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DEVELOPING A CURRICULUM IN GIS: THE NCGIA CORE CURRICULUM PROJECT

Karen K. Kemp and Michael F. Goodchild

National Center for Geographic Information and Analysis, University of California, Santa Barbara, USA

ABSTRACT We describe a major effort by the NCGIA to develop teaching materials in support of courses in Geographic Information Systems. The project is motivated by the current high level of demand for GIS professionals, and by the need to distinguish between software training on the one hand, and education in the intellectual and conceptual basis of GIS on the other. The teaching materials were assembled from contributions by the GIS community, and tested in a number of institutions world-wide. The revised version of the curriculum was released in the summer of 1990.

Introduction

The use of Geographic Information Systems GIS is expanding rapidly throughout the world, creating a tremendous demand for training in GIS. This article describes a major initiative by the National Center for Geographic Information and Analysis (NCGIA) in the United States to provide a significant improvement in the current state of GIS education. We begin with a review of the motivation for and goals of the project. This is followed with a description of how the curriculum was developed and a brief overview of its contents. The NCGIA is a federally funded research consortium formed in response to a call for proposals from the U.S. National Science Foundation (Abler 1987). Following a lengthy review process, the University of California at Santa Barbara, the University of Maine and State University of New York at Buffalo were granted in, August 1988, a five-year mandate to conduct research and educational initiatives directed at decreasing or removing impediments to the adoption of GIS technology. The research agenda is wide ranging and is described in detail in NCGIA (1989). The educational initiatives are designed to improve access to GIS education and to increase the availability of skilled GIS personnel, researchers and faculty. The Core Curriculum project described in this article forms the initial centrepiece of the Center's educational program.

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Motivation for the Project

While a few large scale GIS have been operational in government departments for over two decades, systems for small and medium sized agencies have become widely available only within the last eight years. Recognizing the value of this newly accessible technology, thousands of administrative agencies around the world have moved rapidly to embrace it. Geographic Information Systems can now be found in planning and management offices at all levels of government and business in most countries. This has created a critical shortage of well-trained GIS operators, analysts and managers.

Universities have found it difficult to respond to this sudden demand for education and training in GIS. The usual fiscal and planning barriers to rapid implementation of new courses are particularly severe due to the high level of investment required. Moreover, an extreme shortage of people capable of teaching GIS has hampered the development of such courses. Instructors preparing to teach courses in established specialities of geography have not only a multitude of texts and readings available, but also their own experiences as students and researchers from which they can distil a conceptual framework of the important principles of the subject. By contrast, and with the exception of a very few 'pioneers' in the field, GIS is a new area of study to most of its potential instructors, very few of whom have taken courses, let alone done research, in GIS. As a result, many who have begun to teach GIS courses have found that the courses they develop are focused too much on technology and lack a strong theoretical basis. Recognizing this situation, the NCGIA has directed its initial educational efforts at the development of the Core Curriculum in GIS. The Core Curriculum is seen as an effective means of achieving part of the Center's general goal of reducing impediments to the use of GIS. There are many issues that the NCGIA recognized as critical and that form the guiding principles behind the development of the Curriculum.

Many types of professionals are needed by the growing GIS industry. The proliferation of systems in planning and resource management offices has made the lack of trained GIS operators critical. This kind of training can be accomplished most directly by in-depth exposure to specific hardware/software systems. Beyond this functional level, there is a need for people with a broader exposure to GIS, with a general idea of where GIS fits into existing managerial and planning decision processes. Managers and analysts need both a solid understanding of the principles on which the systems are built, and a grasp of the real problems which GIS has been developed to solve. This class of skills, combining technical knowledge with an understanding of context, seems particularly scarce at the present time. At another level, people are needed who can carry out basic research so that GIS can reach beyond being simply an applications driven toolbox and become a fully functional system for guiding spatial analysis. A recognition of this range of needs has been a driving force in the curriculum design.

There is, however, a more philosophical objective to be achieved in this curriculum. Although in its early stages the development of GIS has been driven largely by applications, it is important now to address theoretical aspects. GIS is distinguished from other spatial data handling activities by its

emphasis on analysis. GIS can, in fact, be used to teach many fundamental concepts about spatial analysis, and to provide spatial analysis with a much-needed conceptual framework (Goodchild 1987). Additionally, besides its obvious importance in many of the current application areas such as resource management, urban planning, facilities management, land records management and marketing and delivery planning, GIS has great potential as a technology for science. Largely unrealized so far are the uses these technologies have for global science, public health research, regional economic modelling and housing and transportation research. GIS technology can provide tools for the development of new paradigms for the science of spatial information. Intelligent application of these tools requires the recognition of formal models of geographic phenomena expressed in digital representations. Theories of spatial statistics, spatial sampling and data collection contribute to these new perspectives as does recent research in spatial learning and reasoning and in the use and value of spatial information.

While the formalizing of a basic core of theory in GIS is the fundamental goal of this project, our secondary goal is more subtle. Here we seek to begin a dialogue on the role of GIS within geography and other disciplines. Is there a separate discipline of GIS? Where does it fit within the current body of knowledge taught in geography? Can it be a unifying theme? The academic controversies that arise during the development of the Core Curriculum will provide an opportunity for the exchange of ideas on these issues.

Recognizing GIS as a loose consortium of topics without boundaries, the NCGIA has chosen to concentrate its efforts on defining the core rather than exploring the limits of GIS. We see the challenge in the development of this curriculum to be a careful balancing between the needs of the job market and the recognition of GIS as a new opportunity for advancing spatial research and analysis. We do not wish to perpetuate the black box image of GIS by training uninformed operators. On the other hand, we do wish to provide our students with marketable skills. To this end, the basic philosophy in the development of this curriculum is to provide a general education on the basic principles and concepts of GIS, to examine the theory and tools of spatial information analysis and to provide a broad exposure to GIS applications so that objective decisions can be made about system acquisition and implementation. The approach is that of the generalist.

By distilling the expertise and experience of many current GIS educators into a comprehensive set of curriculum materials, we hope that it will be possible to speed up the recognition of the basic core of knowledge fundamental for a working GIS professional. While the curriculum is presented as a complete course, it is hoped that individual instructors will use it as a framework for developing their own department- and discipline- specific courses. Hence, while the exact contents of the curriculum as it is eventually distributed will date quickly, the philosophical motivations reflected in the general structure and content will be important for a much longer period.

Developing the Curriculum

For a number of reasons this project did not follow traditional curriculum development strategies. Not the least of these is the fact that the curriculum was developed by university academics, most of whom have not received formal training in the theories of curriculum development. Another reason for departure from the traditional approaches is the academic level of students for whom this material is intended. It is inappropriate to follow the objective-task-subtask model common in elementary curriculum projects since the university lecture model provides education at a broad knowledge level that does not break down easily into testable components. Finally, the course developers have no control, nor do we wish any, on the manner in which the material is ultimately presented. It is inconceivable to expect that the materials would be presented precisely as provided by a range of academics in different schools and disciplines. As a result, it was necessary to develop a broadly appropriate general set of materials that can be arranged and presented according to each instructor's preference. The overall design is modular, allowing the instructor to adopt and adapt the entire sequence, or one of its three courses, or clusters of lectures within each course, or single lectures.

The planning of the Core Curriculum began with the writing of the Proposal submitted to the National Science Foundation in January, 1988. Based on a model previously used at the University of California at Santa Barbara (UCSB) for the development of a one-year course sequence (3 quarters) in remote sensing, three major course topics were identified. These were 1 an introduction to the theory and techniques of GIS, 2 technical issues and 3 application issues. The first course would be an introduction to the hardware, software and operations of GIS, providing the essentials required by a beginning GIS technician. The advanced courses were to focus on two distinct aspects: one dealing with technical aspects, exploring areas related to the computer science and computer cartography roots of GIS; and the other dealing with the applied aspects of spatial analysis, spatial decision making and management issues.

Immediately following the late summer 1988 announcement of the awarding of the grant to the consortium, work on the curriculum began in earnest. The project is headed by Michael Goodchild and coordinated by Karen Kemp, Ph.D. candidate, in the Department of Geography at the University of California at Santa Barbara. Twenty-five specific lecture topics were identified for each of the three course areas. Recognizing that many institutions do not operate on a three quarter system and that the sequence developed may not necessarily be the one adopted by individuals teaching from the materials, topics were grouped into modules which allow for reasonable flexibility in the arrangement of lectures.

This 75-lecture outline was then reviewed and largely rewritten with input from all three sites of the consortium as well as other GIS professionals who were able to review a copy of the lecture outline made widely available during the Fall of 1988. Sessions were held at several conferences during this period. Discussion centered around the number of lectures required for certain fundamental topics, the inclusion of several marginal topics and the sequence of topics. Needless to say, different individuals had different perceptions of the importance of topics. By December, 1988 a final lecture outline had been agreed upon. While it might not completely satisfy those already teaching GIS, the outline would provide new instructors with a good basis for the development of their own courses. This outline is presented in Table I, with the addition of a few minor changes that were required during the writing of lecture modules.

Course Content

Several other authors have described GIS curriculum development projects. Unlike the majority of these which examine the role of GIS education within the larger context of a complete departmental or university program (Nyerges 1989; Nyerges and Chrisman 1989; Poiker 1985; Morgan 1987; Maher and Wightman 1985; Goodchild 1985; Hamilton 1989), our aim is to develop a core of material from which individual instructors will develop general introductory courses. Thus we have chosen the term 'core curriculum' rather than 'model curriculum', as the latter suggests an ideal, rather than a core around which one can build a specialized program. A similar approach has been taken by the Royal Institute of Chartered Surveyors, in Britain, through the AutoCarto Education Trust (Unwin and Dale 1989) in the development of their suggested GIS course syllabus. The RISC/AutoCarto proposal addresses many of the issues recognized by the NCGIA, and though the structure of the suggested course differs somewhat from ours, it is similar in many ways and confirms the relevance of the philosophical approach taken by the NCGIA.

In the 'Introduction to GIS' course, students review hardware and software components, explore several applications and are introduced to data structures and basic functions. Several different GIS are reviewed. Specifically, students completing this first course learn to: identify and describe the hardware components of a GIS; state differences between database models; describe and evaluate methods of data capture and sources of data; discuss the nature and characteristics of spatial data and objects; list and define typical GIS operations; identify types of products from GIS; identify various applications of GIS; classify systems according to their characteristics; and, recognize differences between raster and vector systems.

Laboratory exercises are included to give students hands-on experience. Depending on the objectives of specific institutions, laboratory exercises can be used to provide in-depth instruction on a single system or to give a broader exposure on several different ones. The exercises provide training in: the operation of computers; the procedures involved in completing simple GIS operations; issues of data integration into systems; and, the use of GIS in resource management problems.

In an introductory course of this nature it is important to put students into a practical, 'hands-on' environment as rapidly as possible, to build motivation and to provide practical illustration of concepts. For this reason the first course introduces raster systems first, on the grounds that the conceptual material needed to understand these systems is less than for vector systems. Students are thus able to work with a practical GIS within two to three weeks of the start of the course.

The 'Technical Issues in GIS' course deals with GIS algorithms, data structures, advanced computational topics and analysis of error. Laboratory

TABLE 1. NCGIA CORE CURRICULUM COURSE AND LECTURE SEQUENCE

INTRODUCTION TO GIS

A. Introduction
1. What is GIS?
2. Maps and map analysis
3. Related technology

B. Hardware/System Software
4. Output peripherals
5. Input peripherals
6. System software

C. Raster-Based GIS
7. The raster GIS
8. Raster GIS capabilities
9. Raster GIS systems

D. Data Acquisition
10. Socio-economic data
11. Environmental data

E. Nature of Spatial Data
12. Spatial databases
13. Spatial database models

F. Spatial Objects and Relationships
14. Relationships among spatial objects
15. Spatial relationships in spatial analysis

G. GIS Functionality
16. The vector or object GIS
17. Vector GIS: Using the data
18. GIS products
19. Current market for GIS
20. Generating complex products
21. Modes of user/GIS interaction
22. GIS for Archives

H. Raster/Vector Contrasts and Issues
23. Raster/vector/object database debate
24. History of GIS
25. Trends in GIS

TECHNICAL ISSUES IN GIS

A. Coordinate Systems & Geocoding
26. General coordinate systems
27. Map projections
28. Affine & curvilinear transformations
29. Discrete georeferencing

B. Data Structure and Algorithms: Vector
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

C. Raster Data Structure, Algorithms
35. Raster storage
36. Hierarchical data structures
37. Quadtree algorithms and indexes

D. Data Structures and Algorithms for Surfaces, Volumes and Time
38. Digital elevation models
39. TIN data structure
40. Spatial interpolation I
41. Spatial interpolation II
42. 3D and temporal databases

E. Databases for GIS
43. Database concepts I
44. Database concepts II

F. Error Modeling and Data Uncertainty
45. Accuracy of spatial databases
46. Managing error
47. Fractals
48. Line generalization

G. Visualization
49. Visualization of spatial data
50. Color theory

APPLICATION ISSUES IN GIS

A. GIS Application Areas
51. Review of GIS applications I
52. Review of GIS applications II
53. Review of GIS applications III
54. Example applications I
55. Example applications II

B. Decision Making in a GIS Context
56. Multiple criteria methods
57. Network Models
58. Spatial decision support systems

C. System Planning
59. Needs awareness
60. System planning overview
61. Functional requirements analysis
62. Benchmarking
63. System choice
64. Pilot project
65. Database design
66. Case study of database design project

D. System Implementation
67. Costs and benefits
68. Legal issues
69. Introducing GIS into organizations
70. Implementation strategy
71. Development of a national GIS policy
72. GIS and global science

E. New Directions in GIS
73. GIS and spatial cognition
74. Knowledge based techniques
75. The future of GIS

exercises include technical programming. Students learn to: identify sources of error; compare and contrast different coordinate systems and projections; describe several methods of storage of spatial data objects and to evaluate these methods for various applications and data types; construct simple algorithms to conduct basic GIS operations such as overlay, intersection, area measurement; recognize significant aspects of map accuracy and data quality; and, conduct error tracking and estimation procedures. After consideration of the course content, the third course was renamed 'Application Issues in GIS' since its purpose is to discuss operational and management issues, in addition to reviewing application areas. Ways in which traditional planning and management theories and techniques can be implemented in GIS are examined. Students learn which issues need to be considered when proposing and implementing a new GIS and have opportunities to evaluate how GIS can be used to answer specific planning problems. Topics covered help students to: evaluate the use of spatial analysis techniques in the GIS context; describe applications of GIS in various fields; discuss social impacts of GIS, including legal aspects and effects on management decisions; describe relevant aspects of the implementation of GIS in an institutional setting, including incorporation into an agency, cost and benefit assessment, benchmarking, and request for proposals; and, identify future directions in GIS.

Preparation of Materials

Having identified the lecture topics, the next step was to compile the materials. Although GIS is a new subject, there are many individuals in the international GIS community who have considerable teaching and research experience and who, it was felt, could contribute to the project and help it gain wide acceptance. In December 1988, we sent letters to about 60 professionals in North America and the UK requesting their assistance. To put each request in perspective, we provided each person with a detailed lecture outline listing the 75 topics with three or four specific items listed under each topic. Unfortunately, our short time frame made it necessary to give potential contributors only six weeks for their submissions. (Of course, as it later turned out, some of the deadlines were extended several times.) In spite of this, the response was very positive and in the end 35 contributors provided materials for 56 of the lectures.

In retrospect, there are several lessons to be learned from this approach. While we expected contributors to be able to produce their submissions of six to eight pages of lecture notes, plus three or four references and questions quickly, we underestimated the amount of effort many of them would put into the project. In several cases we did not ask for lectures in the areas of contributors' current interests or research as we based our assignments on the topics and quality of past efforts. Given sufficient lead time, it would have been much better to have allowed contributors to pick their own topics. While the extremely short deadlines were initially justified, in the end they were not critical and another month or two would have allowed several others to have participated.

As one would expect, the form of the submissions varied considerably. There were basically three types of lecture notes received. One was the framework outline that would provide an instructor who is very familiar with the material with a complete structure for the presentation of the lecture. A second form was the detailed outline with specific examples, definitions and descriptions included. The third form was the commentary, written as an article, which could be used by an instructor as background material for the development of the actual lecture. The detailed outline form is the model chosen for the draft version of the curriculum materials as it provides a structure for the lecture, with sufficient details for the beginning, though not inexperienced, instructor to present in one hour.

While several contributors provided slides to support their lectures, it was decided that, as far as possible, only black and white graphics which could be used as overheads would be provided. This decision arose primarily from our own personal preferences of lecturing with the lights on. However, images that could only be useful if reproduced in colour were included as slides in the final package. We felt slides to be essential in the lecture on colour systems, and in some of the application lectures. (The recent development of photocopiers that create colour overheads from slides may provide alternatives for the final version of the materials.)

Once the materials had been received and converted to the appropriate electronic form, the formulation of the actual notes began. Generally speaking, the tasks of the editors were to develop a clear progression through the various topics, eliminate redundancies between different contributors, fill in areas not covered or for which submissions had not been received and maintain a consistent style throughout.

Since the Technical Issues course was being offered at UCSB in the spring quarter of 1989, this was the first volume to be edited and assembled. Lectures were developed as needed from the submitted materials or written from scratch if a contributor had not been assigned in time for the classroom presentation of a specific lecture. Often lecturing directly from the submitted materials, we were able to assess the different formats in terms of their ease of use in the classroom. Revisions and in some cases total rewriting of the contributed notes provided final versions. Although the other two courses could not be developed while being taught, the experience in this course provided a clear vision of the form of materials and depth of coverage needed. Once the school year ended in California, revisions of the lectures began in earnest. Starting at lecture one and moving sequentially through the contributions, the body of material was gradually compiled. Aware of the potential impact that these materials may have, we often found ourselves involved in lengthy discussions on minor details as the lecture development progressed. A particularly difficult topic was the choice of the 'correct' jargon (terms). The terminology in GIS is not yet strictly established and we were reluctant to use one term over others if distinct definitions were not broadly acknowledged. Generally, terminology was based on the most commonly used forms with other important ones included as alternatives.

Another area of discussion was the need for the repetition of material already covered in earlier lectures or courses. Unlike a textbook, it is impossible to browse backward through lectures. Hence, it is necessary to repeat some lists, definitions or concepts so that the important items are recalled at the appropriate time and placed into new perspectives. This causes some redundancy in the notes that is only apparent as a problem if the lectures are presented in a different sequence or if the notes are read like a book.

Research assistants were assigned to produce graphics and track down references. It was decided to include within the text, where necessary, small representations of blackboard sketches that instructors might wish to use to illustrate the material. Also, in addition to the graphics for overheads, some lectures include detailed handouts which provide examples which can be reviewed in greater depth outside the classroom. Since no generally accepted textbook is available, the need for such handouts is likely to be very high and satisfied only partially by the selection of materials provided in the current draft version.

Laboratory Materials

Since the objective of this curriculum is to provide a basis for teaching the conceptual aspects of GIS, laboratory materials were designed to supplement the lectures, rather than to provide training in the use of one or more specific GIS systems. Although we are aware of the strong demand for intensive, hands-on technical training in the use of specific GIS packages, it

was felt that labs designed to reinforce these lecture concepts could not adequately provide technical training as well. We feel that short workshops on specific software, or major student projects in which the entire process from data collection to report generation is performed, may be better ways to address this demand.

Thus, it was decided that lab exercises would be provided as detailed handouts (supplied with digital datasets) which set up a problem situation, and then lead students carefully through each step of the required analytical procedures. Probing questions require students to explain why certain choices are better than others and how they might proceed through similar problems. Although it was recognized that instructors who provide students with considerable supervision would find that this level of detail makes the labs too 'cookbookish,' we felt it was necessary to include all the details that would be needed by students working without supervision. Of course, due to the potential range of students being instructed, this, too, presented a very difficult question regarding the level at which the materials should be written. Unlike the lecture notes which we assume each lecturer will modify to his/her own style, the laboratory exercises may be presented exactly as provided. It was necessary, therefore, to simply commit to a single approach.

For reasons very different from those related to lecture notes, laboratory materials presented us with another set of controversial issues. An initial survey of institutions taking part in the evaluation program indicated a very wide selection of equipment and software available for student use. Severe time restrictions made an ambitious laboratory exercise development program unrealistic. It was decided to concentrate our efforts on the two GIS programs (one each for raster and vector data structures) that were most common among the curriculum test sites (IDRISI and ARC/Info), and on a single source language (BASIC). Six basic lab exercises were developed for each of the first two courses. Since the distribution of the draft version, conversion of these labs and datasets to other software implementations by test sites, GIS vendors and other institutions has been encouraged and undertaken.

As the third course focuses on institutional and administrative issues rather than the more concrete concepts covered in the introduction and technical courses, the need for 'hands-on' laboratories to supplement the lectures is less urgent. Instead, instructors are encouraged to offer discussion sessions in which the students can explore the controversial aspects of the material. Useful starting places for these discussions can be found in the questions included at the end of each set of lecture notes.

Final Product

The final product of this first stage of the curriculum development project consists of three loose leaf (ring) binders, one for each course. Each binder contains 25 sets of lecture notes (each about 8 pages long and containing 3 or 4 questions and 3 or 4 references for more information), 6 sets of lab notes (first two courses only), approximately 75 overhead and handout masters, disks containing the text of the lecture and lab notes as well as data sets for laboratories and colour slides (19, 6 and 18 for each course respectively).

Binders for the first two courses were completed at the end of July, 1989 and the third binder was completed October 15, 1989.

The need for instructional materials in GIS as perceived by the Center is very evident in the numbers of requests for the materials. Although the materials were only in a draft form and had not been widely publicized, over 110 copies had been distributed by the end of October, 1989. Many of these copies went to test sites who had signed a 'Memorandum of Agreement' obligating them to participate in the evaluation program. Institutions agreeing to teach the entire set of three courses were provided with the materials free of charge. Others who were teaching and evaluating only portions of the course paid part of the production and mailing costs of the materials they received (US $110 total for all three courses).

During the 1989/90 academic year the curriculum underwent an intensive one year evaluation in classrooms at over 70 institutions in the US, Canada, the UK, Australia, New Zealand and Hong Kong. The Center provided instructors and students participating in the test program with a variety of evaluation tools. These included surveys of students before and after taking the course, weekly reviews from instructors on lecture and lab materials, and personal contacts with as many evaluators as possible. Two user group meetings were held at major conferences in North America (GIS/LIS '89 and the Association of American Geographers, Annual Meeting) during the 1989–90 school year. Input from the evaluators is a critical part of the revision process. A preliminary review by Kemp of the evaluation program is presented in a subsequent paper in this volume. Recognizing that this project also has significance in a much broader sense, we plan to track the development of the courses at our test sites. There is an interesting study to be done on the evolution of the curriculum as individual instructors personalize their own courses from this standardized beginning. The effect of our decisions on content, terminology and focus may become apparent. Lessons learned from this project will provide a model for other major curriculum development projects.

The Future

We hope that the revised version of the Core Curriculum will satisfy our immediate objectives, and provide a significant contribution to GIS education. At the same time one advantage of curriculum teaching materials over more conventional textbooks is their flexibility, and the ease with which they can be updated as the field evolves. So although we would like to call the 1990 version 'final', we have no doubt that revisions will be desirable, and that it would be better to think of the curriculum as continually evolving. Whether there will be future versions depends to a great extent on the availability of resources, on whether we can devise an acceptable mechanism for revision, and on future trends in the field.

Although the curriculum is arranged to fit a one-year sequence of courses, we would like to encourage its adaptation to other formats. For example, it might be useful to develop a set of student notes to complement the materials, which are currently oriented to the needs of the instructor rather than the student. Perhaps the materials could be used as the basis of a shorter, more

intensive course in GIS. We would like to encourage translation into other languages, and have had several discussions along these lines.

Although the three courses described in this paper constitute the Center's main effort in education, there are several additional areas which we feel would be fruitful for future consideration. These include: background notes providing instructors with more in-depth coverage of topics; training modules on specific software systems to provide in-depth technical exposure; applications modules which will allow students to work in teams to organize and conduct complete GIS analysis projects; and case studies, designed after the business school case study model, which would allow students to make realistic management decisions based on actual data. Compilation of these materials will, of course, depend on the continued assistance of many GIS professionals.

We hope that this project will provide the framework for development of and discussion about a strong, well-recognized theoretical basis for GIS. Once we have a model for the content of GIS courses, we can begin to concentrate on how best to provide our students with the knowledge to incorporate this important technology into their range of geographic skills.

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The NCGIA Core Curriculum Project

Following the evaluation program described in a separate paper in this volume, the Curriculum was revised and released in its final version in July

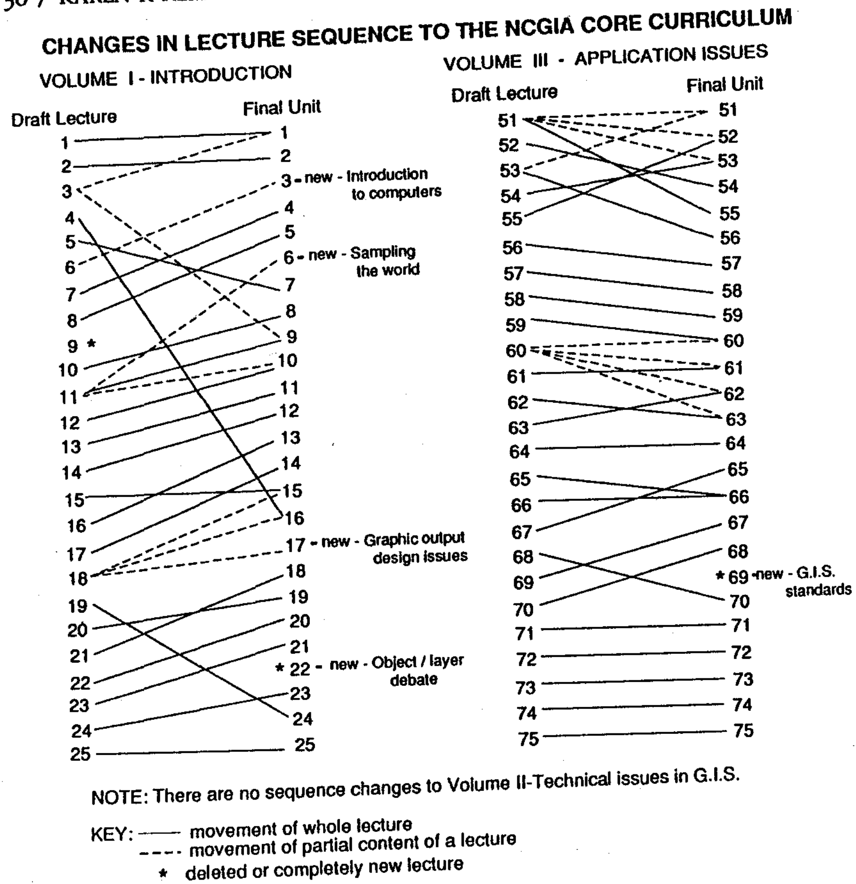

FIGURE 1.

1990. Although the Curriculum did not change in any substantial way, a number of organizational changes were made. Figure 1 shows how the draft version lectures were reorganized for the final version. Table 2 provides a detailed outline of the final topic sequence.

As of June 1991, over 650 copies of the Curriculum have been distributed to 40 countries. A review of the distribution statistics to January 1991 can be found in Goodchild and Kemp (1991).

Since we have insisted that the Curriculum will not be updated in future versions, we are now concentrating our educational activities in a number of new areas. These include: the development of a volume on laboratory GIS courses; a report on instructional GIS laboratory facilities; an elctronic bulletin board for Curriculum users and others interested in GIS education; various international activities including a distribution program to help universitites in third world and Eastern European countries obtain the Curriculum and discussions on the development of a European version.

REFERENCE

GOODCHILD, MICHAEL F., and KEMP, KAREN K. 1992. NCGIA Education activities: The core Curriculum and Beyond. *International Journal of Geographical Information Systems*, vol 16(1), in press.

TABLE 2

Curriculum Outline

I INTRODUCTION TO GIS

A *Introduction*

1 What is GIS? Contributing disciplines and technologies, major areas of practical application.
2 Maps and map analysis. What is a map? What are maps used for? Automated cartography, GIS compared to maps.
3 Introduction to computers. Computer data, hardware, storage, software.

B *A First View of GIS*

4 Raster GIS. The raster data model, creating a raster, cell values, map layers, examples analysis.
5 Raster GIS capabilities. Display, local operations, operation on local neighbourhoods, extended neighbourhoods and zones.

C *Data Acquisition*

6 Sampling the world, Representing reality, spatial data sampling reality, data sources, errors and accuracy.
7 Data input. Models of data input, digitizers, scanners, conversion from other sources, rasterizatior and vectorization, integrating different sources.
8 Socio-economic data. Socio-economic data for GIS, sources, US Census, TIGER, land records.
9 Environmental and natural resource data. Characteristics, sources, remote sensing, example.

D *Spatial Databases*

10 Spatial databases as models of reality. Organization mandates, fundamental database elements, issues in database design.
11 Spatial objects and database models. Representing point, line and area data,
12 Relationships among spatial objects. Examples, coding relationships, object pairs, cartographic and topological databases, planar enforcement, relationship in raster.

E *Vector View of GIS*

13 Vector GIS. Arcs, database creation, adding attributes, example analysis.
14 Vector GIS capabilities. Simple display and query, reclassify, dissolve and merge, topological overlay, buffering.

F *Using the GIS*

15 Spatial relationships in spatial analysis. Analysis of one class of objects, object pairs and more than one class, analysis which defines new objects, GIS analysis functions.
16 Output. Text, graphic and hardcopy output, CRTs, technical aspects.
17 Graphics output design issues. Label placement, principles of graphic excellence, design of graphic output.
18 Modes of user/GIS interaction. Queries and products, typical queries, user interfaces.

19 Generating complex products. Product definition, problems, site suitability.
20 GIS for archives. Nature of archives, examples, fate of original systems.

G *Past, Present and Future*
21 The raster/vector database debate. Coordinate precision, speed of computing, mass storage, characteristics of phenomena.
22 The object/layer debate. The layer view, the object view, applications, exceptions.
23 History of GIS. Multiple theme maps, early computer era, CGIS, Harvard Lab, Bureau of the Census, ESRI.
24 GIS marketplace. Market potential, product characteristics, vendors' products.
25 Trends in GIS. Advances in hardware, software and data availability, new applications of spatial data.

II TECHNICAL ISSUES IN GIS
H *Coordinate Systems and Geocoding*
26 Common coordinate systems. Cartesian, polar and global coordinate systems, latitude and longitude, storing coordinates, precision.
27 Map projections. Distortion properties, figure of the earth, developable surfaces, projection based coordinates – UTM, SPC.
28 Affine and curvilinear transformations. Rotation, translation, scaling, reflection, affine transformations in GIS, rubber sheeting.
29 Discrete geo-referencing. Street address, postal codes, PLSS, Census systems, issues.

I *Vector Data Structures and Algorithms*
30 Storage of complex spatial objects. Polygon and arc based data structures, storage of object attributes, representation of topology.
31 Efficient storage of lines – chain codes. Representing irregular lines, chain codes, storing chains, applications.
32 Simple algorithms I – intersection of lines. Algorithms and heuristics, simple intersection, special cases, complex lines.
33 Simple algorithms II – polygons. Area, point in polygon, centroid location, skeleton.
34 Polygon overlay operation. Operations requiring overlay, general concepts, computational complexity, sliver removal.
J *Raster Data Structures and Algorithms*
35 Raster storage. Storage options, run encoding, scan order, decoding.
36 Hierarchical data structures. Indexing pixels, quadtrees, coding and accessing data, advantages.
37 Quadtree algorithms and spatial indexes. Area, overlay, adjacency, contiguous patches, tesseral arithmetic, vectorization, quadtree and R-tree indexes.

K *Data Structures and Algorithms for Surfaces, Volumes and Time*
38 Digital elevation models. Estimating elevation, slope and aspect, determining drainage networks.
39 The TIN data model. Choosing vertices, triangulation, storing TINs, algorithms on TINs.
40 Spatial interpolation I. Classification of procedures, point based interpolation, B-splines, Kriging, trend surface, Fourier series, distance-weighted averages.
41 Spatial interpolation II. Areal interpolation, special cases, spatial interpolation in GIS, expert systems.
42 Temporal and three-dimensional representations. The vertical dimension, methods of representation, time dependence and models.

L *Databases for GIS*
43 Database concepts I. Concepts, database management systems, hierarchical model, network model, relational model.
44 Database concepts II. Relational model in GIS, data security, concurrent users.

M *Error Modeling and Data Uncertainty*
45 The accuracy of spatial databases. Accuracy, precision, components of data quality, testing attribute accuracy, error in database creation, data quality reports, tracking error, measuring accuracy.
46 Managing error. Error propagation, sensitivity analysis, artifacts of error, storing accuracy information.
47 Fractals. Why learn about fractals?, concepts, self-similarity and scale dependency, fractals in GIS, Richardson plots, error in length and area measurements.
48 Line generalization. Elements of line generalization, reasons for simplification, simplification algorithms, evaluation, linear smoothing.

N *Visualization*
49 Visualization of spatial data. Cartographic background, graphic variables, perceptual and graphic limits, representing uncertainty, temporal dependence, showing a third dimension.
50 Color theory. Color vision, measurement, color specification systems.

III APPLICATION ISSUES IN GIS
O *GIS Application Areas*
51 GIS application areas. Core groups of GIS activity, GIS and cartography, surveying and engineering, remote sensing and science and research.
52 Resource management applications. Characteristics, adoption, functionality, Big Darby Creek project.
53 Urban planning and management applications. Characteristics, adoption, example – assessing community hazards.
54 Cadastral records and LIS. Land surveys and land records, cadastral maps and surveys, MPC.
55 Facilities management. Automated mapping, facilities management, AM/FM, example system.
56 Demographic and network applications. Marketing and retailing, redistricting, vehicle routing and scheduling, vehicle navigation systems, highways planning and management.

P *Decision Making in a GIS Context*
57 Decision making using multiple criteria. Spatial decision making, multiple criteria analysis, solution techniques, example.
58 Location-allocation on networks. Location-allocation problems, applications, example on a network, problems with network analysis.
59 Spatial decision support systems. Decision support systems, spatial decision-making, SDSS system architecture, development of DSS, current status of SDSS.

Q *System Planning*
60 System planning overview. Problem recognition and technological awareness, developing management support, Newport Beach GIS project.
61 Functional requirements study. Developing an FRS, methods, components of the completed FRS, weaknesses of the process.
62 System evaluation. Strategic plan, request for proposals, hardware and software issues, system choice.

63 Benchmarking. Qualitative and quantitative benchmarks, developing a model, application of the model, example.
64 Pilot Project. Formats, management of a pilot, examples.
65 Costs and benefits. Defining costs and benefits of GIS, comparing costs and benefits, example.

R *System Implementation*
66 Database creation. Issues in database creation, key hardware parameters, tiles and layers, data conversion, example.
67 Implementation issues. Theories of computing growth, resistance to change, implementation problems, strategies to facilitate success.
68 Implementation strategies for large organizations. Location within the organization, multiparticipant projects, US Forest Service national GIS plan, components of the plan.

S *Other Issues*
69 GIS standards. Types of standards, implementing standards, what to standardize?
70 Legal issues. Information as a legal and economic entity, liability, access and ownership.
71 Development of a national GIS policy. Review of the Chorley Report, background, recommendations, findings, outcomes, related activities in other countries.
72 GIS and global science. Sources of global data, challenges to data integration, examples of databases at global scales.
73 GIS and spatial cognition. Spatial learning, form of spatial representation, effects on spatial reasoning, how natural language structures space, relevance to GIS.
74 Knowledge-based techniques. Knowledge acquisition and representations, search mechanisms, inference.
75 The future of GIS. Remote sensing analogy, convergence or divergence? Prospects for the future.

G.I.S. A VIEW FROM THE OTHER (DARK?) SID PERSPECTIVE OF AN INSTRUCTOR OF INTRO GEOGRAPHY COURSES AT UNIVERSITY LEVE

Derek Thompson
Department of Geography, University of Maryland, Collegı Maryland, USA

ABSTRACT A review of available software for geographic information systen they have little current value for teaching fundamental geographic concep analysis capabilities are limited; multi-media data are not well supported; pedı or goals are not addressed; and service delivery components such as user int addressed very infrequently. A review of introductory and advanced geogra a basis for identifying concepts that could be taught with the aid of GIS. A sur college geography teachers provides a framework for beginning to establ functionality for pedagogic purposes. Supply and demand characteristi qualitatively; and some thoughts are offered on priorities for the future.

Introduction

I believe that introductory college geography courses are improvement in a number of ways by exploiting GIS technology but not necessarily current software products. I am assuming tl instructors wish to improve geography teaching and the learnin for students. My perspective is one of an instructor of introduct courses at a university in the United States. Even so, perhaps my some interest and relevance for non-geographers, and for instru about GIS. I make no apologies for being discipline specifi examined how other academic disciplines are developing their ε contemporary computing technology in order to appreciate l occurring in geography.

Characteristics of Introductory Geography Courses

I have not located any document which sets out what is bei geography at the post-secondary level of education. I have seen how geography is taught at this level. In the absence of sı materials, I have examined several introductory texts (De Bli Larkin *et al.*; Norris *et al.*; and Stoddard *et al.*) as to content. I h