Geographic Information Science & Technology

Body of Knowledge 2.0 Project

Final Report

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1. Introduction

The first edition of the Geographic Information Science & Technology Body of Knowledge (GIS&T BoK1; DiBiase et al. 2006), published in 2006, was the first comprehensive attempt to inventory the knowledge and abilities in our field. Building on the previous efforts of Duane Marble and colleagues that had developed “Model Curricula” for GIS&T education, the UCGIS Education Committee, under the leadership of David DiBiase and with support from Esri, gathered and organized contributions from over 70 scholars and practitioners into a single, coherent document. The GIS&T BoK, which divided the field into 329 topics spread across 73 units and 10 knowledge areas, continues to be a widely used and referenced by scholars and practitioners. It is now available as an open access digital document through a collaboration involving the University Consortium for Geographic Information Science (UCGIS), the Association of American Geographers (AAG), and Esri.

The first edition was warmly received and numerous groups have initiated projects to extend and advance these materials. These projects have pursued various goals – some, for example, have used the GIS&T BoK1 to guide or evaluate curriculum development (e.g. Prager and Plewe 2009; Ahlqvist 2011; Prager 2012), some have focused on its shortcomings in terms of content (the lack of attention paid to GPS, ontologies, remote sensing, etc.), some have endeavored to add new perspectives (notably several European projects), and still others have deployed modern, state-of-the-art cyber-infrastructure tools to build prototypes that could support continuous review and revision of the GIS&T BoK materials (e.g. Painho and Curvelo 2012; Ahearn et al. 2013; DeMers et al. 2013).

However, much has changed since the first GIS&T BoK was published in 2006. The GIS Certification Institute (GISCI) was established in 2004 and both this group and the American Society of Photogrammetry and Remote Sensing now support successful geospatial certification programs. The U.S. Department of Labor published the first Geospatial Technical Competency Model (GTCM) in 2008 (DiBiase et al. 2010). Many large encyclopedia, handbooks, manuals and textbooks have been published (e.g. Kemp 2008; Shekhar and Xiong 2008; Wilson and Fotheringham 2008; Bosler et al. 2010; Longley et al. 2011; Kresse and Danko 2012; Richardson et al. 2015) and several new academic journals that cover all or parts of the spatial domain have been launched (e.g. *Journal of Spatial Information Science* and *Journal of Spatial and Spatio-Temporal Epidemiology,* whose inaugural issues appeared in 2010). A series of large online GIS&T graduate programs has also emerged (led by the numerous programs offered under the banner of the UNIGIS International Association and Pennsylvania State University’s World campus). There has been tremendous growth in the numbers and kinds of geospatial programs offered by community colleges and the successful launch, funding and now refunding of the GeoTech Center by the National Science Foundation. The geospatial group at Penn State offered a MOOC (Massive Open Online Course) on maps and the geospatial revolution that has attracted over 100,000 participants since the fourth quarter of 2013.

Much of this growth has both contributed to and is a response to the spatial "turn" that has swept through the physical sciences, social sciences and the humanities during the past two decades on the one hand (e.g. Ethington 2007; Scholten et al. 2009), and to the burgeoning presence and growth of geospatial applications across the public, private and not-for-profit sectors (e.g. BCG 2012; Oxera 2013) on the other hand. The past decade has also witnessed the establishment of various kinds of spatial enterprises within universities with the common characteristics that these enterprises draw their expertise from many traditional fields (geography, computer science, etc.) and they present themselves as inherently cross-cutting in terms of approach and impact (e.g. the launch of the University of Southern California's Spatial Sciences Institute and the University of Minnesota's U-Spatial Initiative). The enabling technologies have evolved as well – software often comes bundled with data nowadays, there are numerous proprietary and open source platforms of various sizes and levels of sophistication, and there has been a general evolution from map overlay to first geodatabases and more recently, to Cyber-enabled geoprocessing, distributed map services and web maps. And last but not least, all of this must be understood within the context of Web 2.0 and the fundamental ways in which this enables different approaches for spatial data acquisition, knowledge creation, publishing, and various forms of knowledge dissemination.

Given these changes and trends, the UCGIS launched an initiative in 2013 to create a second edition of the GIS&T BoK, building on the momentum of the aforementioned trends and seeking to re-engage and enlist participants from a broad swath of universities and other academic research institutions, government agencies, non-governmental organizations, as well as the private sector. The GIS&T BoK2 project is a priority for the UCGIS and several board members are actively involved in various facets of the project. Three informal workshops have been held (University of Southern California, Los Angeles, February 2013; Annual Meeting of the Association of American Geographers, Los Angeles, 2013; University Consortium for Geographic Information Science Summer Symposium, Washington DC, June 2013) in which key stakeholders, including partners (organizations) and participants (individuals), were identified, and participants took stock of what has been accomplished and what could be gained from a larger (i.e. broader and more inclusive) collaboration coordinated by the UCGIS. Professor John Wilson, of University of Southern California, was asked to guide and lead this project, and in the fourth quarter of 2013, he established a Steering Committee to help (see Table 1 for a list of members). The work to date in 2014 has focused on three tasks: (1) a series of group discussions on the second day of the May 2014 UCGIS Symposium that aimed to clarify the content and kinds of fundamental knowledge, tools, and applications that comprise the GIS&T domain in 2014; (2) participation in a series of workshops and related discussions connected with the *Geographic Information: Need to Know (GI-N2K): Towards a More Demand-driven Geospatial Workforce Education/ Training System* project that was recently funded by the European Community; and (3) the preparation and release of a series of technical specifications to guide the procurement of technology to support the BoK 2.0 project.

Table 1: List of GIS&T BoK2 Project Steering Committee Members

Sarah Battersby, Department of Geography, University of South Carolina
Michael Goodchild, University of California, Santa Barbara
Diansheng Guo, Department of Geography, University of South Carolina
Francis Harvey, Department of Geography, University of Minnesota
Rodney Jackson, GeoTech Center, Jefferson Community and Technical College
Krystoff Janowicz, Department of Geography, University of California, Santa Barbara
Joseph Kerski, Esri, Denver, Colorado
Werner Kuhn, Department of Geography, University of California, Santa Barbara
Wenwen Li, School of Geographical Sciences and Urban Planning, Arizona State University
Amy Lobben, Department of Geography, University of Oregon
Marguerite Madden, Department of Geography, University of Georgia
Jeremy Mennis, Department of Geography and Urban Studies, Temple University
David O'Sullivan, Department of Geography, University of California, Berkeley
Marco Painho, Institute of Statistics and Information Management, New University of Lisbon
Jane Read, Department of Geography, Syracuse University
Douglas Richardson, Association of American Geographers, Washington, DC
Anthony Robinson, Department of Geography, Pennsylvania State University
Diana Sinton, University Consortium for Geographic Information Science, Ithaca, NY
André Skupin, Department of Geography, San Diego State University
Josef Strobl, Department of Geoinformatics, University of Salzburg
Lynn Usery , Center for Excellence in Geospatial Information Science, U.S. Geological Survey
Fahui Wang, Department of Geography and Anthropology, Louisiana State University
Shaowen Wang, Department of Geography and Geographic Information Science, University of Illinois, Urbana-Champaign
Nigel Waters, Department of Geography, University of Calgary
John Wilson, Spatial Sciences Institute, University of Southern California
Kenneth Yanow, GeoTech Center, Southwestern College
Xinyue Ye, Computational Social Science Lab and Department of Geography, Kent State University

This report describes the results of the discussions during the May 2014 UCGIS Symposium, as well as two web-based Qualtrics surveys that were distributed around the same time. These activities had three goals as follows:

1. To solicit the community's help in identifying key stakeholders, including partners (organizations) and participants (individuals), in taking stock of what has been accomplished in terms of using and/or updating the first GIS&T BoK to date, and would could be gained from a larger (i.e. broader and more inclusive) collaboration coordinated by UCGIS.
2. To solicit the community's help in elucidating the core GIS&T concepts and the relationships linking the pedagogical approaches used in geographic information science

and those of other disciplines that might need or wish to be integrated into the GIS&T BoK2.

3. To learn whether or not the UCGIS Symposium participants, as one sample of current GIS&T researchers and practitioners, see geographic information science as an enabling discipline (i.e. like statistics) and if so, to learn more about the pathways that take one from fundamental science to state-of-the-art applications.

The remainder of this report is organized as follows. Section 2 describes the methods and protocols used for the surveys and small group discussions at the 2014 UCGIS Summer Symposium. Section 3 describes the results gathered from each of these approaches and the kinds of content and deliverables that will be needed moving forward. Section 4 then draws some conclusions and outlines plans for future work.

2. Methods

Prior to the Symposium itself, John Wilson drafted two surveys that were coded in Qualtrics at the University of Southern California. The first and more substantial of the two surveys asked respondents to answer two questions about each of the 329 topics included in the first edition of the GIS&T BoK. Respondents could choose to answer all 658 questions (i.e. two questions for each of the 329 topics) or a random selection of 120 questions (i.e. two questions for each of 60 randomly chosen topics). The first question tackled the importance of the existing topics and asked the respondents to rank the topics from 1 (high importance) to 2 (high-moderate importance), 3 (moderate importance), 4 (moderate-low importance), 5 (low), and 6 (no longer relevant). The second question asked the respondents to rate how well the existing descriptions of these topics were written such that 1 indicated they were superbly written, 2 indicated they were satisfactory as written, 3 indicated they needed updating, and 4 indicated they needed complete rewriting.

The second Qualtrics survey provided a sample topic and template, and asked respondents to propose new topics for inclusion in the GIS&T BoK 2.0 Project. A total of just six new topics were submitted via this survey prior to the 2014 UCGIS Symposium.

Invitations to complete these surveys were distributed widely to the GIScience community in early to mid-May 2014, via list-servs and email messages to organizations, agencies, and individuals involved with GIScience. By the time of the Symposium, 23 sets of responses had been returned for Survey 1, and six for Survey 2. The surveys themselves remained open through 30 September, 2014.

The second day of the 2014 University Consortium for Geographic Information Science Symposium (Tuesday, 20 May, 2014) was devoted to the BoK2. John Wilson presented an overview of plans for the day (see Appendix 1 for a copy of the slides), beginning by framing some of the competing visions or arguments that might be invoked to justify efforts to revise the GIS&T BoK1 and explaining the roles that he and the Steering Committee would play. He described how the GIS&T BoK1 was organized, discussing how the hierarchical organization (knowledge areas, units, topics, and objectives) shaped the contents of the document. He next introduced the two Qualtrics surveys that had been launched and summarized the preliminary results in preparation for the day's work.

The ~100 symposium participants were divided into five groups, pre-organized by Wilson to ensure effective distribution of perspectives and areas of expertise. Two facilitators had been previously chosen for each of these groups, and recorders were also identified who would gather transcripts of the day's discussions to prepare and report back to the conference as a whole at various times throughout the day.

The day was structured around four breakout sessions during which each of the five groups was asked to discuss a series of designated themes and identify within these which topics were of importance and which ones currently included in the BoK needed to be revised, updated, added, deleted, etc. The themes that differentiated the four sessions were:

1. The Geospatial Revolution, Principles of Spatial Thinking.
2. Technology Platforms, Support and Skills, Spatial Data Acquisition and Curation.
3. Spatial Modeling, Analysis and Visualization, Outcomes, Maps and Services.
4. Geospatial Applications, Emerging Topics and Trends.

Last but not least, the participants were asked to focus on content with the goal that their work would help to frame and guide the work of the GIS&T BoK2 Steering Committee going forward. The transcripts from the five groups were gathered at the end of the symposium, tidied up and included as Appendix 2 in this report. The synthesis offered in Section 3 below was prepared to show how the participant's observations and views can help to guide the collection and framing of the content for the GIS&T BoK2 Project.

3. Results and Discussion

3.1. Symposium Conversations

The transcripts from the group discussions on the second day of the 2014 UCGIS Summer Symposium are fascinating in showing the magnitude and complexity of a project like this on the one hand, and just how much has changed since the first edition of the GIS&T BoK was published in 2006 on the other hand. The main topics and ways in which these were framed during the day by the five groups are described in the six paragraphs below.

The Blue Group (facilitators Rodney Jackson and Jane Read) spent a good part of the morning pondering the purpose, context, outcomes and audience for the GIS&T BoK 2 Project. These participants wanted a "living" document as well as a book and thought the hierarchical structure deployed in the first edition might be changed going forward. They also spent some time discussing how to accommodate guiding principles and cross-cutting themes. Scale, for example, should pop up in several places in the second and subsequent editions. This naturally led to further consideration of the audience and format and of course the observation that so much more was possible in terms of web-based delivery than was possible in 2006. They also considered numerous ways to frame and introduce the spatial sciences throughout the day, including the possibility of a framework that started from data science before moving to computational science and then introducing the spatial sciences as a special instance of both.

The transcript for the Blue Group reproduced in Appendix 2 shows that their deliberations simultaneously pushed for both more breadth and depth throughout the day. This group was good at zooming in on details to set the stage for the next part of their discussions, in posing important questions, and in occasionally answering their own questions. Their work included a brief exchange with the GIS&T BoK2 Project Steering Committee chair (Wilson) that may or may not have been helpful and some wonderful suggestions for topics that will be need to be included for the first time or completely reformulated and retained going forward, and how the various topics would need to be framed to be relevant in 2014.

The Green Group (facilitators Joseph Kerski and Jeremy Mennis) offered a commentary that was broad and expansive, and occasionally deep as well. This group seemed more comfortable with treating the Geospatial Revolution as a possible starting point and offered some clever ideas on how to frame the technology pieces at various times throughout the day. They provided a relatively long and novel list of topics that would need to be covered under spatial data acquisition and curation but seemed to run out of steam once they dived into spatial analysis and modeling (as one or two other groups did) towards the last part of the afternoon's discussion.

The Pink Group (facilitators Michael Goodchild and Douglas Richardson) followed the schedule and tackled the various topics in the same order as they were asked to from start to finish. After starting with a relatively high level discussion of the challenges and issues at hand, their transcript provides a relatively high level synthesis that followed the topic list. The list of topics that needs to be compiled for the first time, or gathered from the GIS&T BoK1 and revamped to match today's opportunities and challenges provided in Appendix 2, reads like a checklist that could be used to both guide and evaluate progress as the GIS&T BoK2 Project moves forward. The emphasis afforded "place" and its role as a potentially new and important organizing concept for the BoK2 Project going forward was just one of several noteworthy suggestions that popped up throughout the Pink Group' deliberations.

The Purple Group (facilitators Anthony Robinson and André Skupin) started by framing the GIS&T BoK as a reference document for accreditation activities and talking at some length about the relationship between the content and ways to navigate through this content. This group provided a long list of topics that they thought should be included under the geospatial revolution banner and then engaged in a lengthy discussion of the principles of spatial thinking, advocating that this is something quite different than the foundation used for the GIS&T BoK1. This particular group's discussion spanned the full range of topics they were asked to consider and the individual members excelled at the rapid iteration of core principles, concepts and examples. The resulting transcript reproduced in Appendix 2 provides many good ideas that can be used as a roadmap or checklist for the GIS&T BoK2 Project.

The Yellow Group (facilitators David O'Sullivan and Lynn Usery) split their time between pitching questions and answers. Their initial discussion of the Geospatial Revolution, for example, mixed questions about the role of GIScience and the GIS&T BoK1 in society with descriptions of the character and significance of the Geospatial Revolution. The discussion in this group made numerous references to learning outcomes whilst thinking that the primary goal of the GIS&T BoK1 was to produce a reference document that could be used to guide and assess the quality of academic programs. The transcript of their deliberations reproduced in Appendix 2 shows how the Yellow Group covered a long list of topics and offered numerous opinions as to how they should be framed as well as listed some important questions whose answers would have helped to further frame what should be included in the GIS&T BoK2 Project. Their discussions also emphasized the importance of choosing a spatiotemporal focus (as opposed to a singular spatial focus), and how many things related to data acquisition, analysis and modeling had evolved or changed completely since the GIS&T BoK1 was published. And finally, this group, like several of the others, offered various opinions about the connections between cartography and visualization and how each had evolved relative to the other such that cartography may well now be best positioned as a special instance of the broader visualization narrative going forward.

3.2. Survey Results

Many of these same themes from the Symposium discussions were gathered from responses to the first Qualtrics survey. The main trends are captured in Tables 2 and 3 and discussed below, and the responses, themselves, are summarized in a series of tables organized by knowledge area in Appendix 3.

The metrics listed in Table 2 gives a sense of the numbers of topics by knowledge area that the GIS&T BoK2 Steering Committee should focus on as it works to guide the authorship of a new edition of the GIS&T BoK. The relatively low mean scores for many of the topics that were included in the DA-Data Analysis, DM-Data Modeling, GC-Geocomputation, GS-GIS&T and Society, and OI-Organizational and Institutional Issues knowledge areas suggest the places where the most work will be needed to reformulate topics and perhaps to add new topics or drop existing topics altogether. The topics included in the GC-Geocomputation knowledge area seem especially problematic given that nearly half were judged to be "moderate" or "moderate-low" in terms of importance. In addition, the topics listed in the final column of Table 2 show those that scored highest and lowest in terms of importance by knowledge area.

Table 2: Ratings of the Importance of Topics Grouped by Knowledge Area. Respondents were asked to mark each topic with a 1 (high importance), 2 (high-moderate importance), 3 (moderate importance), 4 (moderate-low importance), 5 (low importance), or 6 (no longer relevant).

Knowledge areas (KA)	No. of topics	Mean scores			KA mean score	Highest and lowest mean scores by topic
		1-2	2-3	3-4		
AM Analytical Methods	59	**36**	21	2	1.92	1.24 (AM4-4 Map algebra) 3.28 (AM12-3 Integer programming)
CF Conceptual Foundations	30	**16**	13	1	1.91	**1.00 (CF3-1 Space)** 3.07 (CF2-7 Political influences)
CV Cartography & Visualization	27	**19**	7	1	1.70	1.10 (CV2-2 Data abstraction: Classification, selection, & generalization) 3.13 (CV5-3 Map reproduction)
DA Design Aspects	32	5	**22**	5	2.35	1.57 (DA2-1 Problem definition) 3.40 (D3-5 Capital facilities & equipment)
DM Data Modeling	23	9	**12**	2	1.99	**1.00 (DM3-2 The raster model)** 3.75 (DM4-3 The hexagonal model)
DN Data Manipulation	14	**10**	3	1	1.71	1.33 (DN2-1 Scale & generalization) 1.33 (DN2-3 Classification & transformation of attribute measurement levels) 3.11 (DN 3-3 Reconciling database change)
GC Geocomputation	40	5	16	**19**	2.78	1.56 (GC8-3 Problems of scale & zoning) 3.56 (GC3-3 CA Simulation & Calibration)
GD Geospatial Data	47	**27**	15	5	1.99	1.36 (GD5-3 Map projection parameters) 3.29 GD8-1 Tablet digitizing)
GS GIS&T & Society	25	5	**16**	4	2.29	1.67 (GS1-4 Privacy) 1.67 (GS6-1 Ethics & geospatial information 3.30 (GS2-4 Agency, organizational & individual perspectives
OI Organizational & Institutional Aspects	32	4	**20**	8	2.55	1.75 (OI1-5 Future trends) 3.78 (OI1-4 Learning from experience)
Totals	329	126	145	48	2.12	

These entries point to the two of 329 topics that were rated "high" by all of the survey respondents and to the many more whose importance was rated relatively low and/or whose meaning was unclear just eight years after the publication of the first edition of the GIS&T BoK (DiBiase et al. 2006).

The metrics reported in Table 3 provide another way to find problematic topics from the first edition of the GIS&T BoK. This table highlights the numbers and percentages of topics by knowledge area that the survey respondents rated as "low" or worse (i.e. no longer relevant) in terms of importance to the GIS&T field. The metrics in the final column of this table show how the same five knowledge areas can be highlighted since 30% or more of the topics spread across the DA-Data Analysis, DM-Data Modeling, GC-Geocomputation, GS-GIS&T and Society, and OI-Organizational and Institutional Issues knowledge areas were rated by at least one respondent as low or worse in terms of importance to the GIS&T field.

Table 3: Low Ratings of the Importance of Topic by Knowledge Area. Respondents were asked to mark each topic with a 1 (high importance), 2 (high-moderate importance), 3 (moderate importance), 4 (moderate-low importance), 5 (low importance), or 6 (no longer relevant).

Knowledge Areas (KA)	No. of topics	No. of topics with ≥ 1 rating ≥ 5	No. of "5" ratings	No. of "6" ratings	No. of topic ratings ≥ 5	% of topics with at least one rating ≥ 5
AM Analytical Methods	59	13	14	5	19	22.0
CF Conceptual Foundations	30	7	7	2	2	23.3
CV Cartography & Visualization	27	5	2	3	5	18.5
DA Design Aspects	32	12	16	4	20	**37.5**
DM Data Modeling	23	7	8	5	13	**30.4**
DN Data Manipulation	14	1	1	0	1	7.1
GC Geocomputation	40	22	37	0	37	**55.0**
GD Geospatial Data	47	12	13	6	19	25.5
GS GIS&T & Society	25	10	7	6	13	**40.0**
OI Organizational & Institutional Aspects	32	19	15	18	33	**59.4**
Totals	329	108	145	48	169	32.8

A quick look at the tables reproduced in Appendix 3 will show how the two criteria used to construct these summary tables might be used to prioritize work on reviewing and updating the topics in the first edition of the GIS&T BoK. The topics listed in red in Tables A3-1 to A3-10 met one or other or both of two criteria:

1. The mean response rating the importance of this topic was no better than moderate (i.e. ≥ 3.0).
2. The responses included one or more ratings that indicated the topic was of low importance or worse (i.e. assigned a mix of 5s and/or 6s).

The largest numbers of candidate topics needing revision fell in the same five knowledge areas identified with the first approach (as expected) but the tables listed in Appendix 3 give perhaps a better sense of the magnitude of the job of sorting through the 329 topics that comprised the GIS&T BoK1 and for using these entries to generate a new edition of the GIS&T BoK.

The entries highlighted in red in Appendix 3 show that approximately one-third (111 topics; 33.7%) of the 329 topics included in the GIS&T BoK1 failed one or both of the aforementioned tests and that the largest numbers occurred in the GC: Geocomputation (24 of 40 topics; 60.0%), OI: Organizational and Institutional Aspects (19 of 32 topics; 59.4%), DA: Design Aspects (13 of 32 topics; 40.6%), and AM: Analytical Methods (13 of 59 topics; 22.0%) knowledge areas. These results, taken as a whole, would appear to confirm the need for a major revision of the GIS&T BoK1.

The daunting magnitude of the task at hand is further borne out by the summary results for the second question on the first Qualtrics survey that asked respondents to rate how well the existing descriptions of each of the 329 topics in the GIS&T BoK was written. The summary results reproduced in Table 4 at the top of the next page show that relatively few of the respondents thought the descriptions of topics were superb as written (4.8% of responses overall and less than 10 responses for the topics included in five of the 10 knowledge areas), the mean scores for the DA: Design Aspects, GC: Geocomputation, GD: Geospatial Data, GS: GIS&T & Society, and OI: Organizational and Institutional Aspects all exceeded 2.5 (where a rating of "2" indicated a topic description was satisfactory as written and a rating of "3" indicated a topic description that needed updating), and most significant of all, that 58.7% of the responses across all 10 knowledge areas indicated the need for updating and/or a complete rewriting. The large number of responses for AM: Analytical Methods reflects both the large number of topics (59 versus 14-47 topics for each of the other nine knowledge areas) and the tendency for some respondents to start the survey but quit before making it to the end. As a result, the responses per topic for the first two knowledge areas averaged 17 and 13 for AM: Analytical Methods and CF: Conceptual Foundations, respectively compared to just 9-10 responses per topic for each of the final eight knowledge areas.

Table 4: Ratings of the Topic Descriptions by Knowledge Area. Respondents were asked to mark each topic with a 1 (superbly written), 2 (satisfactory as written), 3 (needs updating), or 4 (needs complete rewriting).

Knowledge Areas (KA)	No. of responses	Ratings				Mean ratings	% with ratings ≥ 3
		1	2	3	4		
AM Analytical Methods	1,030	77	559	323	75	2.31	38.6
CF Conceptual Foundations	388	29	187	124	48	2.43	44.3
CV Cartography & Visualization	282	15	116	118	33	2.49	53.5
DA Design Aspects	309	1	104	136	68	2.80	66.0
DM Data Modeling	235	7	99	114	15	2.48	54.9
DN Data Manipulation	134	16	55	50	12	2.31	46.3
GC Geocomputation	370	8	134	123	105	2.82	77.8
GD Geospatial Data	470	20	207	170	73	2.59	51.7
GS GIS&T & Society	234	3	92	82	57	2.73	55.1
OI Organization & Institutional Aspects	298	3	121	116	58	2.70	58.4
Column Totals / Mean	3,750	179	1,371	1,356	844	2.57	58.7

The second Qualtrics survey yielded 10 proposals for new topics to be included in a second edition of the GIS&T BoK2. A total of 45 individuals opened the survey but no more than 10 continued beyond the instructions and posted submissions. Their submissions were given the following names: (1) Address fundamentals; (2) Aerial photography; (3) Attribute uncertainty; (4) Crowdsourcing; (5) Cyberinfrastructure; (6) Humanities GIS; (7) LiDAR; (8) Open source geospatial architectures; (9) Pycnophylactic reallocation; and (10) Volunteered geographic information. This is not the time to discuss the merits of the various proposals but the list itself is instructive for at least three reasons. The first is the large variability between the 10 proposals in terms of their granularity because some purport to cover broad swaths of the geographic information science landscape (e.g. Cyber or Humanities GIS) and others focus on specific techniques (e.g. pycnophylactic reallocation) or data sources (e.g. LiDAR). The second is the obvious and probably not so obvious connections between these topics and some of the topics that were already included in the first edition of the GIS&T BoK. And finally, the names assigned to some of these topics point to the challenges in terms of delineating boundaries – for example in terms of deciding where geographic information science starts and stops and in terms of how geographic information science is linked or connected to geography, computer science or software engineering, among others.

3.3 Additional Commentary

These same concerns about the granularity of individual topics, the connections among both new and existing topics, and about where to draw the boundaries were replayed in numerous informal conversations at the 2014 UCGIS Symposium and in some additional commentary volunteered by two of the UCGIS Symposium participants. The latter point to the magnitude of the task at hand and they are included more or less in their entirety here because they may help to inform our work on the GIS&T BoK2 project moving forward. For example, those who take the time to read and reflect on these commentaries might also (as I have done) think how they would have crafted such a response if they had done so around the time of the Symposium itself.

The first of these two reports was submitted prior to the Symposium itself and started with a critique of the survey itself, commenting that clicking two radio buttons per entry seemed like low-grade data and that the survey might have been better organized to provide easier ways to make repeated comments, such as topic X is pitched at too fine a level of granularity, topic X seriously overlaps with topic Y, or topic X was included purely because of one or two strong voices on the committee, reflecting longstanding political issues. In cases of duplication, this particular survey respondent noted how they had tended to select "moderate" (in terms of importance) and "needs rewriting" (to characterize the quality of the existing entries).

Notwithstanding these problems, this respondent reported that they repeatedly chose "high" and "needs updating" for the majority of topics because nearly every topic is still relevant (i.e. important) and nearly every topic needs an update although some more than others. This respondent also offered a series of specific comments and critiques of individual knowledge areas, units and topics:

1. The data mining entries overlap of course with the spatial analysis entries and asked whether or not they should all be bundled under analytics to be current?
2. The topic AM10-3: Knowledge Discovery suggests that only data mining can lead to knowledge.
3. The level of detail on spatial optimization seems heavy since this and several other topics seem only marginally relevant to GIS&T. This may be an appropriate criterion for making deletions if the development of the GIS&T BoK2 is conceived as a zero-sum game (i.e. meaning that the new edition will be roughly the same size as the first edition of the GIS&T BoK).
4. Several of the topics included under the CF: Conceptual Foundations knowledge area seem to duplicate other material.
5. Much of what was included under the CV6-4: Map Analysis and CV6-6: Uncertainty topics can be found in the spatial analysis entries.

6. Many of the DA: Design Aspects knowledge area entries seem thin, perhaps indicating that the granularity used for these topics was too fine.
7. Many of the DN: Data Manipulation entries seemed to duplicate other material.
8. The GC: Geocomputation knowledge area may lack merit as a standalone knowledge areas since the GC2-5: Geospatial Data Classification entry duplicates other material on classification and the meaning of GC2-7: Space-scale Algorithms topic is not clear.

Finally, this respondent rounded out their extensive commentary by volunteering a list of topics that they thought would be important additions to the GIS&T BoK2. This list included the changing nature of science (i.e. big data, the fourth paradigm, open data, open-source software, replicability and the norms of science) and the role of place, Point-of-Interest (POI) databases, and "platial" systems.

The second commentator focused their message on the ways in which the individual topics were described in the first edition of the GIS&T BoK, the value of crowdsourcing and need for some kind of editorial oversight to avoid unnecessary "bloat", and last but not least, the need to think carefully about the methods of delivery.

This respondent noted how there was something missing from the BoK1 entries that they had found very useful with the older UCGIS Core Curriculum (Kemp and Goodchild 1991, 1992, 2000). One of the reasons this particular individual used the NCGIA Core Curriculum for many years is that it included the definition of the term/topic and then a paragraph summarizing the key things that should/might be considered when teaching about that topic. Table 5 provides two examples from these documents to show how each handled latitude and longitude. They noted how with some of the entries in the BoK1, there is a bit of this, but also how with others, it is lacking. They argued that this needs to be in there, notwithstanding the fact that the BoK is not intended to be a "one-stop shop" for everything that an instructor would need to know about, say, Digital Terrain Models, but they argued that the core "what is it" and "what are key things to teach about it" both need to be included in the topic descriptions. They also noted that they were conscious of the time factor involved in making sure this exists for every entry, but they felt that it is worthwhile, and really, that the inclusion of these pieces would not take that long for those people responsible for them and who know the topics inside and out.

This particular respondent also thought that the GIS&T BoK2 project was a natural one to be crowdsourced. They noted that this approach would bring a whole series of issues and challenges, but that in the long run, it would ensure that the GIS&T BoK remains a viable, living, breathing resource for years to come. They worried that if we were to do it like we did it during the last decade before crowdsourcing was a viable option, we will be in the year 2024, or sooner, given accelerating rates of change, be needing to update the GIS&T BoK again.

Table 5: The descriptions of geographic coordinate systems as included in the National Center for Geographic Information and Analysis GIS Core Curriculum (Kemp and Goodchild 2000) and the first edition of the GIS&T BoK (DiBiase 2006).

NCGIA GIS Core Curriculum

Unit 14 – Latitude and Longitude

Advanced Organizer

Topics covered in this unit

- This unit provides an overview of latitude and longitude, including:
  - Earth rotation, the North and South Poles, and the Equator
  - Parallels of latitude and meridians of longitude
  - Determination of north or south position with latitude
  - The use of longitude to determine east or west position
  - The measurement of latitude and longitude with degrees, minutes, and seconds

Learning Outcomes

- After learning the material covered in this unit, students should gain an appreciation for:
  - The relationship between plane and earth coordinate geometries
  - The importance of the earth's rotation and poles to measurement and point location
  - The use of latitude and longitude to determine locations on the earth's surface
  - The differences and relationships between latitude and longitude
  - Using latitude and longitude to measure distances

Instructors' Notes
Full Table of Contents
Metadata and Revision History

UCGIS GIS&T Body of Knowledge

Topic GD3-1 Geographic Coordinate System

- Distinguish between various latitude definitions (e.g., geocentric, geodetic, astronomic latitudes)
- Explain the angular measurements represented by latitude and longitude coordinates
- Locate on a globe the positions represented by latitude and longitude coordinates
- Write an algorithm that converts geographic coordinates from decimal degrees (DD) to degrees, minutes, seconds (DMS) format
- Calculate the latitude and longitude coordinates of a given location on the map using the coordinate grid ticks in the collar of a topographic map and the appropriate interpolation formula
- Mathematically express the relationship between Cartesian coordinates and polar coordinates
- Calculate the uncertainty of a ground position defined by latitude and longitude coordinates specified in decimal degrees to a given number of decimal places
- Use GIS software and base data encoded as geographic coordinates to geocode a list of address-referenced locations

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They advocated two strategies for minimizing the issues and challenges connected with crowd-sourcing: the first envisaged that we could deploy a core set of UCGIS members to serve the 'gatekeepers' or 'moderators' of the content that comes in and second, that we need guidelines for submissions that are clearly stated from the outset. This respondent thought those UCGIS members could serve for a specific amount of time and be responsible for specific parts of the content, being very conscious of the potential of this effort to swallow up great chunks of time that nobody has. For example, person X could be responsible for the five entries on data quality for six months or one year. They thought that people would be much more likely to volunteer if you gave them short time-limited tasks (as opposed to a nebulous ill-defined set of duties).

This individual also agreed with the comments about the “bloat” potential of the project that were made as a part of Wilson’s opening remarks (Appendix 1). They suggested several strategies to contain and minimize the likelihood of such an outcome. Their approach anticipated placing an initial set of core topics agreed to by the GIS&T BoK2 Steering Committee for the wider GIS&T community to update. This would eliminate the tendency for many in the community to write new entries that they are passionate about/have expertise in, such that we would not ever get the core topics finished. Then, once these core topics are addressed, we could invite the community to write new entries. This particular commentator had given this strategy considerable thought and whilst acknowledging that some will grumble about "why are these topics included but not those topics?", they did not think it would micro-manage the project unduly, because eventually the topics would be opened up in the future (though still within the boundaries of what would benefit the entire GIS&T community (rather than someone’s pet project) and whist still subject to review from the committee, of course).

The final part of their commentary reflected on various elements of the group discussions during the second day of the UCGIS Summer Symposium and how the group they had joined had talked about a series of "big" dreams (i.e. ideas), and that one of those big ideas focused on methods of delivery. They noted how we have many good ways of allowing people to access the content once it is online these days and the benefits that would follow the development of some sort of fluid delivery system. The first of their two examples – that it would be incredibly useful if we can ensure that the system allows people to construct their own pathway based on data they input about the topics or course they would like to teach and how great it would be if the BoK2 constructed this pathway for the user based on user input – has been discussed in multiple venues and is a key part of the requirements document that was released by the UCGIS leadership. The second example called out the need for a rigorously indexed system that would allow topics to be selected based on keywords (as happens in a traditional book or reference manual). This would support those who do not want a pathway, but it would mean of course that those who create and/or update the GIS&T BoK entries would need to be diligent about clarifying and populating lists of keywords for each topic.

4. Conclusions

The results and discussion from the previous section show how much has changed since the first edition of the GIS&T BoK was published in 2006 on the one hand and the magnitude and complexity of the task of producing a new edition of the GIS&T BoK on the other hand. The transcripts from the five discussion groups on the second day of the UCGIS Summer Symposium coupled with the results from the two surveys indicate a strong desire and need to both refine the content itself and devise new ways in which the content is organized and capable of being used. The most salient findings related to content, management, collection and curation are summarized in Table 6, and notwithstanding the fact that many specific suggestions for content changes have been documented through the Symposium discussions and the surveys, the process to revise content is not yet adequate or complete, and a next round of activities must now be planned.

The UCGIS leadership is working on both of these fronts. A Requirements Assessment for the GIS&T Body of Knowledge 2.0 Curation Effort has been released and will be used to solicit proposals and bids from technology partners who can help with the organization and distribution of whatever new content is generated. This document anticipates various approaches, including semantic representation and linked open data, which would represent a major advance over the printed book format used for the first edition of the GIS&T BoK (DiBiase et al. 2006).

All further efforts to revise the existing content and generate new content should begin to coordinate with the technology discovery, design, development, and implementation effort, since each will inform the other with regards to design and curation. Thus a longer term goal involves thinking about the GIS&T BoK 2.0 project in platform terms. For this, UCGIS envisions a social-computational environment that can effectively facilitate the expansion of the GIS&T Body of Knowledge and cultivate emergent connections to other domains that encapsulate the rich diversity of our field. Such a platform would need a stable and sustainable information architecture and technological infrastructure combined with a robust content management and curation strategy. The platform must also allow for participation by natural learning communities that are focused on various domain areas or interests (e.g. Critical GIS, CyberGIS, Geodesign and Sustainability, among others) and for subject matter experts, educators, and non-technical end users to interact and engage with the materials. Consequently, the platform's design and content curation strategy must address some of the more difficult issues related to knowledge production specifically. These include issues related to varying aspirations and goals in terms of learning outcomes, intellectual property and data ownership, the ethical use of information, and scalability.

Table 6: Major findings from 2014 UCGIS Symposium group discussions and Qualtrics surveys

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Content

- The need to choose topics carefully so that the core principles are enumerated, the size remains roughly the same as the first edition of the GIS&T BoK, and so the granularity is more or less consistent from the start to the end.
- The need to pick a more compelling and robust starting point linked to the principles of spatial thinking, the geospatial revolution or something similar.
- The need to focus on enduring concepts and evolving trends with the dual aims of providing more breadth and depth in future editions of the GIS&T BoK.
- The need to identify and build explicit links to both pertinent enabling infrastructures and application domains.

Management

- The need to make modest but effective use of the GIS&T Steering Committee (and other volunteers) whenever possible.
- The need to define the roles and responsibilities of the Steering Committee members such that they know what they are being asked to contribute and when this work should be completed.
- The need to simultaneously reach out to and engage special interest groups as well as geographic information science scholars and practitioners.
- The need to split our attention between the gaps and the topics in the first edition of the GIS&T BoK for which there was the least support with a view to dropping some altogether and revamping many of the others.
- The need to monitor what the European GI-N2K Project is doing and to look for additional ways to collaborate with this and other groups moving forward.

Collection

- The need to strive to be inclusive and promote a forward-looking view of geographic information science – one, for example, that anticipates future trends such as the need for spatiotemporal rather than a purely spatial framework in all we do, and a world in which the meaning and role of place and placemaking (aka geodesign) takes on a new and elevated significance in the next few decades.
- The need to specify the instructions for enumerating topics carefully so that those wanting to volunteer know exactly what they are being asked to contribute.
- The need to specify the guidelines for enumerating topics carefully so that the content makes the best possible use of the technological platform that is selected and used to host it.
- The need to specify the guidelines for enumerating topics carefully so that the final products can serve multiple audiences and uses.

Curation

- The need to look for ways to first clarify and define the boundaries of geographic information science and second, to develop links to complementary disciplines and knowledge domains.
- The need to look for ways to simultaneously develop and enumerate synergies between the various concepts whilst minimizing any overlaps and redundancies.
- The need to choose a new and nimble, multi-faceted structure going forward.

To conclude, I recommend that any specific plans for continuing and refining the content component, as well as making decisions about platforms for online interaction and distribution, should include several elements and areas that will require careful attention, as listed below. These recommendations build upon all of the feedback provided to date as well as the various working group discussions.

1. Specifying the core concepts and principles. The first edition started from geography (possibly because geographers led this effort) but times may have changed. The Geospatial Revolution and a variety of new academic units (e.g. the Center for Spatial Studies at UCSB, the Department of Geoinfomatics at the University of Salzburg, and the Spatial Sciences Institute at USC), coupled with the spatial turn have brought spatial ways of thinking to many disciplines. This suggests it may be time to frame geographic information science as an enabling discipline so that a "workflow" approach might be best used as scaffolding for generating the new content.
2. Specifying a series of knowledge areas and units around which both existing and new topics can be solicited and organized. These might include broader concerns about the changing role and character of science and technological innovation, knowledge organization and data representation strategies, spatial data acquisition and curation, cross-cutting themes, spatial data analysis, spatial modeling, cartographic principles and visualization, place, as well as typical applications so long as we settle on a "workflow" approach or something similar.
3. Coordinating with and assigning the members of the GIS&T BoK2 Project Steering Committee to take leadership roles in orchestrating the revision of selected parts of the GIS&T BoK.
4. Inviting several existing groups who are currently working on curriculum projects to join forces with the wider UCGIS effort, to help revise and add to selected parts of the existing GIS&T BoK moving forward. These groups include Tim Nyerges's Sustainability Learning Communities Network team, Nancy Wiegand's Geo-Ontology team, Shaowen Wang's CyberGIS team, and Phil Yang's Spatiotemporal Thinking team for example.
5. Engaging, and sustaining engagement, with a wider contributing audience. Identifying mechanisms and approaches for connecting with volunteers interested in revising and adding to selected parts (i.e. knowledge areas, units) of the existing GIS&T BoK.
6. Ensuring that at least one method or approach for engaging with the BoK2 material prioritizes communication, learning, and teaching. For example, going beyond a simple definition of a term/topic by providing a paragraph summarizing the key things that should/might be considered when teaching about that topic.
7. Designing the technology platform to maximize opportunities for future use cases that will allow for an expanding appreciation for geospatial sciences. Consider the Requirements Assessment to have designated the minimum expectations, and next

maximize creative design thinking to envision a system that is flexible, robust, and inspired.

8. Identifying ways in which UCGIS leadership can contribute ongoing, formative leadership and stewardship of the BoK in its future versions and formats.

Reaching a stage when the BoK2.0 platform, and its capacity to include an updated and evolving collection of content, will take several years. The UCGIS leadership believes that this investment in effort will provide some of the fundamental building blocks for a broader and more inclusive spatial science and for a further maturation of the GIS&T field.

My own hope is that the fusion of new content and a new platform can highlight the role of geographic information science as an enabling discipline and demonstrate how one gets from fundamental science to state-of-the-art applications across a large number and variety of domains. A system that draws together cyber-infrastructure tools and up-to-date content will enable a wide diversity of users to clarify multiple curricular pathways with a variety of entry and exit points. This capability will, in turn, provide important guidance for educators seeking to grow and adapt their own curriculum paths and instructional materials to accommodate these changes and related challenges linked to the Geospatial Technical Competency Model, certification, and possibly accreditation issues.

Acknowledgements

The preparation of this report would not have been possible without the participation and contributions of all those who attended the 2014 UCGIS Symposium and those who responded to one or both of the Qualtrics surveys. These contributions were much appreciated and will help to shape what is accomplished going forward. The same was true for the two volunteered contributions featured in this report. And finally, the comments and suggestions received from the UCGIS Executive Committee on ways to streamline improve an earlier draft of this report are greatly appreciated as well. That said, the responsibility for any errors and omissions rest should be attributed to the author as per usual practice.

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Appendix 1: Wilson PowerPoint Presentation

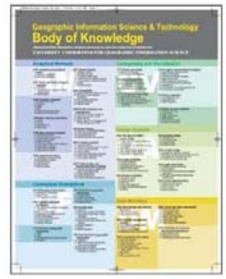
Geographic Information Science & Technology

Body of Knowledge Project

20 May 2014

2006 GIS&T Body of Knowledge

- **David DiBiase**
- Michael DeMers
- Ann Johnson
- **Karen Kemp**
- Ann Taylor Luck
- Brandon Plewe
- **Elizabeth Wentz**



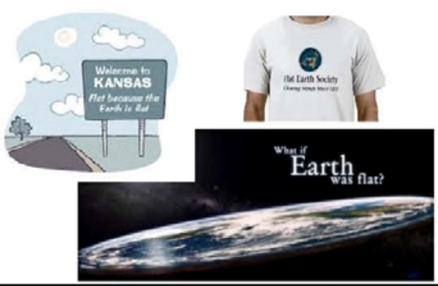
The GIS&T BoK Value Proposition

- ASPRS | GISP | Other Certifications
  - Aimed at individuals (education, training, experience)
  - GISCI is working on an exam now
- USGIF Certification
  - Aimed at academic programs
- GTCM
  - Los Angeles County | New edition in the works …
- Accreditation of academic programs?
- **2014 GIS&T BoK Project provides educators with an opportunity to present their view of the field and what is important and why**

My Role

- UCGIS GIS&T BoK Task Force Chair
- UCGIS Symposium marks a special moment
  - A chance to gather your inputs and counsel
  - A pivotal moment as I will work with the UCGIS leadership, GIS&T BoK Task Force and others to move this process forward quickly in next 12 months
- My role as that of facilitator (with the usual caveats) …

The Limits of Knowledge



UCGIS GIS&T BoK Task Force

- **Sarah Battersby**
- **Michael Goodchild**
- Diansheng Guo
- **Francis Harvey**
- **Rodney Jackson**
- Krystoff Janowicz
- **Joseph Kerski**
- **Werner Kuhn**
- **Wenwen Li**
- **Amy Lobben**
- Marguerite Madden
- **Jeremy Mennis**
- **David O'Sullivan**
- **Marco Painho**
- **Jane Read**
- **Douglas Richardson**
- **Anthony Robinson**
- **Diana Sinton**
- **André Skupin**
- **Josef Strobl**
- **Lynn Usery**
- **Fahui Wang**
- **Shaowen Wang**
- Nigel Waters
- **Kenneth Yanow**
- **Xinyue Ye**

Competing Visions

- Top-down vs. bottom-up design?
- Start anew or build off 2006 GIS&T BoK?
- Positioning (Salzburg, USC examples)
- Connections to other disciplines?
  - Cartography, computer science, geography ...
  - Civil Engineering, forestry, planning ...
- Cloud computing | Big data | Analytics?
- CyberGIS | Semantics | Spatiotemporal?
- Curriculum bloat?
- Internal consistency | linkages?
- Finish line?
- **Inclusive, international, etc.**

2006 Document

- 10 knowledge areas
- 73 units
- 329 topics
- 1,660 objectives

Knowledge Areas

- 10 knowledge areas spanned breadth of GIS&T domain in 2006
- Displayed in alphabetical order in 2006 document
- Represented more-or-less discrete clusters of knowledge, skills, and applications
- Compiled from an iterative process of discussion and revision over period of 8 years

Knowledge Areas (2)

- Analytical Methods
- Conceptual Foundations
- Cartography & Visualization
- Design Aspects
- Data Modeling
- Data Manipulation
- Geocomputation
- Geospatial Data
- GIS&T and Society
- Organizational & Institutional Aspects

Units

- Coherent sets of topics that embodied representative concepts, methodologies, techniques and applications
- Their order in 2006 document was logical but not prescriptive
- Mix of "core" and "elective" units
- Basic premise was one in which all GIS&T graduates should be able to demonstrate some level of mastery of core units

Knowledge Area & Units

Knowledge areas	Core Units	Elective Units	Topics	Objectives
Analytical Methods	3	9	59	306
Conceptual Foundations	2	4	30	85
Cartography & Visualization	3	3	27	205
Design Aspects	1	6	32	135
Data Modeling	3	2	23	141
Data Manipulation	2	1	14	62
Geocomputation	0	9	40	115
Geospatial Data	9	3	47	263
GIS&T and Society	1	6	25	98
Organizational & Institutional Aspects	2	4	32	150
Totals	26	47	329	1,660

Topics & Objectives

- Units are subdivided into topics
- Each topic represented a single concept, methodology, or technique
- 1,660 objectives included in 2006 document were intended to be "representative" rather than "exhaustive"

Educational Objectives

- Educational objectives described student behavior related to a specific topic
- Objectives included both nouns and verbs ...
  - Nouns referred to level of knowledge required to fulfil an objective
  - Verbs referred to cognitive processes involved in fulfilling an objective
- 2006 document incorporated range of fundamental, intermediate level, and high level objectives (by design)

First Qualtrics Survey

- Built around 329 topics; 2 questions per topic
- Q1: Rate the importance of [Topic X]
  - 1 High
  - 2
  - 3 Moderate
  - 4
  - 5 Low
  - 6 No Longer Relevant
- Q2: Rate the existing topic description
  - 1 Superb as written
  - 2 Satisfactory as written
  - 3 Needs updating
  - 4 Needs rewriting
- 23 respondents (3 full surveys; 20 incomplete or partial surveys incorporating 60 randomly chosen topics)

First Survey – Q1 Results

Knowledge areas	High	2	3	4	Low	NLR	Totals
Analytical Methods	**240**	160	135	44	11	3	593
Conceptual Foundations	**138**	68	64	24	7	1	302
Cartography & Visualization	**118**	42	21	10	0	0	191
Design Aspects	55	70	**72**	14	11	1	223
Data Modeling	**88**	39	34	8	7	3	171
Data Manipulation	**53**	20	22	3	1	0	99
Geocomputation	39	65	**96**	39	33	0	272
Geospatial Data	**156**	71	76	27	8	4	342
GIS&T and Society	51	32	**66**	17	6	2	174
Organizational & Institutional Aspects	64	45	**85**	16	7	10	227
Totals	**994**	592	671	202	91	24	2,594

First Survey – Q2 Results

Knowledge areas	Superb	Satisfactory	Needs updating	Needs rewriting	Totals
Analytical Methods	35	**312**	198	32	577
Conceptual Foundations	30	**130**	93	44	297
Cartography & Visualization	11	**82**	69	23	185
Design Aspects	1	74	**98**	44	217
Data Modeling	6	70	**77**	11	164
Data Manipulation	1	**48**	35	10	94
Geocomputation	5	**106**	76	83	270
Geospatial Data	12	**153**	113	60	338
GIS&T and Society	1	**67**	59	42	169
Organizational & Institutional Aspects	3	**90**	81	42	216
Totals	105	**1,132**	839	391	2,467

Second Qualtrics Survey

- Asked respondents to propose new topics
- Describe those topics, links to other topics, etc.
- Six proposals
  - Attribute Uncertainty
  - Crowdsourcing
  - Cyberinfrastructure
  - Humanities GIS
  - LiDAR
  - Volunteered Geographic Information

Marching Orders …

- Four breakout sessions throughout day
- Symposium participants divided into five groups
- Two facilitators per each group as follows …
  - **Blue Rodney Jackson & Jane Read**
  - **Green Joseph Kerski & Jeremy Mennis**
  - **Pink Mike Goodchild & Doug Richardson**
  - **Purple Anthony Robinson & André Skupin**
  - **Yellow David O'Sullivan & Lynn Usery**
- **Groups choose their own recorders and keep a digital record of conversations**

Details

- Talk around designated themes – what topics are important, which ones need to be revised, updated, added, deleted, etc.
- Themes are listed in the program …
  - The Geospatial Revolution, Principles of Spatial Thinking
  - Technology Platforms, Support & Skills; Spatial Data Acquisition & Curation
  - Spatial Modeling, Analysis & Visualization; Outcomes, Maps & Services
  - Geospatial Applications, Emerging Topics & Trends
- Groups will talk among themselves for about an hour per session and we will then take the last 30-45 minutes of each session for the groups to report back to the symposium participants as a whole
- **The focus is on the content and your goal is to help frame and guide the work of the GIS&T BoK Task Force going forward**

Appendix 2: Group Transcripts

Blue Group – Rodney Jackson, Jane Read, facilitators

Geospatial Revolution | Principles of Spatial Thinking

(Question) What goes into the BoK related to these things?

GIScience has sort of "flipped" ... used to be ahead of the BoK … Concentrated and drawing from other disciplines. Maybe now that has flipped … GIScience is now very distributed, drawing from a core of space, place, and geography. So, are we operating in a different context than we were 10 years ago?

Now there is a thing called GIScience that pushes out rather than sucks in other fields.

The position has changed ... we need to have it be outward looking (places/spaces/social media/etc.) – now we can hook up to themes that go far beyond GIScience ... the technology has really moved

(Question) Where is the boundary?

(Answer) Linkages help us expand beyond that.

Since the last BoK, we have expanded … job titles are no longer GIS [something] … but now many things that involve GIS.

From the academic standpoint, we are very distributed … GIS in anthropology, health, other fields.

(Questions) In the past 10 years, has GIScience really changed or just expanded? Is this a change or are people [essentially] just discovering the relevancy of spatial everything?

GIS is massively interdisciplinary ... now it's really getting integrated into everything.

We're back at the flipping point, from the start.

Note that nothing in the BoK is about application areas ... think about cyberinfrastructure, visualization ... things are substantially differently now.

Something very concrete happened … people who were not daily map users are now daily map users. Mapping applications and applications with maps are some of the most popular (mobile) apps. The ubiquity of maps … everyone realizes the power of the map

This has created a cadre of [inspired] neo-geographers.

Everyone on the planet is using maps all the time.

(Questions) What does this say about GIscience and technology? What is the boundary between map users and the spatially focused people?

Scaling has shifted.

There are many pieces to GIScience.

(Question) How to deal with the "I can do GPS, I have it in my car"? The tools are overly accessible but the users are under-informed.

The multitudes at the bottom of the paradigm ... their devices, etc. put them on the map but they're not doing any analysis … these people who are data collectors (personal tracking, etc.) but they themselves are not exploiting the data (they are in fact data points for someone else … they are little sensor platforms).

These people give "votes" on the technology ... they provide input on our technologies ... they are the users of our systems. "What bars are open now?" … This is part of an analysis.

Hence, the view that we don't need funding for a state geographer, for advanced analysis … I can do that on my phone.

The problem is that there is no awareness at the bottom of the pyramid … we need outreach and publicity. A parallel from the library … "we don't need libraries because everything is now online."

Just because you are the blue dot doesn't mean that you know anything about GIScience.

Okay, let's start at the other end of the pyramid … the people at the very top. What is their core knowledge set, and how has that changed?

Construct (an updated version of) Figure 2 on page 12 of the first edition of the BoK.

(Question) Has the pyramid changed?

Back to the flipping idea … the fact that it is a mainstream technology ... that we now care about analyzing social media, etc. ... spatially it's almost like the masses are driving new forms of analysis.

This opens the opportunity to change the conversation away from GIScience and to geospatial technologies ... it's not about GIS anymore, it's about neogeographies, as spatial science (VGI, etc.) … "you repeat this all the time ... I'm not a GIS'er."

(Question) The folks at the bottom of the pyramid … using Google Maps … does that make them more spatially aware?

No.

Spatial literacy … maybe it has a lot of different levels. Spatial relationships, spatial awareness, etc.

(Question) What about maps? What if we move beyond the blue dot … do we have more people looking at maps and trying to understand them? If so … that's a higher spatial literacy. "Even economists are getting interested in maps."

Many people are making maps, regardless of how ugly [the maps] are … that drives what we do.

The growth of online map applications has gone through the roof because it's driven by the consumer.

There's also a shift in the map aesthetic … two huge stories:

1. The wind map of the U.S.; and
2. Maps of flights over the US.

These represent an engagement with spatial information that is technologically possible that wasn't at the time of the last BoK.

But, being able to make that map requires huge skills.

There is a distinction between the users and the practitioners … let's not focus too much on the users, except for maybe a statement at the beginning. Maybe?

There's a blurring between end-users and GIS folks. Maybe you have a billion people using maps ... 100 million of them make a nice KML document ... there's a continuum which is enabled by the technology. It would be interesting to know how many are in different parts of that. Goes from "where am I" to "I create my own map" to ArcGIS Online or map my ride or map my vacation photos.

And that's the point of it all, but that's not what the BoK is articulated toward. We just need to acknowledge that they're there.

In the context of VGI, these people matter … the platforms they are using are critical for us to know about and understand. (GPS in phones, Google Earth, etc.).

We return to the question: How much is the BoK driven by the folks at the bottom of the pyramid?

Those folks at the bottom of the pyramid are still generating data.

The changing volume and velocity in the data (==> big data) … this is something we need to understand. This is both science and social. Different sources, different qualities, etc.

Those mainstream platforms were designed by people and embody technologies that are new to make them happen ... all of those [new technologies] should be part of the new BoK.

Should they? There's a boundary ... they'll be irrelevant in 3 years.

Maybe don't focus on the technologies ... focus on the quality and suitability of data, evaluate the collection methods and the technology involved.

(Questions) Does the technology infrastructure matter more? How much of that more CS stuff is key?

If we're assessing both science and technology, we have to admit that in the past decade we have experienced a technology revolution in the geospatial realm. Have we also experienced a science revolution? That is a question. One thing: geolocation services. Another [revolutionary] thing: cyberspace, social media as one example ... this is a rich, fertile environment for new spatial principles and scientific discoveries.

The question of technology … if we put real hard "stuff" about technology in the BoK, it will be outdated in two years. Perhaps we should put an emphasis in about system architecture, not just software … to come up with core applications, GIS professionals need to understand the stacks … these are unique from non-spatial stacks.

There's an entire social aspect to systems and technologies and architectures. Need to realize what capabilities are (present, limited) … for example, Google Maps is very limiting in some ways. The ability to interpret and understand technological and architectural choices … this is defining us. If we don't understand that, someone else puts us in a box.

Cyberinfrastructure is a critical piece of the puzzle. In the education realm, we cannot treat this as a black box. This must be critically visible … along with the critical thinking behind the infrastructure.

One thing we should think about: How does this get updated and maintained? The pace of technology change is accelerating (possibly) … to decide that something should go into the BoK … is this the best way to keep this updated? Maybe we tweak this daily or annually [like a Wiki or something similar].

(Question) How far are we equipped to look ahead?

Maybe we look ahead to the frontiers we see now. If we try to cover all of our bases, it may not be so good for what we need right now. Possibly … no matter what we do now is going to be dated in 3-5 years. Maybe we do this periodically at UCGIS.

Example: Sensor arrays. Soon, we will have sensors all over the place that will feed into GIS. This goes beyond remote sensing. Example: I'm interested in visualization, but that's not really in cartography ... we could spread out a lot at the theoretical level and we want to not do that. (There is a BoK for cartography, for sensors, for remote sensing ...).

But, the idea of a sensor web and the idea that it allows broad, high-fidelity, high-resolution sensing and understanding the implications of that … that does fit into the key concepts of GIScience.

(Questions) Do these categories break down when we look ahead? Do we want to question these as well? Given the way that things are going ... would we re-conceptualize the framework? These categories come from 2003, fashioned after CS and their BoK.

One thing that impairs people's understanding of this work is that the connection between the work and the BoK is not straightforward. This brings up the U.S. Department of Labor’s Geospatial Technical Competency Model (GTCM) document, which defines three spectrums … data acquisition, modeling and analysis, programming and applications … for geospatial professionals). Maybe we could create a parallel structure and then go into great detail.

Maybe we don't need to think about this as "what silos do these things fit in" … what if we approach this more atomically, like the network of things. So, think about a topic first, then what groups of things to put together.

We have not discussed the intended audience of this document is.

Having this as a hard-copy is limiting. General appeal of having things that a more flexible to edit.

Back to audience. Publishing this as a book or booklet was a rhetorical statement because the intended audience (GIScience) would listen to it more seriously if it came from AAG, as a book. Now that we've accomplished that, we have the ability to step away from the book format.

This and the earlier (NCGIA) Core Curriculum served a very core role … in the lead institutions and other public institutions … that was the intended audience. We're trying to improve the education and training. Look around at the increase in masters, doctoral, bachelors and associate degree programs. We (i.e. the big universities) should be leading that.

One way the BoK is used is in program reviews, to say "here's what my profession says matters; we're only covering 30% of that so now we need to hire another person to cover the other ... percent."

(Question) Could we do some sort of mapping of these things? Lots of papers authored on this, Prager and Plewe authored a couple of these papers.

Focus is on people; so, we need to dial in the content.

Back to "the granularity of the things" … there is no crossover in the first edition of the BoK as it is written, i.e. topics in one column do not spill over into additional columns. We need to have the things independent and also connected. The bottom-up approach is important … the connections and web parts may be more suited to online.

The GTCM provides a series of lenses … one possible granularity.

The BoK speaks to practitioners, the administrators who support them ... the GTCM has a very different audience.

But there should be an interface between the two … they are about the same enterprise. This is an opportunity, but it doesn't have to be a driving objective. It would be nice if we can make sense of the relationship between the two.

(Question) What is the interface of this content with what we do on a day to day basis? It was really involved / challenging to organize curriculum around the BoK. We need to understand how this influences our daily work … we are the primary audience for this. This document is for higher education and educators.

But maybe that's where it started … this is a core element for a model curricula. Now it's only rarely used to help design curricula. This is the evidence that backs up Goodchild's claim in 1992 … that GIScience is a distinct, legitimate field.

This document laid the foundation for the GTCM … the practical application of the BoK goes much further.

Another important driver in the 1998 part of this conversation was to make sure that we knew how to design systems … this was the most important thing to the original authors … who saw things drifting away towards just spatial things.

We are trying to think of the really high-end science research … not the technicians who do need some of this … but all of the skills that the high-end has, and that some of the low ends will need.

But, understanding the role of stacks, the implications of the citizen-sensor, etc., we can identify the next wave of these topic areas.

Computer Science (CS) was the top of the pyramid when CS was flourishing. We now may have enough advances in scientific computing to provide an anchor (i.e. a set of nodes) … high performance, scalable systems, (spatial) data mining … these are not clearly CS advances, but some are more organically connected to spatial science than others. We may need to drill down a little bit. Example … the use of natural language processing to identify place names.

The top of the pyramid involves spatial stats, and other things … algorithmic and computational thinking ... we must always be pushing the research frontiers.

(Question) What's the new rhetorical question? The BoK was originally put out as being the new rhetoric.

The ability to revise the BoK as a community document shows a coherence and a persistence to the field. Originally we were asserting the field ... now we are sustaining the field. For example, in light of the field of CS – they've had a BoK since the 1960s and it's the essence of their professionalism. This creates a stronger claim to the legitimacy and authority of the field.

The goal is to get something done, do your best, but know it's not going to be perfect.

There is an opportunity here to create an extensible framework. There is an opportunity to be more open-ended, to evolve this, and make it more agile.

This has to do with the maintenance infrastructure of the document.

(Question) Are there examples of online BoKs from other disciplines?

The Apache Foundation model, OCGR model, http://www.cips.ca/CBOK.

The audience is GIS professionals and academics.

The book format is useful, but a living document is key … maybe every two years we revise an electronic book, or what?

This is a ton of work. Maintaining this is a ton of work. This is a problem.

The differences (from when the first edition was authored to now):

Volume and velocity of data

The end-users in various domains vs. professionals

The technology revolution has happened … but maybe not a science revolution

The possibility to align a new, revised BoK with the U.S. Department of Labor's GTCM (which is being revised as well).

The structure of the first edition of the BoK is not sacred.

Technology Platforms | Support & Skills | Spatial Data Acquisition & Curation

The idea of having one knowledge area that conflated GPS, remote sensing, surveying and positioning is definitely a legacy of the original concept.

The original authors were more concerned with analysis and system design and not data … they were not interested in spatial data acquisition … with the result, these important topics were compressed.

(Question) What's the minimum disaggregation that is needed to be true to that field?

The current 'lumping' is a major disservice to the enterprise.

One problem area is cross-cutting themes, e.g. scale … we dealt with this in the past via an index … but an online setup could network these.

Our focus (now) is on the content. What is new? What needs to be dropped?

New: VGI, sensor networks.

'Geospatial knowledge, data, etc.' are not represented in the coherent way they deserves. GPS, remote sensing, etc.

We need to recognize the role of geography, computer science and big data. Data management, analysis, communication … these are all related to the scalability, things we may have taken for granted in the past.

There is a Data Science associated with geographic information. In certain instances we have the opposite problem with big data. As new methods are developed, we need to be able to specify collection strategies … big datasets with lots of uncertainty vs. precise but very minimal datasets.

This may give us something to use in terms of structure. In terms of science: data science, computational science, spatial science, etc.

Can break geospatial data into categories: (1) How you acquire it? (2) What you do with it?

(Question) Should there be a cross-cutting category?

It may be that we have a series of girding principles.

Earth measurements, geodesy … these are underpinning, if not girding kinds of things … spectral types of things. We don't have to have all of that in the BoK but we should have pointers to those principles that inform our discipline … e.g. measurement science.

Another angle might be that there is a collection of foundational principles that apply to GIScience but also extend beyond it. These may already be in GD [i.e. the Geospatial Data Knowledge Area in BoK1] but it's about changing the context in which these are couched. There are many sciences outside of GIScience that build on these.

Part of the initial conversation: cross-cutting themes, foundational principles. At some point, we were going to build pointers to other fields … statistics, measurement science … don't need to build those into the BoK but need to point out that they are involved and relevant.

The first edition take on these kinds of topics may have been a function of format ... what would we be able to change if we don't constrain ourselves to any specific structure? May be able to adopt a mutable, agile structure … a kind of optional girding!

Another important topic is data curation … the data life cycle, stewardship, long-term preservation.

You say "data acquisition" and the librarians hear "I am going to go fly a plane, contact a satellite, etc." but really they know that you are going to go to a data repository, which is all curated and manipulated and ... when talking to students, the librarian impresses on them that this data is already highly manipulated and focus on what will you do with the information, data, etc. that you have further manipulated? People may want to go back to your data, the original data.

Metadata, curation may be problems … because nobody wants to write metadata.

Similarly, data discovery is a very, very tough thing … hard to formalize. The first edition of the BoK mentions warehouses … but now there's data in a bunch of different places.

Themes from yesterday included triaging … "what do you keep?" … this is particularly key as the volume of data that you're dealing with increase.

Data curation (i.e. what do you keep?) is key and is missing from the first edition of the BoK … need to fix that. Stewardship, preservation (i.e. freezing data in safe and storable formats) are also important.

We might frame this as spatial data science … "data science for spatial data"

We like this because it's inclusive but also has a pretty good boundary.

But, note that we don't necessarily want to include analytics.

Other important topics include linked data, knowledge organization, ontologies, and knowledge structures.

(Question) Where are gaps in knowledge? See "eve" example from yesterday.

Take the example of biostatistics. You learn R programming. You learn how to use GitHub to do version control of both data and code (mostly code) … goes through data acquisition, data cleaning ... exploratory data analysis and statistics. Just to explore and understand your data … this is different from understanding the world.

Spatial data science could represent a new knowledge framework but there's a problem in that there needs to be a separate category for the analytics.

The piece of knowledge that's needed has to do with the data ecosystem, the data that exists in the world, the types of data that it's possible to create and gather. Data acquisition … creating new data as well as working from already-existing data.

Technology Platforms; Support & Skills

The cloud is new.

(Question) Is this in the context of GIST specifically or in managing a BoK?

(Wilson): When you think of the field, the organizing construct used to be overlay – cartography, data alignment, etc. – then in the 1990s it's all about the geodatabase – now it's moving towards web services.

(Question) What are the consequences for what a student needs to know to work effectively across that range?

To be a master of the field, you may need to have some knowledge of all of that, the relative advantages and disadvantages of each. What are the parts? How are they connected? What happens when something breaks?

(Question) How are the opportunities manifested in today's technologies?

An example Wilson's opening remarks this morning … you take out a term paper, replace it with story maps with video, multimedia, still photos, and more … so you build the picture of a place from first-hand experience [rather than just text].

(Question) Great, but ... what is the framing for that?

Pluralism … visualization ... the end product is a narrative, argument, or story that is something spatial ... maybe? [At least in that particular example].

(Question) What is the platform? Are we talking web? Cloud?

The first edition of the BoK was published in 2006 during the pre-platform age ... all kinds of things have changed since 2006. The ecosystem involves many more small developers, applications.

Platform means something fundamentally different now.

Phase1 relied on the overlay as the organizing structure … phase 2 the geodatabase … phase 3 is marked by a total lack of structure … there is no SQL … data fusion … ubiquity?

The National Science Foundation and some other organizations may have already done this homework and we just have to add the spatial uniqueness.

Platform (from a CS perspective) still has technology cache, but may or may not be technology neutral.

Cyberinfrastructure may be a unique concept to science ... and this may leave people in GIS&T a bit confused. That said, the target audience for this document is GIScientists ... so maybe this term is okay.

(Question) Are web services another form of data?

They are a service-oriented architecture on the one hand ... enterprise architecture ... in the IT domain they have a very standardized architecture framework.

Service oriented.

Data architecture.

Distributed computing [this may be task-driven].

Pervasive computing [this is just 'there' … like the technology in your toaster].

Data fusion.

Cloud computing … if there is only one thing we include maybe it is this. The investment by industry here is much, much bigger than anything else.

Ubiquitous computing … sensor networks? [But maybe that's data] ... but is that different from pervasive computing? Distributed computing?

(Question) Where is the social aspect of computing? The social aspect of cyberinfrastructure and cyberGIS? This would increase access to the services and technologies. The digital divide … who gets it, who doesn't. The flipside is because of this new form where we are able to address some more complex problems and the social dynamics that are involved in them.

Collaborations.

Community engagement.

Interactions.

Two sides: (1) this [technology increase] is helping scientific problem solving in general; and (2) certain people [have access to this] and other people don't. Digital divide maybe expanding. Must keep an eye on the social elements.

Equity and access issues.

(Questions) What is next? With respect to cyberinfrastructure, platform, technology?

We are getting to the question of what to teach … not necessarily what is happening at the research frontier.

It's hard to project what's coming down the pike in the future but we've been semi-successful in the past. What can we do to prepare people to move forward?

We should be able to train our workforce to target the future. One idea is that cloud computing is the future, it is not going to go away because of industry investment. When government agencies come up with their GIS solutions, must go in the Cloud. From the GIS perspective, Esri has come up with the idea of the geoplatform.

This is a huge consideration at Esri … linked to their desire, need to support for a variety of devices. People need to know where they draw the line … support devices natively (a ton of work) or do things on HTML5 (loss of performance but easier).

<u>Spatial Modeling</u>

Increase in horsepower is a big change. Problems that were once computationally difficult no longer require algorithms to solve, now easier because of computing power.

(Question) Does that impact the average user? What if this is blackbox-ish?

Just because we have increased computational ability doesn't mean that things have gotten easier. Example: school bus routing is still a really challenging problem.

We have a lot more potentially useful computational tools.

There are multiple trends on this front: (1) aspiration to make analytics simple and more accessible, just like maps are accessible to the masses; we want analytics to be accessible as well; (2) as we make things simple, we are hiding the tricky stuff … the workflow pipe is actually a complex entity. We have some competing objectives here (development of new capabilities and innovative pieces).

(Key question) What are the basic understandings behind all of this?

We need to understand who the learners are for all of these different parts. People who just want to use the powerful analytics, people who want to understand the process or parts of it. We used to want to teach people how to create maps but we've already done this.

One change concerns what we teach someone to do … e.g. modeling in AML vs. modeling with workflows, toolboxes, etc. One angle that we need to consider is the superimposition of modeling and "platforms" and how that combination enables us to change what the entry point is for modeling.

Now you can dive into spatial modeling easier … but you still need to understand the fundamentals.

Broad use of open source software! This means you can do all of the same things, but there's a lot to learn there. And now someone who is technically inclined can see how things are actually done at the code level.

Scale of access, of integration … e.g. counties that use PostgreSQL and Esri or something else.

Extra set of skills to use open source … must be able to vet quality, the appropriateness of individual models, know how to participate in community. Programming skills … which might be (1) they can construct a line of code and/or (2) they can actually fix things using code [i.e they know Python].

Fundamentals are very similar. Still have to get to the same basic concepts of spatial analysis and "computational" thinking.

<u>Analysis and Visualization</u>

(Question) How do virtual globes change how we understand visual data?

This is a growing area ... extends across fields … visual literacy, web design. Example of the wind map.

An analog in statistics might be the idea is that everyone understands a boxplot intuitively. Need to know audience.

Need to capture things that are and/or are not spatial.

Visualization ties into map services. A visualization that starts in one place can end up in different places.

Need to consider x/y/z/t and principal components.

Parallel programming is a variable to include here. Parallel programming, scalable programming, algorithms, and distributed programming.

Moving from things being "2.5-D" [layer stacks] to software that's 3D at its core. This might change how we approach projection (for example). Graphics programming is a part of this, too.

(Question) Does the x/y/z/t structure require us to change the data model or data structure?

The ubiquity of maps in general is driven by the proliferation of maps and visualization (e.g. phones, tablets, etc.).

Small screens, user interface … and a cartographic theory to support this … "responsive design" (algorithms need to know how to parallelize and how to best parallelize tasks at hand).

Context-dependent user interface ... not just the whole earth catalog of tools but a system that has a sense for what you are trying to accomplish and can present a subset of tools based on what you are doing.

Some of this ties back to theory of human-computer interaction and the responsiveness of the interface based on your interaction.

Need to emphasize spatial cognition and perception.

Hey! It looks like ... we're going from this big new topic back to our fundamentals.

This makes sense ... to really approach these topics you need to think from soup to nuts.

Need to incorporate real time visualization and analysis of data.

(Question) How do we handle the analysis thing in this setting?

Visualization is going to require … thinking about architecture, database design, processes, capabilities, etc.

Visualization has been viewed historically as an exploratory part of cartography. Visualization may no longer be a part of cartography. It has expanded beyond cartography. That knowledge area has expanded to become much more computational in nature. A good chunk of visual analytics is embedded in analysis.

When the first edition of the BoK was published in 2006, the end products were on desktops or imposters. Nowadays, they are on a phone or small screen. Now things are end-to-end, everything is there... interactive/new form of data is now never really "done" (unlike the posted map or desktop application).

There aren't many dead-end visualizations these days … here's your picture and it's done. Data is fed real-time into many applications.

Cartography is now an aspect of visualization whereas in 2006 the opposite was the case. And visualization is larger than cartography.

Visualization from a technology point of view has been progressing very quickly.

Computation is much more relevant to this area. Analysis is driving everything.

<u>Outcomes</u>

Decision support, hypothesis generation, narratives and journalism.

(Question) What is the knowledge that is needed in this particular framing?

Understanding the flow of information … this is a cognition thing.

Organizational, participatory planning. Tricky because outcomes become less tangible, changes in behavior or policy or something … decision process becomes ever more prominent.

Nature of decision-making, different forms of reasoning (abductive / deductive / inductive), storytelling plus cognition.

Split between theory and hypothesis-driven research.

Can add qualitative data into the GIScience framework … reaching new audiences.

Overlay process … still very qualitative (going back to older data framing).

<u>Maps and Services</u>

Actionable information … using what we do to shape what other people do.

May be tied to "flipping" earlier – I need information that informs my decision now; this may be in a specific context (e.g. I am monitoring deforestation in the Amazon) … contextualizing information for decision-making (maybe in real-time settings).

BoK1 talked about what we do and how we do but not why we do what we do … so need to focus on that now. Save money, save lives, scientific breakthroughs ... There needs to more about why, maybe.

Super common forms of this: Getting directions, finding the closest Chinese food … this is where most of the consumers are interacting.

Categories – (1) decision support; (2) knowledge formation; (3) narratives / journalism.

Possible tie in with visual analytics … actionable information for knowledge formation.

Sometimes the action is that you're going to use a map to generate a hypothesis … e.g. mapping cancer prevalence across space.

Challenge is to extract the general principles to build a BoK.

AI might be a means to an outcome – either (1) decision support or (2) a question is generated.

(Question) What makes a map or visualization actionable?

Uncertainty, quality of data, etc.

In the old world, the map was the outcome … in the new world, the map is a stepping stone to doing something else. Now the map is dynamic, ongoing … e.g. USGS gauges, water levels are rising, etc.

We need visualization technologies, we need data science, etc.

A framing idea is that we also need data permissions, creative commons licensing (i.e. the business dimensions of this stuff).

Spatial analysis … many algorithms will have to change … for example, when dealing with social media data.

Spatial modeling … summary.

Increase in horsepower.

Increase in computational ability does not mean that the problems we are solving have gotten easier. There are competing objectives: (1) aspiration to make analytics simple and more accessible; (2) as we make things simple, we are hiding "the tricky stuff".

For example, one can use modeling as a pedagogical tool now to teach fundamentals whereas before that wasn't an option because of the technology. Now the barrier to entry is much lower.

Open source software requires extra skills.

Depending on what you want to accomplish, you don't have to start at the fundamentals … this changes how we get to the core.

Changes curricular pathways. Individuals will be able to build what they want and/or need going forward.

Outcomes

In the old paradigm, the map was the outcome.

In the new paradigm, the map is a stepping stone to doing something else. Now the map is dynamic or ongoing. The map is never done … as was said before.

To support this, we need visualization technology and data science, computational skills … back to the fundamentals we discussed this morning.

Outcomes fall into three categories which we tied to actionable data: (1) decision support; (2) storytelling and narratives; and (3) hypothesis generation.

Next steps would include going through existing BoK, restructuring its content into this new framework based on outcomes, actionable data, etc.

As an example, decision support could house ethics and legal topics.

Storytelling … qualitative GIScience.

Decision support … lying with maps, ethics, and legal issues.

Hypothesis generation … actionable data.

Actionable information is a means to an outcome.

Geospatial Applications

Wilson's introduction in which he pitched the idea that "you just get a show and tell of two hours" and wondered how do you cover all of the GIS everything when you may or may not really get to take the audience into the spatial weeds, details, etc. was totally amusing … welcome to what happens at liberal arts colleges.

Need good representation across disciplines.

How to get formal participation is another (i.e. different) question.

Applications that fall through the cracks ... applications fall through one or more domains. An example … I'm into land use, transportation, and water resources … the integration of these domains has been good.

Each of these processes has an influence on the other ... Look at the idea of pairwise domains, see how the BoK is working across different domains. Need to ask and answer following question … is there something about how things are working across these domains so that we can make the BoK richer?

Different use of BoK – the (Ahearn et al.) NSF project ... this is not the collection of the things you should teach, or where you would pull topics to teach. This is a domain reference system – just like latitude and longitude, understanding the Earth came through measurement ... similarly, experts sat down and laid down their travel logs to describe the domain … what is it shaped or structured like ... This is what the BoK is. We've been building tech pieces to operationalize that system … so you can map anything. Any research paper, any professional article … you can map that via the BoK.

Pathways to knowledge … we've extended what is in its essence a standard hierarchical structure of super- and sub-concepts. We have pre- and post-requisite relationships ... typical pathway backbones ... similarity relationships ... versioning that is 'this is this concept … it is the newer version of that old concept' [linkage from BoK1 to BoK2].

"I would be careful about asserting too much about the relationship of applications, applications are orthogonal to this."

The BoK is an ontology and should be useful in practical terms.

Coming from 2006 to now ... it would be quite valuable if we could generalize some application experiences – ways of coming up with applications. This is very valuable knowledge … make the BoK more accessible to some communities who would look to the BoK [as a place to build knowledge, seek direction, guidance, etc.]

Green Group – Joseph Kerski, Jeremy Mennis, facilitators

Geospatial Revolution | Spatial Thinking

Started with a discussion of what is meant by the geospatial revolution, how it should be introduced, and what the purpose of the introduction is.

Purpose related to how we came to today; why are we all teaching geospatial.

1. What stages geospatial has gone through and the terms relevant to each stage.
2. Reveal the origins of the geospatial revolution.
3. Discussing the revolution important in engaging students and creating interest.
4. Need to convince students / colleagues about the fact that a revolution has taken place and is still taking place.

Penn State’s geospatial revolution series (http://geospatialrevolution.psu.edu/) provides a good model for updating. Much of what is current in the revolution wasn’t anticipated or envisioned at the time the first edition of the BoK was developed.

Important to emphasize why we need GIScience particularly because of the ubiquitous nature of geospatial technologies. To update the BoK, highlight the components that didn't exist in 2006.

The geospatial revolution should be refined as an elevator speech to answer the question why should geospatial be supported at my university.

Geospatial revolution should form the basis of an awareness course.

Introducing spatial thinking could follow the model of how mathematics has established itself as a core discipline … very successful in getting math into all grade levels. The BoK could be our contribution to making the case.

Math is teaching you to think a certain way.

Focus of BoK on spatial as a way of thinking analogous to justification of math as a necessary skill; thinking spatially; learning to read; learning to be spatial; foundational.

Identify some core elements like learning to read; what it is used for.

Is there a way to describe spatial thinking without examples? Defining the construct is difficult. We need to define the constructs that allow people to come up with their own examples.

There might be multiple constructs.

Discussed what the boundaries of the BoK should be and how it should be focused.

Relevance to other fields should be documented. In the context of other fields, what is relevant to geospatial? Could go for a smaller BoK.

One point of view is that the users of the BoK pull what they need. Thus, it must be big. So much won't be covered. It shouldn't just be career-related. The U.S. Department of Labor's Geospatial Technical Competency Model (GTCM) is more practical for preparing for jobs.

An alternative viewpoint is that the BoK is great, but there are only 18 credit hours in a certificate program, so how does one focus?

The current BoK is knowledge focused and should stay that way. It doesn't list specific skills. It's academic … basic and advanced. Currently, very flat. The relative importance of topics is not noted.

The BoK documents all knowledge an advanced student needs. Someone who's getting a MA, MS or PhD in the field should know all this stuff; but not necessarily domain users.

Need to define the boundaries of the BoK. What is spatial thinking? What composes the geospatial revolution?

Boundaries are important … by having the BoK does that imply that we have a defined field that will stay stable?

Defining boundaries is a matter of identity … people need to identify themselves as GI specialists. BoK is a way to create an identity.

(Question) Should the body of knowledge be so specifically geographic?

1. Should we link to the brain mappers; chemists; architects; etc.?
2. BoK won't be considered relevant to other fields.
3. Should the geospatial revolution be situated in a larger revolution?
4. There is a big difference between something that is just spatial or geospatial?
5. The downside of opening up the boundaries is that the BoK gets too diffuse and loses definition.
6. However, cross pollination and weird connections are important. Mapping caves is not so different from mapping arteries.
7. Core spatial ideas are the same outside of geospatial; maybe we draw a dotted line around some ideas.

Pathways through the BoK need to be built by the community. Having pathways would be a good value proposition.

As a community, we can come up with what is core to the BoK. The original idea of the BoK is that there are multiple cores depending on the domain.

GIS is persistent as a discipline. The BoK is our stake in the ground.

(Question) Should the BoK be encyclopedic?

Printed book; online version richer.

Comprehensive document conceptually; not exhaustive; we need breadth not depth.

Will it be comprehensive in 10 years … do we build a body of knowledge for today or should it be predictive?

There are core knowledge components to the field.

BoK 1 wasn't intended to be a core. Should BoK 2 be core? Good question for the originators. What it has become is different from what was intended.

Some things will come and go; some of the concepts are not ephemeral; they are hardwired; will not change for millions of years.

<u>Technology Platforms</u>

BoK2 needs to recognize that specific software and hardware have changed drastically.

Now we have tablets, mobile hardware, the Cloud and other Internet-based options, commercial, open source software, etc.

Additionally, the view of desktop tools has changed, there is authoring to the Cloud, streaming data, etc.

Very important in today's world is whether a chosen tool is reliable. Users need to be able to assess whether the tool is going what it says.

That segues into how to support geospatial in an institution.

Using online tools to simplify support doesn't solve the problem entirely. New support issues are created.

IT support is critical. Are these issues core or periphery to the BoK?

Should IT have a geospatial skill set?

Should the BoK include ways of doing business?

The current BoK includes managing GIS infrastructure; standard project management; whole unit on such topics. IT ideas. Understand this as it applies to GIS.

Should the BoK focus on specific technologies? Issues with the technologies is that many are transitory.

Maybe more creative to discuss platforms centered on human behavior.

Deploy the big umbrella of behavior as opposed to how the exact tools work.

Technology is just a vehicle. What are the commonalities? Platform changes the point of collaboration. Need to be included in the front pages.

<u>Spatial Data Acquisition and Curation</u>

This section of the BoK probably needs the most updating.

Needs to include volunteer data acquisition, crowd sourcing, data quality, data availability, mobile technologies.

Data quality is an important issue … for example, what do you have to consider when using tweeted data, etc.?

Instead of organizing by specific human behaviors, consider the human synergy of spatial computing … human-centered … individual centered vs. traditional desktop.

Think about it from a use standpoint instead of from a technology standpoint.

Think about technologies as enabling affordances.

Knowledge is not hierarchical; it is a network.

Curation is changing.

Data representation.

Visualization – the term may be prohibitive because it is visual only.

(Question) Can we expand the idea of data representation?

Multimodal input, etc.

Issue of how people process information, maps. Since 2006 emphasis on how consumers make sense of maps.

Data discovery and representation. Issue of inclusivity with respect to those with disabilities.

Noted that the term visualization is used for data representation for the visually impaired and the blind.

Maps used to be printed and static.

(Question) How does one position cartography moving forward?

Noted that color blindness is very prevalent.

Noted issue of diminishing role of cartography. Understand big data using representations. Large group of mapping needs. Cartography as a component of other courses.

Communication as a key component. Appears as a heading but is lost in the details. Cartography as spatial thinking.

In teaching, need to start at the very basic level … most students don't understand isolines, contours

Don't be limited by technology.

Issues not limited to geographic, but information systems.

Some technical things can be removed.

New things … higher dimensional and resolution in space and time.

Spatial analysis … new techniques that are still relatively obscure – that didn't exist, and techniques that existed in 2006 but are now far more prominent or even required in certain circumstances.

Historical perspective is missing.

Data privacy, regionalization, scale of representation, appropriate scale

Data on mobility, movement. Analyses of movement.

Difference between practical and more basic versus research oriented techniques.

Collaborative environment for spatial analysis.

Data stream processing for large data streams.

Interoperability … sharing of models. OGC web processing but few implementations. Standardize methods / scripts as a way of sharing models. Online communities … best practices. Crowdsourcing as a way of model sharing.

Python programming.

Geographic profiling.

Spatial analysis may change due to data explosion … very large data may need to test significance if you have the whole population, very large data … everything will be significant, can use simulation to generate distributions … don't need to assume distributions.

Cloud-based paradigm touches on other issues, i.e. metadata.

New paradigm for BoK2, changes everything.

There is a scientific data revolution, about funding, curating,

Behind in data sharing practices.

Big issue of non-reproducibility of science now.

Not just lack of sharing (due to IRB, HIPAA), but also just disorganization, much preprocessing.

Touches on data processing.

Actionable items. Can journals require data sharing? Like funding agencies such as NIJ (National Institute of Justice) require those funded to deposit data in ICPSR (Interuniversity Consortium for Political and Social Research).

Window following publication where data is private, then data are shared.

So what question, following all analysis, mapping.

(Question) What's missing?

Qualitative analysis / GIS. Qualitative data. Humanities GIS. Narratives with location information. Semi-structured data. E.g. interviews, flicker photos, historical gazetteers.

<u>Outcomes</u>

Data warehouses, data clouds.

Semantics, ontology, connecting functional processing, D3 (representation of the data comes from the data), GeoSPARQL.

Difference between map, layer, service, layer you can edit. Extra learning component … not only foundational concepts but also web technologies. Should not devote a lot of energy to specific implementations.

Need to be different access points, i.e. one for K12, one for physical applications, one for social, etc.

Some things are fundamental and will not change, such as the concept of layer. Or did it? Was cartography thought of in thematic layers prior to Tobler's 57 paper? Or was it derived from color plates?

Spatial actuation. Coupling of sensing of systems with some action within the system. Self-monitoring systems / sensor arrays.

Pink Group – Michael Goodchild, Douglas Richardson, facilitators

Started with a discussion of two general issues:

Should BoK2 cover topics that most would regard as prerequisites, e.g. English, stats, math? No, but BoK2 should cover subsets of these topics that are specifically geospatial, e.g. spatial stats.

The nature of pedagogy and curriculum is changing, we suspect that these changes will ultimately have an impact on content.

The Geospatial Revolution

(Question) What is it and what are its parts?

Consumerization, democratization, VGI, consumption, interaction with peers, societal awareness, privacy.

Spatiotemporal data, sensors, real-time data.

The spatial turn in the humanities and social sciences.

The changing nature of science: open data, big data, open-source, fourth paradigm, replicability, and plagiarism.

Virtual spaces as well as real (i.e. physical) spaces.

Cyberinfrastructure, collaboration, HPC.

The changing nature of maps, the story map.

Ontology, semantics, the semantic web.

Spatial thinking … reference the NRC (2006) Learning to Think Spatially report … what is it, what are examples and what are principles? The nature of GI.

Conceptual foundations … should include empirical (design and evaluation) principles such as TfL.

The indoor environment should be addressed in BoK2, GIScience is not limited to the outdoors.

Data Curation

GIScience is ahead of many fields in development of data curation, e.g. metadata … BoK2 should cover provenance, privacy, metadata 2.0

Analysis

Need to sort out terms, overlaps between analysis, data mining, analytics, geovisualization, etc.

How to organize the mass of material, compare the 800+ functions of ArcGIS.

Techniques for big data science.

Qualitative methods.

Animation as a dimension of visualization.

The user experience … start with the questions, rather than assume the user can assemble functions to answer questions.

Modeling

Need to define … this is not data modeling, this is not what Esri understands by modeling in ModelBuilder … instead it is representation of dynamic processes, e.g. migration, erosion, etc.

Includes CA, ABM, both well treated in BoK1.

Needs a separate section, the existing "GC: GeoComputation" knowledge area is not an effective division in BoK1.

Need to include spatial interaction modeling, flows.

Validation and calibration knowledge has improved since BoK1.

Here is one place where geodesign could sit.

Uncertainty.

Need to address visualization of uncertainty, animation as a visualization technique.

Map design.

Real-time analytics.

Early warning, continuous monitoring.

Conflation … fusion … integration … synthesis are growing in importance with big data.

Collaboration as an essential element in analysis and modeling.

Place needs to be drawn out, not simply represented by gazetteer entry, it’s a core concept in geography.

Purple Group – Anthony Robinson, André Skupin, facilitators

(Question) What is important about BoK?

If there is an accreditation based on the BoK, how to develop curriculum?

Learning outcomes … knowledge is only one piece, mindset, practices and behaviors are also important.

Need to elaborate pathways through knowledge, everyone cannot know everything.

Accreditation is important, but need to be careful about bloating. Pathways and interdependencies more important that core, elective distinctions.

(Question) What about remote sensing?

Need to anticipate linkage to other disciplines, and include these.

Primary objective is to update BoK, then think about curriculum, and linkages to other disciplines.

One might anticipate a couple of steps. The first concerned the enumeration of topics, new concepts, etc. and the second focused on structuring …hierarchical and pathways, specific curriculum structures do not need to be modeled, but there can be typical pathways and curricula structures, what needs to taught first, how to build on that …

Levels should be clear – from the most basic to the most advanced.

Need to include remote sensing, image processing, etc.

Need to address assessment … outcomes.

Work on content, then structure emerges, think about missing pieces as first step.

Create three lists … fundamental concepts, middle level and high level concepts while enumerating topics.

We have basic topics that appear in multiple other topics (e.g. color classification appear in remote sensing, stats, cartography).

No Alpha sequencing, need structure (conceptual foundations, spatial principles, etc.).

Both hierarchical (or inheritance) and networked (or pathway) structures are needed.

The Geospatial Revolution

Big Data.

Ubiquity of location-based services and devices.

Mobile devices and active/passive engagement.

Citizen's awareness, social media.

Spatial citizenship.

Geodesign.

Commercial use … location analytics, business intelligence.

Individual, micro-scale targeting.

VGI, crowd-sourcing in crisis mapping.

Just-in-time geo-computing.

Semantic interoperability … machine learning, discovery, interoperability among spatial analytics and computing.

Open data and processes, open-source.

Business of GIS has changed fundamentally.

CyberGIS, mapping and analysis in the cloud.

Very different types of data and data sources … unstructured data, heterogeneous data/sources.

Spatial information retrieval has changed.

Conflating authoritative and volunteered data, metadata and provenance (not just of data but also of execution of spatial analysis to ensure replicability); also known as learning resource analytics or paradata.

Archiving and curation.

Incorporating GIS with other applications (e.g. Excel, R).

Scientific workflows.

Geospatial intelligence.

Democratization … mash-ups, ease of engagement with mapping and scripting.

User experience (GeoUX).

Data privacy (Consumer Bill of Rights … virtual privacy), mediating/obfuscating methods, geographic information and the individual.

Counter-mapping (active strategies to protect privacy): geo-fencing and geo-cloaking.

Scales of human concerns.

Principles of Spatial Thinking

Scale, distance and direction.

Autocorrelation and interactivity.

Uncertainty.

Differentiation and homogenization, aggregation, connectivity.

Scale-dependencies.

Not just spatial also temporal.

Limits of logical, or traditional ontological approach … difficulties trying to fit world in discrete concepts.

Fields vs. objects.

What are the principles that inform all topics and categories?

How do people pose a geographic question around these topics … What spatially informed questions?

Spatial thinking and non-geographic spaces.

What is a-spatial thinking? Saying what it isn't …

The ability to visualize and interpret: location, position, distance, direction, relationship, movements, and change and space and time.

It happens in the brain – brain mapping, perception, spatial cognition.

Spatial cognition researchers who look at how people use maps and space.

Navigation, spatial decision-making.

How people think about their spaces – place-based spatial.

Platial.

How do we represent place digitally?

Action, reaction, feedback, emergence.

Technology Platforms| Support | Skills

Cyberinfrastructure, CyberGIS, mapping and analysis in the Cloud.

Sensor-web.

Streaming / real-time.

Programming … scripting (how to express yourself with code, poetry in Perl).

Geo-computation … Inference, prediction, scale-dependence, estimating, interpolating.

Data art … producing artistic outputs.

HCI … connect to another body of knowledge … CHI.

Agile design, iterative design.

System design … has evolved from UML/system architecture to interface design.

UX, GeoUX.

Web-clients.

Distribution.

Use of APIs, use others' code.

Database systems … query, SQL, indexing.

Semi-structured data.

Physical geography of CyberGIS / SDI.

<u>Spatial Data Acquisition | Curation</u>

SDI.

UAVs, drones.

Digitizing.

Remote sensing.

Geointelligence from non-spatial data and non- or semi-structured data.

Collective sensing (voluntary and involuntary).

VGI.

Citizen observatories.

Social media.

Business of GIS&T (non-technical aspects).

IP … data rights, legal issues when mixing 'private' and publicly contributed data.

Licensing.

Accuracy.

Uncertainty.

Data integration … types of data and data sources, fusing different processes, etc.

Putting geography back into GIS&T.

Stewardship … updating, validating, etc.

(Question) What to keep?

Abstraction, generalization, and formalization.

Data modeling, specifications, data engineering.

Data privacy (Consumer Bill of Rights … virtual privacy), mediating … obfuscating methods, geographic information and the individual.

Counter-mapping (active strategies to protect privacy), geo-fencing, and geo-cloaking.

Sustainability … funding streams and energy / water.

Semantic interoperability … machine learning, discovery, interoperability among spatial analytics and computing.

Open data and processes, open-source.

Conflating authoritative and volunteered data, metadata and provenance (not just of data but also of execution of spatial analysis to ensure replicability), also known as (paradata … describes assumptions and constraints).

Spatial Analysis | Modeling | Visualization

EDA, data mining.

Marketplace of spatial analysis tools as add-ins to other software.

Natural language processing (NLP).

High dimensional representation techniques, network analysis … was planar now high-dimensional.

Mixed media grounded in geography.

Ontological reasoning and analysis.

3D/4D.

Semantic visualization.

Tracking spatial behavior … helps us recognize and represent emergent phenomena.

All web-enabled and distributed.

Real time geo-processing.

Spatial decision modeling.

Scale of behavior … individuals making individual choices, groups, institutions, etc.

Modeling for decision making in heterogeneous data environments.

ABM … scaled up.

Visualization of social networks … multi-dimensional (real and virtual spaces).

There are many methods of and approaches to reasoning.

Stronger focus in visualization to support reasoning, and different stages of reasoning.

Geographic extensions to statistical analysis.

Conceptual, computational and visual transformation lead to outcome.

Complexity has increased so documenting processes, workflows, etc. is important.

Uncertainty, uncertainty, uncertainty!

Outcomes | Maps & Services | Actionable Information

In the world of mashups with all of their geographic, semantic, and ontological dimensions we need to evangelize good cartographic practices.

Things that have value, concepts surrounding value. Mapping not just as outcome but as a tool for support deeper analysis.

Have non-actionable information because technology transition has occurred more quickly than knowledge transition … maps can be dangerous!

Various levels of public awareness about how to interpret maps.

Community created products that may or may not explain something.

Processes are more complex (data, sources, etc.).

Principles of how to convey information such as visual variables.

How to produce services … data, geoprocessing, visualization services, etc.

There may be legal considerations as well as risk and trust issues related to data and services.

Location-based services.

Looking forward rather than backwards, now scenario planning possible in a spatial-temporally explicit way (e.g. geodesign) … representation, simulation, and alternative futures.

Geo-gaming for collaborative decision making.

Need to teach geographers how to have fun!

Geospatial applications.

Geo-fencing, Geo-trigger services (rule-based environments that runs in real time).

Yellow Group – David O'Sullivan, Lynn Usery, facilitators

(Question) How is BoK1 being used?

Curriculum construction. To respond to accreditation concerns. For educating administrators. Communication, information dissemination.

(Questions) Who is, are the audiences of the work? How is the work or results going to be used? How is BoK going to be linked to the GTCM? What are the methods that other groups use for updating material?

DACUMS (Developing A CUrriculuM) approach.

Need for guidance on how the BoK is used.

We have responsibility to guide users.

We need an inventory of how the BoK is being used.

It will be good to link this work to learning outcomes.

It can be used for program review.

It can be used for research … for evaluations and to help in framing the field and defining its credibility within and outside the university.

Concerns about the process and goals.

We need a way to get feedback from the wider community.

We need to collaborate with the GeoTech Center. UCGIS should establish better linkages with other groups.

(Questions) Should it be broader than just education? Impact of BoK on education? Is there an impact on research?

It was not designed for that, but there has been an impact.

Geospatial Revolution and Its Impact on the BoK

(Question) What is the Geospatial Revolution?

Last 10 years, GIS has become ubiquitous. Core technologies are invisible. Location-based services are more pervasive, e.g. 50 billion geospatially tagged … the Internet of Things.

(Questions) What's the disciplinary home or context for GIS&T? Is it geography, information science, computer science … in framing a new version of this, one of big questions that we need answered? What is the core science and technology that becomes a specialist area?

This project should not focus on the everyday reactive aspects of using GIS but it should improve our thinking.

(Questions) What is the linkage with spatial thinking? Has the technology helped or hindered? What is the role of Neogeography? What is the science behind user engagement?

We have to broaden our understanding about who is doing GIScience and who is thinking about GIScience.

General discussion (i.e. talking points).

Conditions were right … when the field evolved (Context).

The symbiotic nature of knowledge creation (Context).

The emergence of Google (Industry Role).

Awareness of knowledge (Education/Awareness).

Webinar and online workshops (Modality of delivering knowledge).

Avoiding the hierarchy and the lack of connections between the nodes (Modality of delivering knowledge).

The lattice … not the tree (conceptual).

NCGIA Core Curriculum (historical context).

There are so many textbooks and products out there (Education/Awareness).

Future … creative commons licenses (Open Access).

Open Source, Big Data, Cloud Computing (Topics).

Specialized disciplinary experts (Participants, Engagement).

We require easy-to-use interfaces (Modality of delivering knowledge).

Geospatial Revolution is driven by applications … who can accomplish that? How can we help? (Education).

Web GIS (Topics).

(Questions) What are the skills needed to prepare students? (Education) … What is the content? (Content) ... What is the content curation strategy? (Sustainability) ... What about new entrants and non-experts? How do we educate them? (Audience) ... Who is the intended audience? (Audience) … What are the direct and indirect impacts? (Outcomes).

Remember the advantages of staying with learning outcomes … for academic educators.

Next version … should have broader reach and connectivity (Goals, Expectations).

(Question) Are there major gaps? – (Purpose).

Technology Platforms | Support | Skills | Spatial Data Acquisition & Curation

(Questions) What is the relationship between GIScience and computational science? What are the implications if we consider GIScience as part of computational science vs. geography? What does the platform for BoK2 look like, what does it need to support, how do we get data into it and curate it? What are the pathways and what skills do we need to follow that pathway? How do we allow domain experts to define pathways for their domain? What is the background for the necessary skills (e.g. spatial thinking)? Where does spatial thinking sit in this process? What are the principles that people must have so that they don't do stupid things?

We need definitions of platform and computational science.

Content to be added: (1) Web services; (2) Mobile applications (including design, user experience issues).

Spatial Analysis, Modeling, Visualization, & Spatial Thinking

Do we want to list a load of topics … no, not really.

GIScience can lay claim to these topics more strongly than some of the other areas.

Most of these things are already present in the BoK.

Is there anything missing?

Not so much is missing but they may have changed in terms of implementation, use, and impact?

Needs to be spatio-temporal, not spatial.

Tools and methodology expanding in the context of spatiotemporal because new time series now exist, where previously not available.

Spatial analysis used to be point pattern analysis.

CityEngine, combined with planning and design, is a new visualization platform.

Simulations? Are these a new element?

KDE simulation as an approach to inference.

We did not used to have specific temporal tools, new operators are being developed for that, especially temporal databases.

Dynamic visualization not new, but new types of tools, because of new data (again).

Real-time data.

Temporal analysis as a part of spatial systems is new. Temporal analysis now integral to GIS&T.

Scale, LiDAR data has made topography dynamic at decadal scales vs. in the past you needed geological time scales.

3D now means we are modeling the Earth's surface as a dynamic volume.

Point clouds are a new data type.

Movement analysis: again new types of data (mobile, etc.).

In terms of modeling … another area that has changed, due to computational capacity.

DEMs have moved from interpolating the gaps to filtering the noise, LiDAR.

Demographic data traditionally retrieved from the Census … good spatial detail, but temporal gaps in ACS (American Community Survey) means several new products come with poor spatial support.

For the temporal … what is the level of granularity for BoK … some of this stuff gets highly complex very quickly. Instead of just having space, we can now get spatio-temporal covariance. Instead of spatial structure there is now spatiotemporal covariance structure (again much to do with the data).

Snapshot vs. time interval in temporal data … very different methods of handling time, timestamps, regular intervals, durations, etc.

Query is altered by time also. Different types of spatial data handle time very differently.

When you put space and time together you get very different types of analysis.

Events … when conditions come together, can an event be tracked?

You can start doing this kind of analysis with the large data we now have … traffic, meteorological data, etc. Events as clusters in space-time.

Forecasting? We do it with weather, can we do it in other contexts?

We don't have good null models for spatiotemporal stuff.

Representing process ... we don't have good models for these.

Relations among entities in time.

Social networks.

The move from describing space-time data to modeling space-time data … takes space-time out of its own category and infuse it in all the others.

(Question) How is spatial analysis affected by the changing scale of contemporary data?

The relationships among scope and resolution and scale … big data only makes sense in particular parts of this 'data space' … techniques from CyberGIS that handle all the data at once.

One centimeter data for the whole world is coming and students need to be prepared to deal with it.

Matching scales of data to process scales.

How algorithms and analysis methods are affected by scale and resolution.

How things are defined is changed by resolution e.g. highways stop being single things with 1 cm resolution data.

What happens to inference when you have population data that are not samples … this applies to both social data and to physical data.

Changing concepts of uncertainty.

Spatial analysis that extracts the relevant information from high-resolution data. How to extract relevant information when you have too much information?

Algorithm design computational complexity.

Understanding how problems scale.

Visualization … we've gone from ArcScene to navigation inside an environment.

Fuzziness in visualization, how to incorporate uncertainty in visualizations.

Visualizations … scalability of solutions?

Do cartography and visualization still belong together? Cartography is part of visualization.

Fundamentals of cartographic design by web, mobile, interactivity, data scale? Design for small screens, other types of display, and other media.

What are the best ways to display temporal data beyond animation? Animation not always the best way, small multiples, space-time cube.

Hagerstrand's S-T aquarium.

Visualization as a tool for Exploratory Spatial Data Analysis (ESDA).

Visual analytics.

MacEachren's Cartography-cubed … maps as exploratory tools instead of as end products, changes to cartographic design as a result.

3D printers?

Automated generalization – to provide views on data that is held at highest available resolution.

Models … physical hardware models, process models, statistical models, simulation models. Models are dependent on questions …models have purposes.

Spatial Analysis,

Visualization and Modeling as different facets of the same thing … how we try to understand, explain, intervene in the world via computational representations … which perspective we take is affected by scale, scope, resolution, temporality of the data.

Uncertainty has changed: crowd-sourcing, ill-structured data, attribute uncertainty is a bigger issue.

Outcomes, maps, services, actionable information.

Situational awareness.

Appendix 3: Tables Rating the Importance of Topics by Knowledge Area

Table A3.1 Ratings for Importance of Analytical Methods Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (high importance), 2 (high-moderate importance), 3 (moderate importance), 4 (moderate-low importance), 5 (low importance), or 6 (no longer relevant). The red entries indicate topics where at least one respondent rated the importance as low or that the topic was no longer relevant at all.

Code	Topic	No. of responses	Ratings						Mean ratings
			1	2	3	4	5	6	
AM1-1	Academic foundations	30	15	10	3	2	0	0	1.73
AM1-2	Academic foundations	28	20	6	2	0	0	0	1.36
AM2-1	Set Theory	20	5	2	11	0	2	0	2.60
AM 2-2	Structured Query Language (SQL) and attribute queries	22	14	4	3	0	1	0	1.64
AM 2-3	Spatial queries	27	19	5	3	0	0	0	1.41
AM3-1	Distances and lengths	20	11	6	3	0	0	0	1.60
AM3-2	Direction	19	6	6	7	0	0	0	2.05
AM3-3	Shape	17	7	7	2	1	0	0	1.82
AM3-4	Area	19	9	4	4	1	1	0	2.00
AM3-5	Proximity and distance decay	20	11	6	1	2	0	0	1.70
AM3-6	Adjacency and connectivity	22	11	8	3	0	0	0	1.64
AM4-1	Buffers	20	12	4	3	0	1	0	1.70
AM4-2	Overlay	22	16	4	2	0	0	0	1.36
AM4-3	Neighborhoods	24	16	5	2	1	0	0	1.50
AM4-4	Map algebra	17	14	2	1	0	0	0	1.24
AM5-1	Point pattern analysis	21	10	6	5	0	0	0	1.76
AM5-2	Kernels and density estimation	19	8	5	5	1	0	0	1.95
AM5-3	Spatial cluster analysis	17	10	6	1	0	0	0	1.47
AM5-4	Spatial interaction	19	6	3	9	1	0	0	2.26
AM5-5	Analyzing multidimensional attribute	22	7	7	6	1	1	0	2.18
AM5-6	Cartographic modeling	21	4	8	5	2	2	0	2.52
AM5-7	Multi-criteria evaluation	17	7	5	5	0	0	0	1.88
AM5-8	Spatial process models	17	8	5	3	1	0	0	1.82
AM6-1	Calculating surface derivatives	16	8	4	4	0	0	0	1.75
AM6-2	Interpolation of surfaces	20	11	7	2	0	0	0	1.55
AM6-3	Surface features	19	3	10	5	0	0	1	2.32
AM6-4	Intervisibility	18	7	7	3	1	0	0	1.89
AM6-5	Friction surfaces	18	4	6	7	1	0	0	2.28
AM7-1	Graphical methods	18	7	8	2	1	0	0	1.83

AM7-2	Stochastic processes	17	6	8	3	0	0	0	1.82
AM7-3	The spatial weights matrix	20	7	8	5	0	0	0	1.90
AM7-4	Global measures of spatial association	16	5	7	4	0	0	0	1.94
AM7-5	Local measures of spatial association	16	9	4	3	0	0	0	1.63
AM7-6	Outliers	17	8	8	1	0	0	0	1.59
AM7-7	Bayesian methods	15	2	8	3	2	0	0	2.33
AM8-1	Spatial sampling for statistical analysis	19	12	2	4	1	0	0	1.68
AM8-2	Principles of semi-variogram construction	15	4	5	4	2	0	0	2.27
AM8-3	Semi-variogram modeling	18	7	5	2	3	1	0	2.22
AM8-4	Principles of kriging	18	7	6	4	1	0	0	1.94
AM8-5	Kriging variants	15	6	5	3	1	0	0	1.93
AM9-1	Principles of spatial econometrics	16	5	4	5	2	0	0	2.25
AM9-2	Spatial autoregressive models	16	6	5	3	2	0	0	2.06
AM9-3	Spatial filtering	18	7	6	4	1	0	0	1.94
AM9-4	Spatial expansion and geographically weighted	17	5	10	2	0	0	0	1.82
AM10-1	Problems of large spatial databases	16	7	6	2	0	0	1	1.94
AM10-2	Data mining approaches	16	9	4	3	0	0	0	1.63
AM10-3	Knowledge discovery	17	5	6	6	0	0	0	2.06
AM10-4	Pattern recognition and matching	13	4	3	6	0	0	0	2.15
AM11-1	Networks defined	12	6	3	3	0	0	0	1.75
AM11-2	Graph theoretic (descriptive) measures of	16	6	4	5	1	0	0	2.06
AM11-3	Least-cost (shortest) path	13	8	2	3	0	0	0	1.62
AM11-4	Flow modeling	13	6	3	4	0	0	0	1.85
AM11-5	The classic transportation problem	13	3	4	2	2	1	1	2.77
AM11-6	Other classic network problems	15	3	5	7	0	0	0	2.27
AM11-7	Accessibility modeling	10	4	2	3	0	1	0	2.20
AM12-1	Operations research modeling and location	12	3	4	2	3	0	0	2.42
AM12-2	Linear programming	19	1	6	5	6	1	0	3.00
AM12-3	Integer programming	18	0	6	7	1	2	2	3.28
AM12-4	Location-allocation modeling and p-median problems	14	4	4	5	1	0	0	2.21
Column Totals / Mean		**1059**	**451**	**319**	**225**	**45**	**14**	**5**	**1.92**

Table A3.2 Ratings for Importance of Conceptual Foundations Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (high importance), 2 (high-moderate importance), 3 (moderate importance), 4 (moderate-low importance), 5 (low importance), or 6 (no longer relevant). The red entries indicate topics where at least one respondent rated the importance as low or that the topic was no longer relevant at all.

Code	Topic	No. of responses	Ratings						Mean ratings
			1	2	3	4	5	6	
CF1-1	Metaphysics and ontology	10	2	2	4	1	1	0	2.70
CF1-2	Epistemology	13	3	3	5	2	0	0	2.46
CF1-3	Philosophical perspectives	12	2	3	4	2	1	0	2.75
CF2-1	Perception and cognition of geographic phenomena	8	3	3	2	0	0	0	1.88
CF2-2	From concepts to data	13	2	4	5	1	0	1	2.69
CF2-3	Geography as a foundation for GIS	14	7	3	3	1	0	0	1.86
CF2-4	Place and landscape	18	6	6	4	2	0	0	2.11
CF2-5	Common-sense geographies	13	2	5	6	0	0	0	2.31
CF2-6	Cultural influences	11	5	0	4	2	0	0	2.27
CF2-7	Political influences	13	3	1	4	3	1	1	3.08
CF3-1	Space	9	9	0	0	0	0	0	1.00
CF3-2	Time	8	5	1	2	0	0	0	1.63
CF3-3	Relationships between space and time	15	8	1	5	1	0	0	1.93
CF3-4	Properties	12	10	2	0	0	0	0	1.17
CF4-1	Discrete entities	10	9	1	0	0	0	0	1.10
CF4-2	Events and processes	13	3	6	2	2	0	0	2.23
CF4-3	Fields in space and time	15	8	4	3	0	0	0	1.67
CF4-4	Integrated models	12	7	1	3	0	1	0	1.92
CF5-1	Categories	15	8	6	0	1	0	0	1.60
CF5-2	Mereology: structural relationships	16	3	4	6	3	0	0	2.56
CF5-3	Genealogical relationships: lineage, inheritance	14	3	5	1	3	2	0	2.71
CF5-4	Topological relationships	14	10	1	2	1	0	0	1.57
CF5-5	Metrical relationships: distance and direction	15	10	1	4	0	0	0	1.60
CF5-6	Spatial distribution	10	7	1	2	0	0	0	1.50
CF5-7	Region	16	6	8	2	0	0	0	1.75
CF5-8	Spatial integration	14	6	4	3	0	1	0	2.00
CF6-1	Vagueness	19	5	4	8	2	0	0	2.37
CF6-2	Mathematical models of vagueness: Fuzzy sets and rough sets	15	7	2	5	1	0	0	2.00
CF6-3	Error-based uncertainty	17	14	1	2	0	0	0	1.29

CF6-4	Mathematical models of uncertainty: Probability and statistics	10	7	1	1	1	0	0	1.60
Column Totals / Mean		**394**	**180**	**84**	**92**	**29**	**7**	**2**	**1.91**

Table A3.3 Ratings for Importance of Cartography & Visualization Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (high importance), 2 (high-moderate importance), 3 (moderate importance), 4 (moderate-low importance), 5 (low importance), or 6 (no longer relevant). The red entries indicate topics where at least one respondent rated the importance as low or that the topic was no longer relevant at all.

Code	Topic	No. of responses	Ratings						Mean ratings
			1	2	3	4	5	6	
CV1-1	History of cartography	10	4	3	0	3	0	0	2.20
CV1-2	Technological transformations	14	6	4	2	2	0	0	2.00
CV2-1	Source materials for mapping	10	6	3	1	0	0	0	1.50
CV2-2	Data abstraction: classification, selection, and generalization	10	9	1	0	0	0	0	1.10
CV2-3	Projections as a map design issue	9	7	0	2	0	0	0	1.44
CV3-1	Map design fundamentals	14	9	5	0	0	0	0	1.36
CV3-2	Basic concepts of symbolization	9	8	1	0	0	0	0	1.11
CV3-3	Color for cartography and visualization	9	4	5	0	0	0	0	1.56
CV3-4	Typography for cartography and visualization	11	3	4	3	1	0	0	2.18
CV4-1	Basic thematic mapping methods	8	6	1	1	0	0	0	1.38
CV4-2	Multivariate displays	12	6	4	2	0	0	0	1.67
CV4-3	Dynamic and interactive displays	8	6	0	2	0	0	0	1.50
CV4-4	Representing terrain	14	8	4	2	0	0	0	1.57
CV4-5	Web mapping and visualizations	11	10	0	1	0	0	0	1.18
CV4-6	Virtual and immersive environments	10	5	2	3	0	0	0	1.80
CV4-7	Spatialization	12	5	3	2	2	0	0	2.08
CV4-8	Visualization of temporal geographic data	14	8	2	3	1	0	0	1.79
CV4-9	Visualization of uncertainty	9	5	3	1	0	0	0	1.56
CV5-1	Computational issues in cartography and visualization	11	3	6	1	0	0	1	2.18
CV5-2	Map production	12	3	5	3	1	0	0	2.17
CV5-3	Map reproduction	8	2	0	3	2	0	1	3.13
CV6-1	The power of maps	12	7	3	2	0	0	0	1.58
CV6-2	Map reading	10	6	2	1	0	0	1	1.90
CV6-3	Map interpretation	9	5	2	1	0	1	0	1.89

CV6-4	Map analysis	10	4	3	3	0	0	0	1.90
CV6-5	Evaluation and testing	11	4	3	0	3	1	0	2.45
CV6-6	Impact of uncertainty	13	7	5	1	0	0	0	1.54
Column Totals / Mean		**290**	**156**	**74**	**40**	**15**	**2**	**3**	**1.70**

Table A3.4 Ratings for Importance of Design Aspects Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (high importance), 2 (high-moderate importance), 3 (moderate importance), 4 (moderate-low importance), 5 (low importance), or 6 (no longer relevant). The red entries indicate topics where at least one respondent rated the importance as low or that the topic was no longer relevant at all.

Code	Topic	No. of responses	Ratings						Mean ratings
			1	2	3	4	5	6	
DA1-1	Using models to represent information and processes	14	4	4	5	1	0	0	2.21
DA1-2	Components of models: data, structures, procedures	12	3	3	5	1	0	0	2.33
DA1-3	The scope of GIS&T applications	11	5	1	4	1	0	0	2.09
DA1-4	The scope of GIS&T design	9	1	2	5	0	0	1	2.89
DA1-5	The process of GIS&T design	10	3	2	5	0	0	0	2.20
DA2-1	Problem definition	7	4	2	1	0	0	0	1.57
DA2-2	Planning for design	10	3	2	3	2	0	0	2.40
DA2-3	Application user assessment	8	4	2	2	0	0	0	1.75
DA2-4	Requirements analysis	12	5	3	2	2	0	0	2.08
DA2-5	Social, political, and cultural issues	10	3	2	4	0	1	0	2.40
DA3-1	Feasibility analysis	11	5	1	5	0	0	0	2.00
DA3-2	Software systems	9	3	2	3	1	0	0	2.22
DA3-3	Data costs	10	2	3	4	0	1	0	2.50
DA3-4	Labor and management	6	0	3	2	0	1	0	2.83
DA3-5	Capital: facilities and equipment	10	0	2	5	1	1	1	3.40
DA3-6	Funding	9	1	3	2	0	3	0	3.11
DA4-1	Modeling tools	11	2	5	4	0	0	0	2.18
DA4-2	Conceptual model	13	3	8	2	0	0	0	1.92
DA4-3	Logical models	11	2	4	4	1	0	0	2.36
DA4-4	Physical models	10	2	3	2	1	1	1	2.90
DA5-1	Recognizing analytical components	9	2	3	4	0	0	0	2.22
DA5-2	Identifying and designing analytical procedures	12	3	7	2	0	0	0	1.92
DA5-3	Coupling scientific models with GIS	6	0	4	1	0	1	0	2.67
DA5-4	Formalizing a procedure design	8	0	4	3	1	0	0	2.63
DA6-1	Workflow analysis and design	7	3	2	1	1	0	0	2.00

DA6-2	User interfaces	11	3	2	3	2	1	0	2.64
DA6-3	Development environments for geospatial applications	11	5	3	3	0	0	0	1.82
DA6-4	Computer-Aided Software Engineering (CASE) tools	13	1	4	3	0	4	1	3.38
DA7-1	Implementation planning	13	3	5	2	2	1	0	2.46
DA7-2	Implementation tasks	6	1	2	3	0	0	0	2.33
DA7-3	System testing	7	1	0	4	1	1	0	3.14
DA7-4	System deployment	9	1	1	4	3	0	0	3.00
Column Totals / Mean		**315**	**78**	**94**	**102**	**21**	**16**	**4**	**2.35**

Table A3.5 Ratings for Importance of Data Modeling Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (high importance), 2 (high-moderate importance), 3 (moderate importance), 4 (moderate-low importance), 5 (low importance), or 6 (no longer relevant). The red entries indicate topics where at least one respondent rated the importance as low or that the topic was no longer relevant at all.

Code	Topic	No. of responses	Ratings						Mean ratings
			1	2	3	4	5	6	
DM1-1	Basic data structures	9	6	1	2	0	0	0	1.56
DM1-2	Data retrieval strategies	13	5	2	4	1	1	0	2.31
DM2-1	Coevolution of DBMS and GIS	8	4	1	2	1	0	0	2.00
DM2-2	Relational DBMS	10	6	3	1	0	0	0	1.50
DM2-3	Object-oriented DBMS	11	2	4	4	0	1	0	2.45
DM2-4	Extensions of the relational model	13	3	5	5	0	0	0	2.15
DM3-1	Grid representations	11	4	4	2	1	0	0	2.00
DM3-2	The raster model	10	10	0	0	0	0	0	1.00
DM3-3	Grid compression methods	10	4	1	3	1	0	1	2.50
DM3-4	The hexagonal model	12	0	1	6	1	3	1	3.75
DM3-5	The Triangulated Irregular Network (TIN) model	11	4	2	3	1	1	0	2.36
DM3-6	Resolution	12	7	4	1	0	0	0	1.50
DM3-7	Hierarchical data models	14	4	5	3	2	0	0	2.21
DM4-1	Geometric primitives	10	8	1	1	0	0	0	1.30
DM4-2	The spaghetti model	11	2	2	3	1	1	2	3.27
DM4-3	The topological model	11	8	2	1	0	0	0	1.36
DM4-4	Classic vector data models	8	3	0	3	0	1	1	2.88
DM4-5	The network model	10	7	1	2	0	0	0	1.50
DM4-6	Linear referencing	9	2	3	3	1	0	0	2.33
DM	Apr Object-based spatial databases	7	2	2	3	0	0	0	2.14
DM5-1	Spatio-temporal GIS	10	3	5	1	1	0	0	2.00

DM5-2	Modeling uncertainty	12	3	5	4	0	0	0	2.08
DM5-3	Modeling three-dimensional (3-D) entities	10	5	4	1	0	0	0	1.60
Column Totals / Mean		**242**	**102**	**58**	**58**	**11**	**8**	**5**	**1.99**

Table A3.6 Ratings for Importance of Data Manipulation Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (high importance), 2 (high-moderate importance), 3 (moderate importance), 4 (moderate-low importance), 5 (low importance), or 6 (no longer relevant). The red entries indicate topics where at least one respondent rated the importance as low or that the topic was no longer relevant at all.

Code	Topic	No. of responses	Ratings						Mean ratings
			1	2	3	4	5	6	
DN1-1	Impacts of transformations	9	3	3	2	1	0	0	2.11
DN1-2	Data model and format conversion	8	3	2	2	1	0	0	2.13
DN1-3	Interpolation	12	7	2	3	0	0	0	1.67
DN1-4	Vector-to-raster and raster-to-vector conversions	12	8	2	2	0	0	0	1.50
DN1-5	Raster resampling	12	3	5	3	1	0	0	2.17
DN1-6	Coordinate transformations	8	5	1	1	1	0	0	1.75
DN2-1	Scale and generalization	12	9	2	1	0	0	0	1.33
DN2-2	Approaches to point, line, and area generalization	7	4	2	1	0	0	0	1.57
DN2-3	Classification and transformation of attribute measurement levels	9	6	3	0	0	0	0	1.33
DN2-4	Aggregation of spatial entities	12	7	4	1	0	0	0	1.50
DN3-1	Database change	11	6	3	2	0	0	0	1.64
DN3-2	Modeling database change	10	4	3	3	0	0	0	1.90
DN3-3	Reconciling database change	9	1	1	4	2	1	0	3.11
DN3-4	Managing versioned geospatial databases	8	3	3	2	0	0	0	1.88
Column Totals / Mean		**139**	**69**	**36**	**27**	**6**	**1**	**0**	**1.71**

Table A3.7 Ratings for Importance of Geocomputation Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (high importance), 2 (high-moderate importance), 3 (moderate importance), 4 (moderate-low importance), 5 (low importance), or 6 (no longer relevant). The red entries indicate topics where at least one respondent rated the importance as low or that the topic was no longer relevant at all.

Code	Topic	No. of responses	Ratings						Mean ratings
			1	2	3	4	5	6	
GC1-1	Origins	6	0	1	3	1	1	0	3.33
GC1-2	Trends	9	2	2	4	0	1	0	2.56
GC2-1	High performance computing	13	3	2	5	1	2	0	2.77
GC2-2	Computational intelligence	9	1	0	5	1	2	0	3.33
GC2-3	Non-linearity relationships and non-Gaussian distributions	10	0	4	2	3	1	0	3.10
GC2-4	Pattern recognition	9	4	3	1	1	0	0	1.89
GC2-5	Geospatial data classification	6	3	2	1	0	0	0	1.67
GC2-6	Multi-layer feed-forward neural networks	9	1	1	2	3	2	0	3.44
GC2-7	Space-scale algorithms	9	1	1	3	4	0	0	3.11
GC2-8	Rule learning	12	0	1	7	4	0	0	3.25
GC2-9	Neural network schemes	8	0	0	6	1	1	0	3.38
GC3-1	CA model structure	8	0	3	2	2	1	0	3.13
GC3-2	CA transition rule	10	0	2	3	4	1	0	3.40
GC3-3	CA simulation and calibration	9	0	1	4	2	2	0	3.56
GC3-4	Integration of CA and other geocomputation methods	10	1	3	3	2	1	0	2.90
GC3-5	Typical CA applications	8	0	2	4	0	2	0	3.25
GC4-1	Greedy heuristics	11	0	2	5	1	3	0	3.45
GC4-2	Interchange heuristics	8	0	2	4	0	2	0	3.25
GC4-3	Interchange with probability	10	0	2	2	3	3	0	3.70
GC4-4	Simulated annealing	8	0	1	3	2	2	0	3.63
GC4-5	Lagrangian relaxation	7	0	1	1	1	4	0	4.14
GC5-1	GA and global solutions	9	0	3	6	0	0	0	2.67
GC5-2	Genetic algorithms and artificial genomes	10	2	2	4	1	1	0	2.70
GC6-1	Structure of agent-based models	11	2	3	5	1	0	0	2.45
GC6-2	Specification of agent-based models	11	1	4	5	0	1	0	2.64
GC6-3	Adaptive agents	11	1	2	5	3	0	0	2.91
GC6-4	Microsimulation and calibration of agent activities	8	1	1	3	2	1	0	3.13
GC6-5	Encoding agent-based models	11	1	1	4	4	1	0	3.27
GC7-1	Simulation modeling	10	2	4	3	1	0	0	2.30
GC8-1	Definitions within a conceptual model of uncertainty	9	0	4	3	2	0	0	2.78

GC8-2	Error	12	7	4	1	0	0	0	1.50
GC8-3	Problems of scale and zoning	9	6	1	2	0	0	0	1.56
GC8-4	Propagation of error in geospatial modeling	8	1	5	2	0	0	0	2.13
GC8-5	Theory of error propagation	7	1	2	3	1	0	0	2.57
GC8-6	Problems of currency, source, and scale	7	5	0	2	0	0	0	1.57
GC9-1	Fuzzy logic	11	1	5	5	0	0	0	2.36
GC9-2	Fuzzy measures	12	2	4	3	3	0	0	2.58
GC9-3	Fuzzy aggregation operators	10	1	1	6	1	1	0	3.00
GC9-4	Standardization	8	1	2	2	3	0	0	2.88
GC9-5	Weighting schemes	9	0	4	3	2	0	0	2.78
Column Totals / Mean		**383**	**57**	**91**	**139**	**60**	**36**	**0**	**2.78**

Table A3.8 Ratings for Importance of Geospatial Data Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (high importance), 2 (high-moderate importance), 3 (moderate importance), 4 (moderate-low importance), 5 (low importance), or 6 (no longer relevant). The red entries indicate topics where at least one respondent rated the importance as low or that the topic was no longer relevant at all.

Code	Topic	No. of responses	Ratings						Mean ratings
			1	2	3	4	5	6	
GD1-1	History of understanding Earth's shape	14	5	4	1	3	1	0	2.36
GD1-2	Approximating the Earth's shape with geoids	10	7	2	1	0	0	0	1.40
GD1-3	Approximating the geoid with spheres and ellipsoids	13	7	3	1	2	0	0	1.85
GD2-1	Unsystematic methods	10	1	2	4	2	1	0	3.00
GD2-2	Systematic methods	8	1	4	2	0	1	0	2.50
GD3-1	Geographic coordinate system	8	6	1	1	0	0	0	1.38
GD3-2	Plane coordinate systems	13	12	0	1	0	0	0	1.15
GD3-3	Tessellated referencing systems	7	1	3	1	0	1	1	3.00
GD3-4	Linear referencing systems	10	1	4	4	1	0	0	2.50
GD4-1	Horizontal datums	8	5	1	2	0	0	0	1.63
GD4-2	Vertical datums	6	5	0	1	0	0	0	1.33
GD5-1	Map projection properties	13	9	1	3	0	0	0	1.54
GD5-2	Map projection classes	11	7	2	2	0	0	0	1.55
GD5-3	Map projection parameters	11	9	0	2	0	0	0	1.36
GD5-4	Georegistration	8	5	1	2	0	0	0	1.63
GD6-1	Geometric accuracy	11	7	2	2	0	0	0	1.55
GD6-2	Thematic accuracy	10	5	3	2	0	0	0	1.70

GD6-3	Resolution	6	4	0	2	0	0	0	1.67
GD6-4	Precision	9	6	2	1	0	0	0	1.44
GD6-5	Primary and secondary sources	11	6	1	3	1	0	0	1.91
GD7-1	Survey theory and electro-optical methods	12	5	0	4	3	0	0	2.42
GD7-2	Land records	14	3	3	5	3	0	0	2.57
GD7-3	Global Positioning System	11	8	2	1	0	0	0	1.36
GD8-1	Tablet digitizing	14	2	2	4	4	0	2	3.29
GD8-2	On-screen digitizing	9	4	1	3	1	0	0	2.11
GD8-3	Scanning and automated vectorization techniques	14	1	3	7	2	1	0	2.93
GD9-1	Sample size selection	10	3	6	1	0	0	0	1.80
GD9-2	Spatial sample types	8	3	3	2	0	0	0	1.88
GD9-3	Sample intervals	9	2	6	1	0	0	0	1.89
GD9-4	Field data technologies	10	4	3	3	0	0	0	1.90
GD10-1	Nature of aerial image data	10	5	3	2	0	0	0	1.70
GD10-2	Platforms and sensors	8	6	1	1	0	0	0	1.38
GD10-3	Aerial image interpretation	8	3	2	3	0	0	0	2.00
GD10-4	Stereoscopy and orthoimagery	14	2	5	2	3	2	0	2.86
GD10-5	Vector data extraction	8	2	1	3	0	2	0	2.88
GD10-6	Mission planning	10	1	1	5	1	2	0	3.20
GD11-1	Nature of multispectral image data	14	9	3	2	0	0	0	1.50
GD11-2	Platforms and sensors	11	4	6	1	0	0	0	1.73
GD11-3	Algorithms and processing	12	6	2	4	0	0	0	1.83
GD11-4	Ground verification and accuracy assessment	9	2	2	4	1	0	0	2.44
GD11-5	Applications and settings	12	1	2	3	5	1	0	3.25
GD12-1	Metadata	8	7	1	0	0	0	0	1.13
GD12-2	Content standards	13	5	3	2	1	1	1	2.46
GD12-3	Data warehouse	14	4	5	3	0	0	2	2.50
GD12-4	Exchange specifications	8	3	2	2	1	0	0	2.13
GD12-5	Transport protocols	8	2	4	2	0	0	0	2.00
GD12-6	Spatial data infrastructures	8	3	3	2	0	0	0	1.88
Column Totals / Mean		**383**	**209**	**111**	**110**	**34**	**13**	**6**	**1.99**

Table A3.9 Ratings for Importance of GIS&T & Society Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (high importance), 2 (high-moderate importance), 3 (moderate importance), 4 (moderate-low importance), 5 (low importance), or 6 (no longer relevant). The red entries indicate topics where at least one respondent rated the importance as low or that the topic was no longer relevant at all.

Code	Topic	No. of responses	Ratings						Mean ratings
			1	2	3	4	5	6	
GS1-1	The legal regime	8	1	2	4	0	0	1	2.88
GS1-2	Contract law	14	1	2	7	2	2	0	3.14
GS1-3	Liability	10	1	2	4	2	1	0	3.00
GS1-4	Privacy	6	3	2	1	0	0	0	1.67
GS2-1	Economics and the role of information	12	2	1	7	0	1	1	3.00
GS2-2	Valuing and measuring benefits	12	2	1	6	3	0	0	2.83
GS2-3	Models of benefits	10	2	3	4	1	0	0	2.40
GS2-4	Agency, organizational, and individual perspectives	10	1	2	4	1	0	2	3.30
GS2-5	Measuring costs	10	2	1	4	2	1	0	2.90
GS3-1	Uses of geospatial information in government	9	3	4	2	0	0	0	1.89
GS3-2	Public participation in governing	8	2	2	4	0	0	0	2.25
GS3-3	Public participation GIS	11	5	2	3	1	0	0	2.00
GS4-1	Property regimes	8	2	4	2	0	0	0	2.00
GS4-2	Mechanisms of control of geospatial information	11	5	1	3	1	1	0	2.27
GS4-3	Enforcing control	7	0	4	3	0	0	0	2.43
GS5-1	Incentives and barriers to sharing geospatial information	12	4	3	5	0	0	0	2.08
GS5-2	Data sharing among public and private agencies, organizations, and individuals	10	3	5	2	0	0	0	1.90
GS5-3	Legal mechanisms for sharing geospatial information	7	2	2	3	0	0	0	2.14
GS5-4	Balancing security and open access to geospatial information	9	5	2	1	1	0	0	1.78
GS6-1	Ethics and geospatial information	6	5	0	0	0	1	0	1.67
GS6-2	Codes of ethics for geospatial professionals	11	3	4	4	0	0	0	2.09
GS7-1	Epistemological critiques	10	2	2	4	1	0	1	2.80
GS7-2	Ethical critiques	10	5	0	4	1	0	0	2.10
GS7-3	Feminist critiques	10	2	2	3	2	0	1	2.90
GS7-4	Social critiques	9	3	1	5	0	0	0	2.22
Column Totals / Mean		**240**	**66**	**54**	**89**	**18**	**7**	**6**	**2.29**

Table A3.10 Ratings for Importance of Organizational & Institutional Aspects Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (high importance), 2 (high-moderate importance), 3 (moderate importance), 4 (moderate-low importance), 5 (low importance), or 6 (no longer relevant). The red entries indicate topics where at least one respondent rated the importance as low or that the topic was no longer relevant at all.

Code	Topic	No. of responses	Ratings						Mean ratings
			1	2	3	4	5	6	
OI1-1	Public sector origins	12	4	2	4	1	1	0	2.42
OI1-2	Private sector origins	11	2	2	5	1	1	0	2.73
OI1-3	Academic origins	6	1	3	1	1	0	0	2.33
OI1-4	Learning from experience	9	1	1	3	1	0	3	3.78
OI1-5	Future trends	8	4	2	2	0	0	0	1.75
OI2-1	Managing GIS operations and infrastructure	5	1	1	3	0	0	0	2.40
OI2-2	Ongoing GIS revision	9	3	2	2	2	0	0	2.33
OI2-3	Budgeting for GIS management	10	2	2	3	1	2	0	2.90
OI2-4	Database administration	6	3	0	3	0	0	0	2.00
OI2-5	System management	8	1	1	5	0	1	0	2.88
OI2-6	User support	9	1	3	3	0	1	1	3.00
OI3-1	Organizational models for GIS management	10	4	2	2	2	0	0	2.20
OI3-2	Organizational models for coordinating GISs and/or program participants and stakeholders	11	2	0	8	0	0	1	2.91
OI3-3	Integrating GIS&T with management information systems (MIS)	10	2	0	4	2	1	1	3.30
OI4-1	GIS&T staff development	9	2	0	4	2	0	1	3.11
OI4-2	GIS&T positions and qualifications	15	3	3	7	1	0	1	2.67
OI4-3	GIS&T training and education	8	3	1	3	1	0	0	2.25
OI4-4	Incorporating GIS&T into existing job classifications	9	1	3	1	0	2	2	3.56
OI5-1	Spatial data infrastructures	9	3	2	3	0	0	1	2.44
OI5-2	Adoption of standards	6	1	4	0	0	0	1	2.50
OI5-3	Technology transfer	13	1	3	4	2	0	3	3.46
OI5-4	Spatial data sharing among organizations	10	4	2	3	1	0	0	2.10
OI5-5	Openness	9	5	1	3	0	0	0	1.78
OI5-6	Balancing data access, security, and privacy	14	5	6	3	0	0	0	1.86
OI5-7	Implications of distributed GIS&T	7	2	4	1	0	0	0	1.86
OI5-8	Inter-organizational and vendor GISs (software, hardware, and systems)	11	1	2	7	0	0	1	2.91

OI6-1	Federal agencies and national and international organizations and programs	9	3	0	4	2	0	0	2.56
OI6-2	State and regional coordinating bodies	14	2	1	8	1	2	0	3.00
OI6-3	Professional organizations	16	3	2	5	3	3	0	3.06
OI6-4	Publications	10	2	2	4	1	0	1	2.80
OI6-5	The geospatial community	12	5	1	4	0	1	1	2.50
OI6-6	The geospatial industry	11	1	3	4	3	0	0	2.82
Column Totals and Means		**316**	**78**	**61**	**116**	**28**	**15**	**18**	**2.55**

Appendix 4: Tables Rating the Description of Topics by Knowledge Area

Table A4.1 Ratings of the Descriptions of Analytical Methods Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (superbly written), 2 (satisfactory as written), 3 (needs updating), or 4 (needs complete rewriting).

Code	Topic	No. of responses	Ratings				Mean ratings
			1	2	3	4	
AM1-1	Academic foundations	28	2	12	11	3	2.54
AM1-2	Academic foundations	26	2	14	10	0	2.31
AM2-1	Set theory	20	1	12	6	1	2.35
AM 2-2	Structured Query Language (SQL) and attribute queries	22	3	13	6	0	2.14
AM 2-3	Spatial queries	27	5	14	8	0	2.11
AM3-1	Distances and lengths	20	3	12	5	0	2.10
AM3-2	Direction	19	2	13	4	0	2.11
AM3-3	Shape	17	0	11	4	2	2.47
AM3-4	Area	19	1	15	3	0	2.11
AM3-5	Proximity and distance decay	0	0	0	0	0	0.00
AM3-6	Adjacency and connectivity	22	1	16	3	2	2.27
AM4-1	Buffers	20	3	13	2	2	2.15
AM4-2	Overlay	22	1	16	4	1	2.23
AM4-3	Neighborhoods	24	3	12	9	0	2.25
AM4-4	Map algebra	17	3	11	3	0	2.00
AM5-1	Point pattern analysis	21	4	11	5	1	2.14
AM5-2	Kernels and density estimation	19	4	9	5	1	2.16
AM5-3	Spatial cluster analysis	17	2	9	5	1	2.29
AM5-4	Spatial interaction	19	0	10	5	4	2.68
AM5-5	Analyzing multidimensional attribute	22	2	10	8	2	2.45
AM5-6	Cartographic modeling	21	2	5	7	7	2.90
AM5-7	Multi-criteria evaluation	17	1	9	6	1	2.41
AM5-8	Spatial process models	17	1	8	6	2	2.53
AM6-1	Calculating surface derivatives	16	0	10	6	0	2.38
AM6-2	Interpolation of surfaces	20	1	12	7	0	2.30
AM6-3	Surface features	18	0	11	5	2	2.50
AM6-4	Intervisibility	18	0	12	5	1	2.39
AM6-5	Friction surfaces	17	0	9	7	1	2.53
AM7-1	Graphical methods	18	0	8	7	3	2.72
AM7-2	Stochastic processes	17	2	9	4	2	2.35
AM7-3	The spatial weights matrix	20	1	16	3	0	2.10

AM7-4	Global measures of spatial association	16	2	9	4	1	2.25
AM7-5	Local measures of spatial association	16	2	8	6	0	2.25
AM7-6	Outliers	17	2	11	3	1	2.18
AM7-7	Bayesian methods	15	1	7	7	0	2.40
AM8-1	Spatial sampling for statistical analysis	19	2	11	5	1	2.26
AM8-2	Principles of semi-variogram construction	15	2	6	6	1	2.40
AM8-3	Semi-variogram modeling	18	3	10	4	1	2.17
AM8-4	Principles of kriging	18	2	12	3	1	2.17
AM8-5	Kriging variants	15	1	10	4	0	2.20
AM9-1	Principles of spatial econometrics	16	1	9	5	1	2.38
AM9-2	Spatial autoregressive models	16	2	9	2	3	2.38
AM9-3	Spatial filtering	18	0	11	4	3	2.56
AM9-4	Spatial expansion and geographically weighted	17	1	10	5	1	2.35
AM10-1	Problems of large spatial databases	15	1	4	9	1	2.67
AM10-2	Data mining approaches	17	1	8	7	1	2.47
AM10-3	Knowledge discovery	17	0	5	9	3	2.88
AM10-4	Pattern recognition and matching	13	0	5	6	2	2.77
AM11-1	Networks defined	12	1	6	5	0	2.33
AM11-2	Graph theoretic (descriptive) measures of	16	1	5	9	1	2.63
AM11-3	Least-cost (shortest) path	13	1	6	6	0	2.38
AM11-4	Flow modeling	13	1	7	5	0	2.31
AM11-5	The classic transportation problem	12	0	4	8	0	2.67
AM11-6	Other classic network problems	15	0	8	6	1	2.53
AM11-7	Accessibility modeling	10	0	5	4	1	2.60
AM12-1	Operations research modeling and location	12	0	8	4	0	2.33
AM12-2	Linear programming	19	0	9	6	4	2.74
AM12-3	Integer programming	16	0	5	7	4	2.94
AM12-4	Location-allocation modeling and p-median problems	14	0	9	5	0	2.36
Column Totals / Mean		**1,030**	**77**	**559**	**323**	**75**	**2.31**

Table A4.2 Ratings of the Descriptions of Conceptual Foundations Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (superbly written), 2 (satisfactory as written), 3 (needs updating), or 4 (needs complete rewriting).

Code	Topic	No. of responses	Ratings				Mean ratings
			1	2	3	4	
CF1-1	Metaphysics and ontology	10	2	3	3	2	2.50
CF1-2	Epistemology	13	2	5	3	3	2.54
CF1-3	Philosophical perspectives	12	1	6	2	3	2.58
CF2-1	Perception and cognition of geographic phenomena	8	0	3	5	0	2.63
CF2-2	From concepts to data	12	0	6	6	0	2.50
CF2-3	Geography as a foundation for GIS	14	2	6	4	2	2.43
CF2-4	Place and landscape	18	1	9	6	2	2.50
CF2-5	Common-sense geographies	12	1	3	3	5	3.00
CF2-6	Cultural influences	11	0	6	3	2	2.64
CF2-7	Political influences	12	0	5	5	2	2.75
CF3-1	Space	9	1	4	4	0	2.33
CF3-2	Time	8	0	4	3	1	2.63
CF3-3	Relationships between space and time	15	0	8	6	1	2.53
CF3-4	Properties	12	2	5	5	0	2.25
CF4-1	Discrete entities	10	2	4	4	0	2.20
CF4-2	Events and processes	13	0	7	4	2	2.62
CF4-3	Fields in space and time	15	1	6	5	3	2.67
CF4-4	Integrated models	11	0	2	5	4	3.18
CF5-1	Categories	15	1	9	5	0	2.27
CF5-2	Mereology: structural relationships	15	1	7	4	3	2.60
CF5-3	Genealogical relationships: lineage, inheritance	14	0	9	3	2	2.50
CF5-4	Topological relationships	14	2	7	4	1	2.29
CF5-5	Metrical relationships: distance and direction	15	3	8	3	1	2.13
CF5-6	Spatial distribution	10	2	3	4	1	2.40
CF5-7	Region	16	2	11	3	0	2.06
CF5-8	Spatial integration	13	0	4	4	5	3.08
CF6-1	Vagueness	19	1	12	6	0	2.26
CF6-2	Mathematical models of vagueness: Fuzzy sets and rough sets	15	1	8	5	1	2.40
CF6-3	Error-based uncertainty	17	0	13	4	0	2.24
CF6-4	Mathematical models of uncertainty: Probability and statistics	10	1	4	3	2	2.60

Column Totals / Mean	**388**	**29**	**187**	**124**	**48**	**2.43**

Table A4.3 Ratings for the Descriptions of Cartography & Visualization Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (superbly written), 2 (satisfactory as written), 3 (needs updating), or 4 (needs complete rewriting).

Code	Topic	No. of responses	Ratings				Mean ratings
			1	2	3	4	
CV1-1	History of cartography	10	0	4	5	1	2.70
CV1-2	Technological transformations	14	0	2	9	3	3.07
CV2-1	Source materials for mapping	10	0	4	4	2	2.80
CV2-2	Data abstraction: classification, selection, and generalization	10	0	6	4	0	2.40
CV2-3	Projections as a map design issue	9	1	5	3	0	2.22
CV3-1	Map design fundamentals	14	1	5	6	2	2.64
CV3-2	Basic concepts of symbolization	9	0	5	4	0	2.44
CV3-3	Color for cartography and visualization	9	1	4	3	1	2.44
CV3-4	Typography for cartography and visualization	11	2	6	3	0	2.09
CV4-1	Basic thematic mapping methods	8	1	4	3	0	2.25
CV4-2	Multivariate displays	12	1	5	5	1	2.50
CV4-3	Dynamic and interactive displays	8	1	1	4	2	2.88
CV4-4	Representing terrain	14	1	6	5	2	2.57
CV4-5	Web mapping and visualizations	11	0	2	5	4	3.18
CV4-6	Virtual and immersive environments	10	0	4	4	2	2.80
CV4-7	Spatialization	11	1	3	6	1	2.64
CV4-8	Visualization of temporal geographic data	14	0	7	6	1	2.57
CV4-9	Visualization of uncertainty	9	0	7	2	0	2.22
CV5-1	Computational issues in cartography and visualization	10	1	4	5	0	2.40
CV5-2	Map production	12	0	2	7	3	3.08
CV5-3	Map reproduction	7	0	2	4	1	2.86
CV6-1	The power of maps	12	2	4	5	1	2.42
CV6-2	Map reading	8	1	4	3	0	2.25
CV6-3	Map interpretation	8	0	5	3	0	2.38
CV6-4	Map analysis	10	0	4	4	2	2.80
CV6-5	Evaluation and testing	9	1	5	3	0	2.22
CV6-6	Impact of uncertainty	13	0	6	3	4	2.85
Column Totals and Means		**282**	**15**	**116**	**118**	**33**	**2.49**

Table A4.4 Ratings for the Descriptions of Design Aspects Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (superbly written), 2 (satisfactory as written), 3 (needs updating), or 4 (needs complete rewriting).

Code	Topic	No. of responses	Ratings				Mean ratings
			1	2	3	4	
DA1-1	Using models to represent information and processes	14	0	8	2	4	2.71
DA1-2	Components of models: data, structures, procedures	12	0	5	2	5	3.00
DA1-3	The scope of GIS&T applications	11	0	2	6	3	3.09
DA1-4	The scope of GIS&T design	8	0	1	4	3	3.25
DA1-5	The process of GIS&T design	10	0	2	5	3	3.10
DA2-1	Problem definition	7	0	2	3	2	3.00
DA2-2	Planning for design	10	0	3	5	2	2.90
DA2-3	Application user assessment	8	0	3	5	0	2.63
DA2-4	Requirements analysis	12	0	3	8	1	2.83
DA2-5	Social, political, and cultural issues	10	0	3	3	4	3.10
DA3-1	Feasibility analysis	11	0	6	4	1	2.55
DA3-2	Software systems	9	0	0	5	4	3.44
DA3-3	Data costs	10	0	4	4	2	2.80
DA3-4	Labor and management	6	0	3	1	2	2.83
DA3-5	Capital: facilities and equipment	9	0	2	5	2	3.00
DA3-6	Funding	9	0	3	3	3	3.00
DA4-1	Modeling tools	11	0	2	8	1	2.91
DA4-2	Conceptual model	13	0	7	6	0	2.46
DA4-3	Logical models	11	0	5	6	0	2.55
DA4-4	Physical models	9	0	3	6	0	2.67
DA5-1	Recognizing analytical components	8	0	3	4	1	2.75
DA5-2	Identifying and designing analytical procedures	12	0	6	4	2	2.67
DA5-3	Coupling scientific models with GIS	6	0	1	2	3	3.33
DA5-4	Formalizing a procedure design	8	0	0	7	1	3.13
DA6-1	Workflow analysis and design	7	0	2	5	0	2.71
DA6-2	User interfaces	11	1	2	3	5	3.09
DA6-3	Development environments for geospatial applications	11	0	1	5	5	3.36
DA6-4	Computer-Aided Software Engineering (CASE) tools	12	0	7	1	4	2.75
DA7-1	Implementation planning	12	0	6	4	2	2.67
DA7-2	Implementation tasks	6	0	2	4	0	2.67
DA7-3	System testing	7	0	3	4	0	2.57
DA7-4	System deployment	9	0	4	2	3	2.89
Column Totals and Means		**309**	**1**	**104**	**136**	**68**	**2.80**

Table A4.5 Ratings for the Descriptions of Data Modeling Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (superbly written), 2 (satisfactory as written), 3 (needs updating), or 4 (needs complete rewriting).

Code	Topic	No. of responses	Ratings				Mean ratings
			1	2	3	4	
DM1-1	Basic data structures	9	0	2	5	2	3.00
DM1-2	Data retrieval strategies	12	1	5	4	2	2.58
DM2-1	Coevolution of DBMS and GIS	8	0	1	5	2	3.13
DM2-2	Relational DBMS	10	0	5	5	0	2.50
DM2-3	Object-oriented DBMS	11	0	3	7	1	2.82
DM2-4	Extensions of the relational model	13	0	3	8	2	2.92
DM3-1	Grid representations	11	0	8	3	0	2.27
DM3-2	The raster model	10	0	5	5	0	2.50
DM3-3	Grid compression methods	9	0	3	6	0	2.67
DM3-4	The hexagonal model	11	0	8	3	0	2.27
DM3-5	The Triangulated Irregular Network (TIN) model	11	1	6	4	0	2.27
DM3-6	Resolution	12	0	4	8	0	2.67
DM3-7	Hierarchical data models	14	0	7	7	0	2.50
DM4-1	Geometric primitives	10	2	4	3	1	2.30
DM4-2	The spaghetti model	9	1	4	4	0	2.33
DM4-3	The topological model	11	1	4	6	0	2.45
DM4-4	Classic vector data models	7	0	3	4	0	2.57
DM4-5	The network model	10	1	4	5	0	2.40
DM4-6	Linear referencing	8	0	4	4	0	2.50
DM	Apr Object-based spatial databases	7	0	3	4	0	2.57
DM5-1	Spatio-temporal GIS	10	0	3	6	1	2.80
DM5-2	Modeling uncertainty	12	0	5	5	2	2.75
DM5-3	Modeling three-dimensional (3-D) entities	10	0	5	3	2	2.70
Column Totals / Mean		**235**	**7**	**99**	**114**	**15**	**2.48**

Table A4.6 Ratings for the Descriptions of Data Manipulation Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (superbly written), 2 (satisfactory as written), 3 (needs updating), or 4 (needs complete rewriting).

Code	Topic	No. of responses	Ratings				Mean ratings
			1	2	3	4	
DN1-1	Impacts of transformations	9	0	3	6	0	2.67
DN1-2	Data model and format conversion	8	0	2	4	2	3.00
DN1-3	Interpolation	12	0	6	4	2	2.67
DN1-4	Vector-to-raster and raster-to-vector conversions	12	0	7	5	0	2.42
DN1-5	Raster resampling	11	0	6	4	1	2.55
DN1-6	Coordinate transformations	8	0	5	2	1	2.50
DN2-1	Scale and generalization	11	1	4	4	2	2.64
DN2-2	Approaches to point, line, and area generalization	6	0	3	2	1	2.67
DN2-3	Classification and transformation of attribute measurement levels	8	0	3	4	1	2.75
DN2-4	Aggregation of spatial entities	11	1	6	4	0	2.27
DN3-1	Database change	11	6	3	2	0	1.64
DN3-2	Modeling database change	10	4	3	3	0	1.90
DN3-3	Reconciling database change	9	1	1	4	2	3.11
DN3-4	Managing versioned geospatial databases	8	3	3	2	0	1.88
Column Totals / Mean		**134**	**16**	**55**	**50**	**12**	**2.31**

Table A4.7 Ratings for the Descriptions of Geocomputation Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (superbly written), 2 (satisfactory as written), 3 (needs updating), or 4 (needs complete rewriting).

Code	Topic	No. of responses	Ratings				Mean ratings
			1	2	3	4	
GC1-1	Origins	6	0	2	3	1	2.83
GC1-2	Trends	9	1	1	4	3	3.00
GC2-1	High performance computing	13	0	5	4	4	2.92
GC2-2	Computational intelligence	8	0	3	3	2	2.88
GC2-3	Non-linearity relationships and non-Gaussian distributions	10	0	5	3	2	2.70
GC2-4	Pattern recognition	9	0	3	1	5	3.22
GC2-5	Geospatial data classification	6	0	2	1	3	3.17
GC2-6	Multi-layer feed-forward neural networks	8	0	4	3	1	2.63

GC2-7	Space-scale algorithms	9	0	2	3	4	3.22
GC2-8	Rule learning	12	0	5	1	6	3.08
GC2-9	Neural network schemes	9	0	5	2	2	2.67
GC3-1	CA model structure	8	0	2	4	2	3.00
GC3-2	CA transition rule	10	0	4	5	1	2.70
GC3-3	CA simulation and calibration	9	0	3	3	3	3.00
GC3-4	Integration of CA and other geocomputation methods	10	0	5	3	2	2.70
GC3-5	Typical CA applications	8	0	1	4	3	3.25
GC4-1	Greedy heuristics	11	0	6	4	1	2.55
GC4-2	Interchange heuristics	8	0	3	3	2	2.88
GC4-3	Interchange with probability	10	0	4	3	3	2.90
GC4-4	Simulated annealing	8	0	2	1	5	3.38
GC4-5	Lagrangian relaxation	7	0	2	1	4	3.29
GC5-1	GA and global solutions	9	0	3	3	3	3.00
GC5-2	Genetic algorithms and artificial genomes	10	1	3	5	1	2.60
GC6-1	Structure of agent-based models	11	0	5	4	2	2.73
GC6-2	Specification of agent-based models	11	0	6	2	3	2.73
GC6-3	Adaptive agents	11	0	2	4	5	3.27
GC6-4	Microsimulation and calibration of agent activities	8	1	3	1	3	2.75
GC6-5	Encoding agent-based models	11	0	6	2	3	2.73
GC7-1	Simulation modeling	9	0	1	6	2	3.11
GC8-1	Definitions within a conceptual model of uncertainty	9	0	4	2	3	2.89
GC8-2	Error	12	2	2	5	3	2.75
GC8-3	Problems of scale and zoning	9	0	4	3	2	2.78
GC8-4	Propagation of error in geospatial modeling	8	0	4	3	1	2.63
GC8-5	Theory of error propagation	7	1	2	2	2	2.71
GC8-6	Problems of currency, source, and scale	7	1	1	3	2	2.86
GC9-1	Fuzzy logic	11	0	6	3	2	2.64
GC9-2	Fuzzy measures	12	1	4	6	1	2.58
GC9-3	Fuzzy aggregation operators	10	0	5	4	1	2.60
GC9-4	Standardization	8	0	2	3	3	3.13
GC9-5	Weighting schemes	9	0	2	3	4	3.22
Column Totals / Mean		**370**	**8**	**134**	**123**	**105**	**2.82**

Table A4.8 Ratings for the Descriptions of Geospatial Data Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (superbly written), 2 (satisfactory as written), 3 (needs updating), or 4 (needs complete rewriting).

Code	Topic	No. of responses	Ratings				Mean ratings
			1	2	3	4	
GD1-1	History of understanding Earth's shape	14	2	7	3	2	2.36
GD1-2	Approximating the Earth's shape with geoids	10	1	5	2	2	2.50
GD1-3	Approximating the geoid with spheres and ellipsoids	13	1	7	3	2	2.46
GD2-1	Unsystematic methods	10	0	6	3	1	2.50
GD2-2	Systematic methods	7	0	4	2	1	2.57
GD3-1	Geographic coordinate system	8	0	3	5	0	2.63
GD3-2	Plane coordinate systems	13	1	7	5	0	2.31
GD3-3	Tessellated referencing systems	6	0	3	2	1	2.67
GD3-4	Linear referencing systems	9	0	5	3	1	2.56
GD4-1	Horizontal datums	8	0	1	5	2	3.13
GD4-2	Vertical datums	6	0	2	3	1	2.83
GD5-1	Map projection properties	13	1	7	2	3	2.54
GD5-2	Map projection classes	10	0	6	2	2	2.60
GD5-3	Map projection parameters	10	2	4	2	2	2.40
GD5-4	Georegistration	8	1	4	2	1	2.38
GD6-1	Geometric accuracy	11	1	3	6	1	2.64
GD6-2	Thematic accuracy	10	0	5	4	1	2.60
GD6-3	Resolution	6	0	3	2	1	2.67
GD6-4	Precision	9	2	5	1	1	2.11
GD6-5	Primary and secondary sources	11	1	7	1	2	2.36
GD7-1	Survey theory and electro-optical methods	11	1	5	4	1	2.45
GD7-2	Land records	14	1	4	8	1	2.64
GD7-3	Global Positioning System	11	0	2	7	2	3.00
GD8-1	Tablet digitizing	12	0	6	2	4	2.83
GD8-2	On-screen digitizing	9	0	7	1	1	2.33
GD8-3	Scanning and automated vectorization techniques	14	0	7	6	1	2.57
GD9-1	Sample size selection	10	2	6	1	1	2.10
GD9-2	Spatial sample types	8	0	5	2	1	2.50
GD9-3	Sample intervals	9	0	7	0	2	2.44
GD9-4	Field data technologies	10	0	2	5	3	3.10
GD10-1	Nature of aerial image data	10	0	4	5	1	2.70
GD10-2	Platforms and sensors	8	0	0	4	4	3.50
GD10-3	Aerial image interpretation	8	0	4	3	1	2.63

GD10-4	Stereoscopy and orthoimagery	14	0	5	8	1	2.71
GD10-5	Vector data extraction	8	0	2	3	3	3.13
GD10-6	Mission planning	10	0	5	3	2	2.70
GD11-1	Nature of multispectral image data	13	1	8	2	2	2.38
GD11-2	Platforms and sensors	11	0	3	6	2	2.91
GD11-3	Algorithms and processing	12	0	4	5	3	2.92
GD11-4	Ground verification and accuracy assessment	8	0	3	3	2	2.88
GD11-5	Applications and settings	12	0	3	5	4	3.08
GD12-1	Metadata	8	0	5	3	0	2.38
GD12-2	Content standards	12	0	3	8	1	2.83
GD12-3	Data warehouse	12	1	7	4	0	2.25
GD12-4	Exchange specifications	8	0	2	4	2	3.00
GD12-5	Transport protocols	8	0	2	5	1	2.88
GD12-6	Spatial data infrastructures	8	1	2	5	0	2.50
Column Totals / Mean		**470**	**20**	**207**	**170**	**73**	**2.59**

Table A4.9 Ratings for the Descriptions of GIS&T & Society Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (superbly written), 2 (satisfactory as written), 3 (needs updating), or 4 (needs complete rewriting).

Code	Topic	No. of responses	Ratings				Mean ratings
			1	2	3	4	
GS1-1	The legal regime	7	0	2	1	4	3.29
GS1-2	Contract law	14	1	5	4	4	2.79
GS1-3	Liability	10	0	4	3	3	2.90
GS1-4	Privacy	6	0	2	2	2	3.00
GS2-1	Economics and the role of information	11	0	8	1	2	2.45
GS2-2	Valuing and measuring benefits	12	0	5	6	1	2.67
GS2-3	Models of benefits	11	0	6	4	1	2.55
GS2-4	Agency, organizational, and individual perspectives	8	0	2	4	2	3.00
GS2-5	Measuring costs	10	0	3	6	1	2.80
GS3-1	Uses of geospatial information in government	8	0	3	4	1	2.75
GS3-2	Public participation in governing	8	0	3	3	2	2.88
GS3-3	Public participation GIS	11	1	2	5	3	2.91
GS4-1	Property regimes	8	0	2	5	1	2.88
GS4-2	Mechanisms of control of geospatial information	11	0	4	6	1	2.73
GS4-3	Enforcing control	7	0	4	2	1	2.57

GS5-1	Incentives and barriers to sharing geospatial information	12	1	6	2	3	2.58
GS5-2	Data sharing among public and private agencies, organizations, and individuals	10	0	2	3	5	3.30
GS5-3	Legal mechanisms for sharing geospatial information	7	0	4	1	2	2.71
GS5-4	Balancing security and open access to geospatial information	9	0	2	2	5	3.33
GS6-1	Ethics and geospatial information	7	0	3	2	2	2.86
GS6-2	Codes of ethics for geospatial professionals	11	0	4	4	3	2.91
GS7-1	Epistemological critiques	8	0	3	2	3	3.00
GS7-2	Ethical critiques	10	0	5	4	1	2.60
GS7-3	Feminist critiques	9	0	4	2	3	2.89
GS7-4	Social critiques	9	0	4	4	1	2.67
Column Totals / Mean		**234**	**3**	**92**	**82**	**57**	**2.73**

Table A4.10 Ratings for the Descriptions of Organizational & Institutional Aspects Topics Included in 2006 GIS&T BoK. Respondents were asked to mark each topic with a 1 (superbly written), 2 (satisfactory as written), 3 (needs updating), or 4 (needs complete rewriting).

Code	Topic	No. of responses	Ratings				Mean ratings
			1	2	3	4	
OI1-1	Public sector origins	12	0	7	4	1	2.50
OI1-2	Private sector origins	11	0	4	7	0	2.64
OI1-3	Academic origins	6	0	1	5	0	2.83
OI1-4	Learning from experience	6	0	3	2	1	2.67
OI1-5	Future trends	8	0	1	4	3	3.25
OI2-1	Managing GIS operations and infrastructure	5	0	2	2	1	2.80
OI2-2	Ongoing GIS revision	9	0	1	6	2	3.11
OI2-3	Budgeting for GIS management	10	0	6	3	1	2.50
OI2-4	Database administration	6	0	2	2	2	3.00
OI2-5	System management	8	0	2	5	1	2.88
OI2-6	User support	8	0	3	5	0	2.63
OI3-1	Organizational models for GIS management	10	0	7	2	1	2.40
OI3-2	Organizational models for coordinating GISs and/or program participants and stakeholders	10	0	6	3	1	2.50

OI3-3	Integrating GIS&T with management information systems (MIS)	9	0	3	3	3	3.00
OI4-1	GIS&T staff development	8	0	6	2	0	2.25
OI4-2	GIS&T positions and qualifications	14	0	7	6	1	2.57
OI4-3	GIS&T training and education	8	0	4	3	1	2.63
OI4-4	Incorporating GIS&T into existing job classifications	7	0	3	2	2	2.86
OI5-1	Spatial data infrastructures	8	0	2	4	2	3.00
OI5-2	Adoption of standards	5	0	2	3	0	2.60
OI5-3	Technology transfer	10	0	6	4	0	2.40
OI5-4	Spatial data sharing among organizations	10	0	4	4	2	2.80
OI5-5	Openness	9	0	1	4	4	3.33
OI5-6	Balancing data access, security, and privacy	14	0	6	3	5	2.93
OI5-7	Implications of distributed GIS&T	7	0	2	2	3	3.14
OI5-8	Inter-organizational and vendor GISs (software, hardware, and systems)	10	0	5	3	2	2.70
OI6-1	Federal agencies and national and international organizations and programs	9	0	3	5	1	2.78
OI6-2	State and regional coordinating bodies	14	1	6	4	3	2.64
OI6-3	Professional organizations	16	0	7	8	1	2.63
OI6-4	Publications	9	0	3	3	3	3.00
OI6-5	The geospatial community	11	2	3	0	6	2.91
OI6-6	The geospatial industry	11	0	3	3	5	3.18
Column Totals / Mean		**298**	**3**	**121**	**116**	**58**	**2.70**