adaptations and alternatives for use in other countries and situations.

4. Laboratory exercises

The original concept of the curriculum materials described in the 1988 proposal included laboratory exercises and software evaluations. It quickly became apparent that a centre that depends for its major support on a federal sponsor cannot publish or distribute critical evaluations of private sector products, or make recommendations. The test version of the curriculum included laboratory exercises based on two specific GIS products, but they caused numerous problems at the test sites and were felt by many instructors to be of marginal value. It became clear that the effective design of laboratory exercises raises a host of difficult issues, and so this component was dropped from the revised version of the curriculum until a more comprehensive approach could be developed.

In courses in statistics, it is often argued that the use of software detracts from the aims of the course by encouraging students to think only of inputs and outputs, and not of the logic of data manipulation. Processing data by hand, however tedious, is considered to be more educational than typing instructions to a statistical package. If we were to use the same argument in GIS, it would imply that GIS courses should emphasize the manual processing of geographical data—overlay, for example, should be done at least once by hand so that the student can appreciate what is happening.

On the other hand, the power of digital handling of geographical data underlies many of the arguments for GIS, and needs to be appreciated by the student. GIS technology is a graphic technology with strong visual impact, much of which would be lost without hands-on practical exposure. Students need to appreciate the limitations of software packages as well as their strengths, and to experience the problems that arise when geography is represented in discrete, digital form. As the objective of the curriculum is to provide a basis for teaching the conceptual aspects of GIS, it should be supported by laboratory exercises that show important concepts, rather than simply provide skills training in the use of one or more specific GIS packages. Paradoxically, it may be difficult to provide this kind of insight given the limitations of many current products and the poor level of sophistication of their user interfaces; and moreover, an emphasis on concepts over skills may misread the current needs of the marketplace for GIS human resources.

With this background, the Center's major education project for 1990–1 was the development of an extensive set of laboratory exercises to support the curriculum. The approach taken was very broad, providing a range of support from general guidance on what topics might be appropriate, through the identification of sources of laboratory materials, to examples of specific laboratory exercises, including some developed and tested at the Center. The design consists of four levels of detail. The top level describes four major themes which conceptually-oriented laboratory exercises might address:

- The database as a representation of reality: issues that define and limit the GIS user's view of the world, including: scale, resolution and accuracy; layers, objects and alternative data models; and spatial relationships
- GIS as a management tool: exercises demonstrating the value of GIS in planning, managing or maintaining spatially-distributed facilities, including apportionment, vehicle routing, locating facilities, suitability analysis and spatial decision support
- GIS investigates the world: demonstrations of the use of GIS in scientific investigation, in those areas of science and social science dealing with spatial data; modelling environmental and socioeconomic processes, and exploring cause/effect relationships
- Implementation and design: laboratory exercises in various aspects of GIS design: map projections and coordinate systems, data structures, algorithms, system evaluation, and design of user interfaces

At the second level, each of the themes is defined more precisely as a set of topics suitable for individual exercises. The third level defines generic exercises, with suggestions as to the kinds of data sets and related activities that could be used to demonstrate aspects of each topic. The final level provides databases and detailed exercises that can be used directly in the classroom. At this level only, materials focus on specific GIS packages. Individual exercises might be linked with several lecture topics in the curriculum, and one lecture topic might be supported by several laboratories.

A comprehensive approach to laboratory exercises is clearly a long-term project and far beyond the resources of any one group. The Center has developed this design as a framework and basis for discussion, and welcomes comments and criticisms. One vendor has already released a set of exercises and tutorials linked to the curriculum, and another has developed a full set of laboratories supporting the outline. In the summer of 1991 the Center released a preliminary version of *The NCGIA Guide to Laboratory Materials* (Dodson *et al.* 1991) which addresses the third level (generic exercises) in the form of an annotated catalogue of student exercises, data sets and miscellaneous resources. At the fourth level, two reports contain detailed exercises designed to support the lecture materials in volumes 1 and 2 of the core curriculum (Dodson 1991, Veregin 1991).

5. Evaluation and discussion

The test version of the curriculum provided a wealth of evaluative material that has already been described (Kemp and Goodchild 1992). More general comments on the project have been published, most likely based on the test version rather than on the revision. Heywood (1990) has described the project as 'arguably the most comprehensive curriculum project undertaken in higher education to date'.

The most common criticism of the curriculum is perhaps typified by the comments of Morgan (1990): 'I disagree with the NCGIA's three course approach. Not all academic departments have the faculty and staff, hardware and software resources, and undergraduate and graduate student population to support three courses... NCGIA's core curriculum should be viewed more as a smorgasbord of information...for instructors of GIS courses, rather than as three distinct courses.' Many other users have also approached the materials as a prescription for courses (i.e. a model curriculum), rather than as the collection of adaptable materials or smorgasbord that we originally intended.

Useful comparisons can be made with approaches taken to curriculum development in related disciplines. Like GIS, statistics is often taught on a multidisciplinary basis as a set of analytical tools with applications across a wide range of fields. Unlike GIS, statistics is also identified as a distinct department in many universities, with a strong relationship between the technology of computerized statistical analysis and the parent discipline. Several decades elapsed between the development of many statistical methods and their introduction into the curricula of analytically based disciplines, and there appears never to have been a major effort to develop materials for a core curriculum. Reference has already been made to arguments about the value of computer based laboratory exercises in statistics.

Marble (personal communication 1989) has argued strongly that efforts in computer science be used as a model for curriculum development in GIS. A widely based committee representing the computer science community developed the curricula (ACM 1983) after considerable open and public debate. However, this was a multi-year effort in a single discipline, sponsored by a single professional society able to represent the entire U.S. computer science community. By comparison the GIS community is a poorly defined, loose consortium of interests, so that any comparable effort in GIS seems many years away.

Another potentially useful comparison is with remote sensing. Fifteen years ago, Everett and Simonett (1976) were writing about remote sensing in ways that strongly anticipate the concerns currently being expressed about GIS: 'Remote sensing is not simply a modest extension of conventional aerial photography. Rather, it represents a revolution in the way we think about and approach resource inventory analysis and management problems... Remote sensing is so young that it is still difficult to identify basic primitives or principles representing fundamental, primary, or general truths. Most of the so-called principles are, in reality, concepts—thoughts, ideas, or generalizations which have not yet been subjected to close analysis.' They go on to identify key issues surrounding the use of remote sensing technology, such as data accuracy and uncertainty, scale and resolution. LANDSAT imagery, then becoming widely available, was seen as a major boost to education in remote sensing as a source of teaching materials and 'a focus for integrated, multidiscipline teaching and research'. By comparison, GIS education is faced with a wide diversity of software and approaches, and no unifying source of data.

6. Conclusions

In a recent paper on the NSF Science and Technology Centers (STC) programme, Palca (1991) noted that 'Although they are philosophically committed to education and outreach, some of the centers seem to be groping their way in this area with no clear sense of direction. Graduate education efforts are more focused, but these are closest to what already exists'. NCGIA is not part of the STC programme, but it is similarly committed to education in addition to its main mandate in basic research. Unlike most of the centres in the STC programme, NCGIA is concerned with research into the applications of a largely existent technology, more than with development of the technology itself, and interacts with a large and growing industrial sector. In that sense its education efforts could be seen as even more important to the basic mission of the Center.

On the basis of its widespread distribution and international recognition it seems that the core curriculum project has had a significant effect on the GIS community. Projects such as this are one clear benefit of centres, as compared with conventional project based science funding. A centre is able to act quickly, and to use its resources to interact with the wider community much more effectively. In the long term, we hope that GIS will be able to move towards the computer science model, by developing a model sequence of courses under the auspices of a strong central organization. We hope that the core curriculum has helped make that goal more attainable.

We feel that we have met successfully our original objectives of encouraging the development of quality GIS programmes in universities in the U.S.A and worldwide. It is apparent to us that university GIS education is now thriving and maturing quickly, obviating any need to consider a revision for the curriculum in its current form. However, there will always be a need for a continued discussion of the many important issues related to GIS education and a sharing of ideas and concerns.

Acknowledgments

The National Center for Geographic Information and Analysis is supported by the National Science Foundation, Grant SES 88-10917. Additional support for the core curriculum project was provided by the Office of Instructional Development, University of California, Santa Barbara.

References

Association for Computing Machenery (ACM), 1983, *ACM Curricula Recommendations for Computer Science*, 2 volumes (Washington DC: The Association).

Dobson, J. E., 1983, Automated geography. *Professional Geographer*, **35**, 135–143.

Dodson, R. F., 1991, NCGIA GIS laboratory exercises: Vol. 1, Technical Paper 91–12, National Center for Geographic Information and Analysis, Santa Barbara, CA.

DODSON, R. E., KEMP, K. K., and PALLADINO, S. D., 1991, The NCGIA guide to GIS laboratory materials—1991. Technical Paper 91–20, National Center for Geographic Information and Analysis, Santa Barbara, CA.

EVERETT, J.. and SIMONETT, D. S., 1976, Principles, concepts and philosophical problems in remote sensing. In: J. Lintz Jr, and D. S. Simonett (eds), *Remote Sensing of Environment* (Reading, MA: Addison-Wesley).

HEYWOOD, I., 1990, Geographic information systems in the social sciences. *Environment and Planning A*, **22,** 849–852.

KEMP, K. K., and GOODCHILD, F. M., 1991, Developing a curriculum in GIS: the NCGIA core curriculum project. *Journal of Geography in Higher Education*, **15,** 121–132.

KEMP, K. K., and GOODCHILD, F. M., 1992, Evaluation of the NCGIA core curriculum. *Journal of Geography in Higher Education*, **16,** in press.

MORGAN, J. M. III, 1990, Education and training: meeting the rising demand for GIS personnel. *Geo Info Systems*, **Nov/Dec.**, 22.

MORRISON, J. L., 1983, Automated geography: challenges to academic geography. *Professional Geographer*, **35,** 348.

NATIONAL SCIENCE FOUNDATION (NSF), 1987, *Solicitation: National Center for Geographic Information and Analysis* (Washington, DC: National Science Foundation).

PALCA, J., 1991, NSF centers rise above the storm. *Science*, **251,** 19–22.

VEREGIN, H., 1991, GIS laboratory exercises: Vol. 2, technical issues. Technical Paper 91–14, National Center for Geographic Information and Analysis, Santa Barbara, CA.