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Targeting Disciplines for GIS Outreach Using Bibliometric Analysis

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Academic libraries increasingly offer geospatial services to support the teaching and research activities of all university disciplines. Ironically, services tend to be most used by those who are already routinely using geographic information systems (GIS) in their research and similar activities. We present a workflow by which library-based GIS service providers can identify, connect, and foster relationships with potential GIS users who stand to benefit the most from their services. Potential users include those who are not currently aware of GIS and its potential contribution to their particular discipline. The workflow begins with a bibliometric analysis to assess trends in the usage of GIS across a variety of disciplines. The result of the bibliometric analysis is a categorized list of those departments that stand to benefit the most from GIS services, based on Diffusion of Innovation Theory. Library-based GIS service providers can partner with liaison-librarians who serve as "change agents" to bring geospatial services into those disciplines not involved with GIS. From this, GIS service providers and liaison-librarians can connect with "opinion leaders" within each department to help diffuse GIS throughout their discipline by helping to organize seminars where library GIS service providers can educate departmental faculty. The goal of this workflow is to help library-based GIS service providers identify and collaborate with faculty who stand to benefit the most from GIS services at the library.

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KEYWORDS bibliometrics, diffusion of innovations, early adopters, GIS workflow, Diffusion of Innovation Theory, library-based GIS services, GIS-savvy users

INTRODUCTION

Geographic information systems (GIS) is a term that refers to technologies designed to capture, store, query, and analyze spatial and geographic data. GIS is used within many academic fields (e.g., Couclelis 2004) and is also worthy of study in its own right by the disciplines of cartography, remote sensing, and GIScience (Gold 2006; UCGIS 2006). The prominence of GIS in academe and society is expected to increase coincident with rapid technological evolution, especially in remote sensing applications, mobile devices, and Big Data analytics (Kerski 2015; Guan and Bol 2012). "GIS is a good example of an IT tool that can be used to analyze and visualize huge quantities of historical and topical geo-data and invite new in-depth studies" (Jensen 2012, 73). Those university educational programs that prepare the next generation of GIS professionals are typically centered in academic departments of geography, whereas programs that train students in the application of GIS as a tool in a particular discipline are more diffuse across institutions of higher learning. In recent years, academic research libraries have begun to play a larger role as central providers of GIS services including providing educational opportunities to their university communities (March 2011; Abresch et al. 2008; Argentati 1997). However, with limited resources, an unanswered question remains, i.e., how to strategically design and implement library-offered GIS services so as to maximize their impact (MaKinster et al. 2014). In this article, we propose one way to target specific academic departments (i.e., disciplines) for library-initiated GIS outreach and education based on anticipated impact using bibliometric analysis and the application of Diffusion of Innovation Theory. Bibliometric analysis has been used in the past to understand the usage of GIS outside of geography (e.g., Allen 2005), and we extend this work of using bibliometrics as a first step in a larger workflow that aims to help connect library-based GIS support services with potential new users of GIS.

Potential GIS users across the university fall into two categories whose needs must be assessed using different methods. The first group consists of people who already understand how GIS can be leveraged for research or teaching within their discipline. These users need to be made aware of potential collaborations and training opportunities offered across the university, but do not need to be convinced of the utility of GIS in their discipline(s). This has been the target audience of many library-based GIS support services and the challenge in assessing the needs of this group is merely to seek their input, compile their responses, and develop the requisite support services within the library. The needs of this group are usually assessed through generic surveys to the university community. Many library-based GIS support services have been successful in reaching this population of GIS users (Scaramozzino et al. 2014).

The second group of stakeholders includes university researchers and educators who may not know what GIS is or the full extent of what it can offer their discipline. These stakeholders may be unlikely to respond to surveys and/or be unable to articulate their GIS support service needs (Dodsworth 2010). Currently there is a lack of well-established methods to identify members of this group. One notable exception within the literature is detailed in an article by Dodsworth (2010), which aimed to move beyond providing GIS support to only current GIS users. Dodsworth (2010) developed a library-based indirect outreach campaign specifically to reach non-GIS users. A result of her program was a six-fold increase over five years in non-GIS users taking advantage of library-based GIS services, which outpaced the growth of GIS-savvy service users over the same time period. This single anecdote suggests the largely untapped potential for library-based GIS services to positively impact non-GIS users, perhaps even more so than GIS-savvy users. Reaching non-GIS users with library-based GIS services remains a challenge of contemporary academic libraries and provides a fruitful area of research and an opportunity to increase the impact of library services.

BACKGROUND

An innovation is a new or perceived new "idea, practice, or object" (Rogers 1995, 11). As long as the idea is unknown to a group, it can be considered an innovation regardless of the recency of the idea or technology. *Diffusion of Innovation Theory* is a framework that describes the adoption of an innovation across a group or society. The theory describes the communication, persuasion, decision-making, and implementation of an innovation over time (Rogers 1995). Diffusion of innovations is mediated by social change, that is, it works through communication channels within a social system (Rogers 1995). In nongeography disciplines, the application of GIS as a methodological innovation should follow Diffusion of Innovation Theory. For example, the application of GIS to some nongeography disciplines is not new; however, for other disciplines the tools, methods, and incorporation of spatial thinking could be considered innovative. Diffusion of Innovation Theory has been used in many academic research domains (e.g., Hameed et al. 2012; Damanpour and Wischnevsky 2006; Frambach and Schillewaert 2002) and has recently been associated with GIS diffusion in education (e.g., Milson et al. 2012; Baker and Bednarz 2003).

Characteristics of Innovation

Rogers (1995) identifies several characteristics of innovations. First, the innovation must be advantageous compared to its predecessor. For many disciplines, there is no tool or method predecessors to GIS because spatial context had not previously been considered. Second, the innovation must be compatible with existing methods, meaning that the innovation must complement the well-established tools and methods of a discipline rather than replace them. Third, the innovation must not be too complex for an individual or group to understand. Some faculty may understand the advantages of GIS in their research or teaching, however, they may have not had the time to invest in learning GIS on their own. Fourth, the innovation must be testable, meaning individuals must be able to try the technology to form their own opinions toward it. As geospatial services in libraries increase, researchers and educators across the university campus will have greater opportunity to engage with GIS and form their own opinions in a low commitment way. Finally, Diffusion of Innovation Theory emphasizes the influence of peers on the formation of opinions towards a new innovation. As individuals see colleagues around them adopting an innovation in their own work and being rewarded for it, the more likely they are to engage with the innovation themselves.

Adoption of Innovations

Innovations tend to diffuse through social systems with some regularity and predictability (Figure 1). Adoption of the innovation begins with an *innovation phase* whereby the innovators are the first users. When just the innovators are using a particular technology, usage is low relative to the entire population of potential users. If the innovation shows promise, gradually a second group of users known as "early adopters" incorporate the innovation into their work during the *early adoption phase*. Adoption of the innovation remains slow until the next phase of diffusion, known as the *takeoff phase*, begins. The takeoff phase is dominated by what Rogers (1995) calls the "majority" after which the innovation is likely well-accepted in the population of users. The takeoff phase is perhaps the most exciting period in the adoption of any innovation and is often the realm of research and therefore the focus of academics. Prior to takeoff, there is likely little familiarity with the innovation and therefore skepticism, whereas following the takeoff phase the innovation has likely lost its novelty. In the case of the addition of a new innovation in academic work, adopting a new technology is most innovative before the loss of novelty (i.e., adoption of GIS by a nonuser in geography is unlikely to be celebrated as innovative because the innovation has already reached its saturation point in this discipline). The so-called "late-adopters" are the last group within the community to adopt the innovation. The late-adopters join once there has been a large increase in adoption across a population. At this point, the innovation will reach the *saturation phase* by which the majority of the group uses the particular innovation.

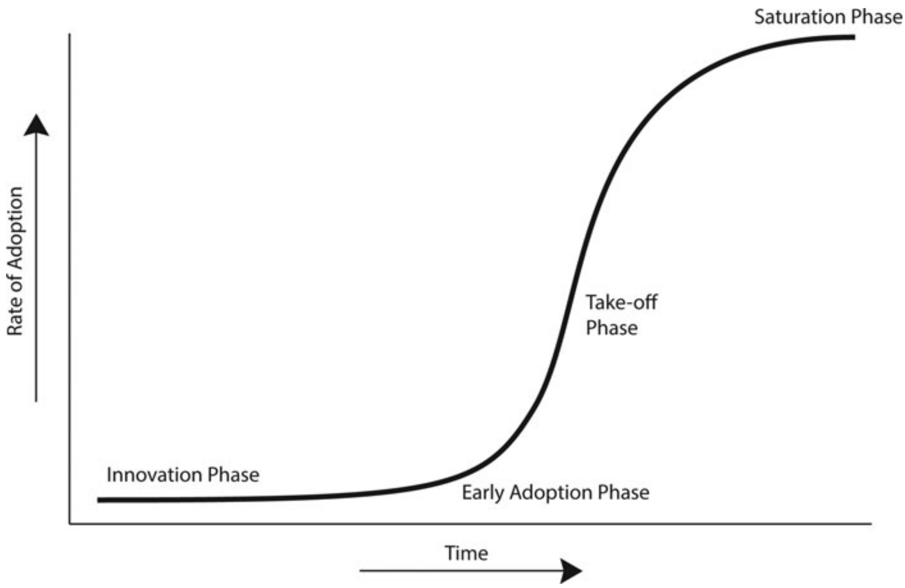

FIGURE 1 Illustration of the diffusion of innovation and ideal curve for diffusion of GIS across university disciplines. Adapted from Rogers (1995).

Communication, Diffusion, and Social Structure

The diffusion of an innovation relies on communication through a social structure about the innovation. Diffusion of Innovation Theory identifies several actors who participate in the diffusion. The *change agent*, or the individual who aims to persuade the group to utilize the new technology, must have some similarity to the group. Similarity with the rest of the group means these individuals share the same culture, language, and social contexts, and this homophyly means these similar individuals will be more effective communicators. *Opinion leaders* are more influential in the uptake of an innovation than one particular change agent. Opinion leaders are individuals who are able to influence others. Opinion leadership is designated through the workings of the social system. These individuals do not necessarily hold high esteem in a group, but they do drive behavior within their social system because they are central within a communication network. This network connects communication and knowledge within the social system. How the opinion leaders interact with a change agent can put their centrality within the network in peril; being cautious while still helping to drive change is necessary to maintain their status within the group.

Bibliometrics and GIS

Bibliometric analysis has become a well-accepted method, especially in the library and information profession, to quantitatively and qualitatively analyze trends in publications (Liu et al. 2016; Tian et al. 2008; Cronin 2001), and can provide one way in which to identify where in the diffusion phases a discipline falls at a given point in time. This type of analysis has been used to evaluate publishing trends both within GISscience and to better understand trends in using GIS outside of the geography discipline (Wei et al. 2015; Mohamad et al. 2013; Allen 2005). Several of these bibliometric research endeavors have implications for the present study. Allen (2005) used bibliometric analysis to identify publication trends on GIS use in agricultural disciplines. Results of the study illustrated that natural resources, urban planning, and environmental sciences were the top agricultural subfields that were using GIS.

Mohamad et al. (2013) used bibliometric analysis to identify patterns in publications about GIS that focused on identifying the research areas currently using GIS, trends in publications over time, types of documents published, as well as language and affiliation of the authorship. The results of their study identified that GIS publications were largely from the United States and were published in English. Their results also showed that publications about GIS are increasing, and these articles mainly focused on the environmental sciences and ecology (Mohamad et al. 2013).

More recent research has aimed at using other bibliometric analysis methods to identify trends, changes, and connections between literatures on GIS. Wei and others (2015) used a document co-citation analysis to investigate evolution of the GIS knowledge domain over time. This research project used network analysis methods to identify connections, and changes within a set of literature. Their study was novel in the type of analysis used, although the authors note its limitations to understanding trends in GIS publishing. Their results revealed that GIS is used across a wide variety of disciplines "which are tied together by GIS technology" (Wei et al. 2015, 382). Similar to Wei et al. (2015), Liu et al. (2016) used network analysis methods to identify connections between authors on topics related to GIS as well as to identify disciplines that are using GIS methods. They found that the top disciplines using GIS were environmental sciences, multidisciplinary geosciences, and ecology.

METHODS

Applying Diffusion of Innovation Theory to the problem of targeting non-geography disciplines for library-based outreach activities suggests a set of methods and general workflow (Figure 2).

First, bibliometric analysis can be used to identify disciplines that are in the takeoff phase of adoption of GIS into their toolbox of well-accepted methods; next, disciplines can be categorized based on their diffusion of innovation phase and those in the takeoff phase can be prioritized; third,

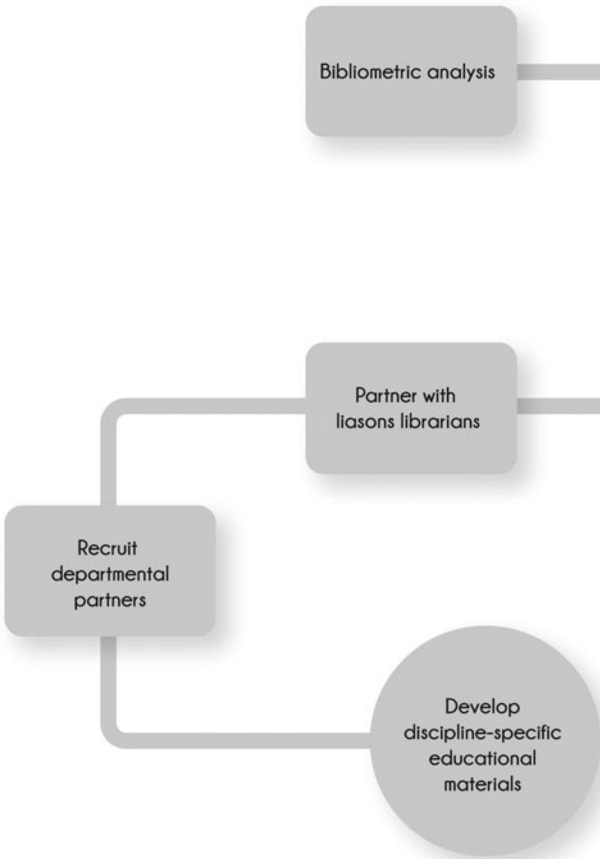

FIGURE 2 Flowchart of how proposed method for using bibliometrics allows for the categorization of disciplines by diffusion stage, followed by partnering with liaison-librarians, and connecting with new departments to develop partnerships for collaboration between the library and the departments that serve to benefit the most.

library-based GIS service providers can partner with liaison-librarians to be change agents in academic departments; fourth, departmental partners can be solicited as opinion leaders in their fields to promote GIS; and fifth, a discipline-specific GIS outreach and education campaign can be developed and implemented for as many high-priority departments as library resources allow. Assuming that bibliometric analysis accurately describes the promise for adoption of GIS into new disciplines, this workflow will ensure that library-based GIS resources are allocated in the most efficient way possible to maximize impact on the university community. "Impact" here is defined as the extent to which library GIS services positively affect the research and teaching practices of departmental faculty and the reputation of university departments as methodological innovators in their respective disciplines.

Why focus on faculty? This focus comes from the perspective that recruiting even just one faculty member to incorporate the teaching of GIS methods in their graduate and undergraduate courses will likely reach more students than library-based GIS service providers could by interacting with students themselves on a one-on-one basis. The authors do not suggest that academic libraries abandon student-focused GIS services, but rather, that departmental faculty may be the conduit (opinion leaders) to introduce GIS tools and methods into their departments and disciplines. In doing so, we hope that they are celebrated as innovators in their fields, and therefore demonstrate the positive impact of offering library-based GIS services to the university.

Using Bibliometric Analysis to Identify Trends

The present study interpreted trends in academic publishing (i.e., bibliometric analysis) as an indicator of adoption of GIS in the tools and methods of academic disciplines. The objective of this step was to identify disciplines that are in the "takeoff" phase and are presently on the very steep slope of the adoption curve as an example of how to begin to follow the proposed workflow. Ideally, these disciplines have begun to use GIS in new ways and at least a few innovators have been successful at publishing this methodological innovation in the primary literature. At this early stage of adoption it is unlikely that there is a faculty-member at every institution using GIS in their discipline; however, faculty-members may be aware of peers at other institutions who have used GIS in exciting new ways in their work.

To demonstrate the use of bibliometric analysis to analyze adoption of GIS in academic disciplines, we used the database tool SciVal to generate a time-series of publications (Table 1, Table 2), although any database of primary literature (or other scholarly output) could be used. SciVal is a value-added tool produced by the company Elsevier that searches the Scopus database of primary literature and is commonly used by university administrations to compare scholarly output between and across institutions (Vardell et al. 2011).

At the time of publication, SciVal indexed publications from 1996 to the present. Since GIS has become more popular in academic research primarily beginning in the 1990s (Liu et al. 2016), the 1996 cutoff year served as a good starting point for bibliometric analysis. To search the database for GIS adoption in disciplines, we used the keyword search term "GIS" in combination with the name of the academic departments at our home institution for the time-period 1996–2015. Academic departments were deemed the most comprehensive search terms for all the disciplines at the university. However, others performing bibliometric analysis could use the names of the academic departments at their institutions or any other terms to describe the disciplines at an institution. The conjunction term used for the search was "AND." There was a total of 131 searches conducted for 95 department

TABLE 1 The Raw Results from Our Bibliometric Analysis from SciVal

	Year																			
Search Term	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Innovation Phase																				
Accounting AND GIS	0	1	0	1	1	1	2	0	1	3	3	2	8	6	7	10	7	9	10	11
Acoustics AND GIS	4	5	4	2	3	5	6	5	7	10	6	8	5	17	11	12	16	11	13	5
Agricultural Education AND GIS	2	0	1	2	1	2	2	2	7	19	14	17	13	31	17	31	29	24	31	59
Animal Science AND GIS	0	0	2	2	1	6	11	5	1	1	3	3	4	3	9	6	12	13	7	7
Architecture AND GIS	0	0	0	0	0	0	1	0	0	3	1	2	2	4	5	6	7	9	8	12
Asian Studies AND GIS	0	0	1	0	0	2	0	2	3	3	2	1	0	0	6	4	2	5	4	6
Biology AND GIS	5	7	7	5	11	8	13	9	6	27	30	26	30	32	40	35	34	35	47	36
Computer Engineering AND GIS	14	10	18	8	9	5	9	6	20	14	32	29	50	53	60	52	43	58	66	31
Curriculum AND GIS	3	3	1	4	9	2	0	3	3	6	8	8	6	9	12	19	24	16	15	7
Education Policy Studies AND GIS	0	0	0	1	0	0	2	0	2	0	2	2	1	2	1	7	4	7	3	3
Educational Psychology AND GIS	0	0	1	1	5	3	1	1	2	2	0	0	4	2	2	7	4	4	8	2
Electrical Engineering AND GIS	4	1	3	2	0	1	3	5	8	7	14	11	15	23	11	31	27	25	30	22
Entomology AND GIS	0	0	0	0	1	1	1	0	0	5	7	6	6	5	4	4	6	4	7	8
Food Science AND GIS	0	0	2	3	6	5	7	10	0	6	7	12	16	9	14	21	15	23	27	29
French AND GIS	15	8	7	2	9	16	17	9	15	17	19	11	27	18	21	19	20	23	23	36
Instruction AND GIS	21	14	10	12	17	18	21	13	14	23	26	26	37	31	31	48	32	43	34	36
Journalism AND GIS	2	2	0	1	1	4	1	2	2	8	25	34	36	24	26	23	20	21	26	15
Labor Studies AND GIS	0	0	0	2	0	2	0	0	0	0	2	1	2	3	1	7	4	6	4	4
Law AND GIS	14	23	15	15	11	17	21	26	18	49	48	56	70	70	68	94	81	100	94	80
Learning Systems AND GIS	5	8	8	13	12	3	15	19	13	29	25	24	43	57	41	52	53	62	57	39
Management AND GIS	9	5	10	8	4	4	10	10	15	19	34	27	39	45	56	57	27	47	48	41
Manufacturing Engineering AND GIS	2	0	1	1	1	1	0	1	1	0	5	2	3	7	3	7	6	10	15	3
Mathematics AND GIS	1	4	0	1	5	5	7	2	16	18	13	9	12	21	23	26	11	26	19	16

Mineral Engineering AND GIS	0	2	0	0	0	1	0	0	3	1	4	2	4	2	2	4	6	7	6	8
Nursing AND GIS	11	8	12	10	8	6	5	14	12	9	17	18	19	22	25	23	32	21	24	32
Nutritional Sciences AND GIS	0	1	0	1	5	0	4	4	1	3	3	4	4	2	12	11	11	12	14	10
Organization AND GIS	3	0	4	2	1	4	0	4	4	7	5	9	7	13	13	6	9	8	5	11
Performance Systems AND GIS	39	45	63	66	73	73	78	78	144	199	189	205	226	277	307	291	308	329	291	260
Philosophy AND GIS	1	1	0	0	5	0	1	0	1	3	1	1	2	1	2	6	5	7	2	0
Security Analysis AND GIS	0	0	0	0	0	0	2	1	0	10	4	11	20	26	27	34	13	22	12	7
Sociology AND GIS	0	0	0	1	1	3	0	1	4	2	1	5	4	4	4	8	4	4	4	6
Spanish AND GIS	1	1	0	1	0	0	0	1	1	4	4	5	2	4	8	4	6	5	7	9
Early Adoption Phase																				
African American Studies AND GIS	0	0	0	0	0	0	0	0	0	1	1	3	1	2	1	8	3	1	6	7
African Studies AND GIS	0	3	1	2	3	1	0	1	0	1	2	7	2	3	4	11	7	10	13	14
Agricultural Engineering AND GIS	10	7	7	13	17	15	14	22	27	32	34	43	47	54	56	78	62	69	81	69
Anthropology AND GIS	0	0	0	0	2	1	0	0	2	1	6	1	1	4	1	5	7	5	9	7
Architectural Engineering AND GIS	0	1	2	1	0	1	5	2	3	5	6	11	8	15	12	6	23	21	26	7
Biochemistry AND GIS	0	1	1	0	1	1	0	2	1	3	6	5	4	4	9	12	7	4	8	6
Chemical Engineering AND GIS	0	0	0	0	2	1	0	0	2	1	1	6	2	5	6	11	6	14	10	15
Chemistry AND GIS	0	0	2	0	0	1	1	2	1	3	5	3	5	4	8	10	9	15	11	33
Classics AND GIS	0	0	0	0	0	0	0	1	0	1	0	0	2	1	2	1	5	2	5	4
Communication Arts AND GIS	0	1	1	0	1	0	1	0	2	2	2	0	1	2	3	3	4	3	5	2
Communication Disorders AND GIS	0	0	3	4	3	3	1	2	5	8	5	6	3	8	3	7	12	12	18	13
Communication Sciences AND GIS	5	3	4	3	6	9	8	20	8	7	8	12	12	14	23	26	17	29	22	33
Economics AND GIS	28	26	17	30	31	36	45	40	48	51	63	82	87	112	137	180	138	148	152	173
Ecosystems Management AND GIS	18	15	14	14	20	22	33	30	44	34	42	57	54	65	71	97	86	88	107	102
Ecosystems Science AND GIS	3	1	0	5	8	12	12	12	5	5	10	25	22	27	23	50	31	27	38	37
Employment Relations AND GIS	0	1	1	1	2	2	2	2	4	7	7	3	9	13	11	20	18	27	41	24
Engineering Mechanics AND GIS	0	2	2	2	1	3	2	1	2	5	13	2	10	12	11	15	13	31	38	12
Engineering Science AND GIS	0	2	1	0	7	3	3	4	8	6	8	12	13	5	17	12	10	10	21	16
Environmental Engineering AND GIS	11	8	9	4	6	6	9	6	15	18	26	23	22	38	48	49	38	66	58	39
Environmental Microbiology AND GIS	0	0	0	0	0	3	1	0	0	3	2	2	2	2	2	3	3	5	4	9
Family Studies AND GIS	0	0	0	0	0	4	3	4	3	6	5	9	6	4	7	13	9	11	11	8
Health Policy AND GIS	0	0	0	1	4	2	1	3	2	3	4	3	9	4	9	18	13	12	23	16

(*Continued on next page*)

TABLE 1 (Continued)

Search Term	Year																			
	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Industrial Engineering AND GIS	4	2	4	2	2	2	2	6	4	12	6	8	18	13	11	22	20	31	39	21
Italian AND GIS	0	0	0	0	0	0	1	0	3	3	3	2	2	7	3	2	5	12	4	11
Landscape Architecture AND GIS	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	2	2	5	3	6
Marketing AND GIS	3	5	1	1	1	0	2	3	3	8	4	6	8	12	14	15	5	17	14	11
Materials Engineering AND GIS	1	7	1	6	4	2	3	0	8	4	11	9	17	17	13	27	21	30	45	18
Mechanical Engineering AND GIS	0	2	2	2	1	3	2	1	2	5	13	2	10	12	11	15	13	31	38	12
Medicine AND GIS	9	10	9	5	13	14	22	24	29	32	52	62	57	76	93	96	112	101	141	118
Meteorology AND GIS	6	5	12	10	18	27	28	36	37	50	41	53	59	58	74	100	74	90	109	91
Molecular Biology AND GIS	0	2	1	2	2	1	0	2	1	6	8	4	7	8	12	11	11	5	13	7
Nuclear Engineering AND GIS	0	0	2	0	0	0	0	0	1	2	1	2	1	1	1	2	0	5	4	2
Park Management AND GIS	5	3	5	6	11	3	8	11	14	13	23	13	25	24	27	33	28	33	41	35
Physics AND GIS	45	39	39	45	48	52	43	64	81	81	89	144	106	131	121	160	160	181	189	166
Plant Science AND GIS	4	2	4	2	12	17	8	9	2	10	13	21	27	25	25	36	17	29	31	45
Political Science AND GIS	1	2	0	0	2	1	4	1	4	4	4	5	3	4	6	10	3	11	10	5
Public Relations AND GIS	0	1	2	0	0	0	0	2	3	3	3	4	6	6	2	5	4	3	6	8
School Psychology AND GIS	1	1	0	0	1	0	0	0	4	1	2	1	4	1	1	0	4	1	2	1
Special Education AND GIS	2	1	1	2	4	2	3	2	2	4	10	7	6	14	11	19	13	22	15	13
Statistics AND GIS	38	62	74	73	83	105	124	130	129	163	204	229	282	316	354	415	355	378	428	374
Telecommunications AND GIS	4	0	4	6	5	4	3	4	6	8	7	5	12	9	19	9	18	6	10	3
Tourism Management AND GIS	2	2	0	1	2	0	1	4	4	2	6	6	15	11	14	19	18	28	23	22
Women's Studies AND GIS	0	0	0	2	0	2	1	2	2	3	2	2	3	11	5	3	4	6	9	9
Takeoff Phase																				
Agricultural Economics AND GIS	0	0	1	1	0	0	5	0	0	0	3	2	6	4	3	7	5	8	10	2
Civil Engineering AND GIS	8	0	5	3	3	2	4	2	6	6	11	9	12	9	14	33	45	51	71	44
Crime AND GIS	4	1	2	2	1	5	1	4	2	3	6	11	10	16	13	14	11	14	21	17
Energy Engineering AND GIS	0	0	1	2	0	0	1	2	2	1	1	4	1	1	5	3	2	9	3	3
Geosciences AND GIS	6	4	4	8	2	4	9	10	17	25	20	15	24	15	37	35	30	82	103	54
Health Administration AND GIS	3	0	1	0	2	2	0	2	3	2	3	3	4	6	7	3	5	6	9	6

Human Development AND GIS	18	24	23	27	34	25	56	44	41	64	76	79	97	120	126	167	154	178	206	181
Materials Science AND GIS	3	2	3	3	12	6	7	11	2	5	8	6	10	11	21	19	13	16	30	41
Medieval Studies AND GIS	0	1	0	0	0	0	0	0	0	1	1	0	0	1	3	3	4	0	5	2
Psychology AND GIS	2	4	3	1	3	5	0	5	4	4	10	3	3	6	7	9	12	5	17	3
Recreation Management AND GIS	6	0	4	1	3	6	8	5	4	10	8	9	18	19	16	24	18	15	28	24
Saturation Phase																				
Computer Science AND GIS	7	9	6	1	22	4	17	10	5	9	13	20	21	38	41	38	35	37	43	24
History AND GIS	0	1	0	0	1	0	0	5	5	14	6	5	8	9	17	23	16	20	21	15
Information Sciences AND GIS	14	15	9	0	36	11	31	20	8	25	21	37	47	71	101	78	66	74	65	43
Information Systems AND GIS	13	21	17	18	14	12	18	23	31	44	62	50	68	76	83	93	58	72	81	83
Information Technology AND GIS	8	16	18	17	36	29	33	40	57	153	123	153	256	331	466	286	242	230	168	105
Justice AND GIS	0	0	0	4	0	5	4	3	3	2	10	11	3	10	9	7	6	11	6	8
Linguistics AND GIS	0	1	2	0	0	1	3	4	0	5	2	3	2	1	8	7	4	8	3	2
Media Studies AND GIS	7	9	9	8	12	10	12	14	31	65	88	140	164	184	179	251	261	270	277	287
Risk Analysis AND GIS	0	4	1	0	3	5	3	6	6	22	30	26	33	38	69	62	40	50	45	21
Risk Management AND GIS	1	1	0	0	0	3	1	1	4	3	8	2	6	5	12	5	6	4	4	5

Note. The results are categorized into diffusion categories of innovation, early adoption, takeoff, saturation, and results that averaged less than one publication per year.

Table 2. Table of Disciplines Averaging Less Than One Publication Per Year

Search Term	Number of Publications 1996–2015
Advertising AND GIS	6
Aerospace Engineering AND GIS	10
Agricultural Sociology AND GIS	4
Ancient Mediterranean AND GIS	4
Applied Linguistics AND GIS	8
Art History AND GIS	11
Astronomy AND GIS	17
Astrophysics AND GIS	13
Biobehavioral Health AND GIS	1
Bioengineering AND GIS	9
Bioethics AND GIS	3
Biomedical Sciences AND GIS	19
Caribbean Studies AND GIS	4
Comparative Literature AND GIS	11
English AND GIS	16
Film-Video Studies AND GIS	16
Finance AND GIS	14
Forensic Science AND GIS	13
Francophone Studies AND GIS	2
Germanic Languages AND GIS	8
Hospitality Management AND GIS	5
Integrative Arts AND GIS	6
Jewish Studies AND GIS	3
Kinesiology AND GIS	1
Latin American Studies AND GIS	9
Middle Eastern Studies AND GIS	16
Music AND GIS	15
Plant Pathology AND GIS	10
Portuguese AND GIS	17
Religious Studies AND GIS	5
Russian AND GIS	12
Supply Chain AND GIS	7
Theatre AND GIS	4
Veterinary Sciences AND GIS	6
Visual Arts AND GIS	4

names. The difference between number of searches and number of departments is a result of some departments having compound names such as "Spanish, Italian, and Portuguese." In these cases, the name was split into two or more searches. Additionally, search results were further refined by limiting them to the Scopus journal categories that aligned with each search term. For instance, "Animal Science + GIS" was refined to only the journals in the Scopus journal category of "Agricultural and Biological Sciences." Lists of publications generated by search results were summed for each year and normalized to account for general publishing trends in each Scopus journal category. For example, the "Animal Science AND GIS" search was normalized by the Scopus publication trends within the category of

"Agricultural and Biological Sciences." Where growth in GIS related publications in a given discipline outpaced the background growth in publications in its respective Scopus journal category, normalized results were positive values, whereas in cases where GIS related disciplinary publications either shrank in number or grew more slowly than the background rate of growth in its respective Scopus journal category, normalization reported negative values. The normalized results were then plotted in a time-series format with normalized publication rate on the Y-axis and time on the X-axis to match the format of the diffusion of innovation curve. To help visualize results, we further fit a nonlinear cubic-regression spline to the publication time-series data along with 95% confidence estimates based on bootstrap random sampling with replacement (see Figure 3). The publication plots were qualitatively categorized as belonging to one of the four phases of adoption of an innovation—-innovation; early-adoption; takeoff; or saturation.

Partnering with Liaison-Librarians and Departmental Faculty

The role of liaison-librarians at academic institutions is changing (Miller and Pressley 2015), but what has remained consistent is that they serve as a conduit to integrate library resources and services into the departments to which they liaise. In the context of the present study, where they are willing and/or interested, liaison-librarians could partner with library-based GIS service providers to be "change agents" in departments that are targeted for GIS outreach and education. With domain specific knowledge and existing departmental contacts, liaison-librarians meet the criteria that change-agents have homophyly with the population of people (i.e., department faculty) whom we hope adopt the innovation (i.e., GIS). In addition to liaison-librarians, identifying one or more departmental faculty who could serve as "opinion leaders" and provide insight to the department and discipline would also be beneficial to a GIS outreach and education campaign. With a thorough understanding of the publication trends within a discipline, library-based GIS service providers can approach potential partners starting with the disciplines that stand to benefit the most from adopting GIS tools and methods.

Develop and Deliver Discipline-Specific GIS Outreach and Educational Materials

The final step in the proposed workflow is to collaborate with partners to develop discipline-specific GIS educational materials. Discipline specific training materials are an important prerequisite to developing familiarity and engaging potential new users of GIS. For an example of some discipline-specific GIS educational materials, see the suite of books and reference materials offered by Esri Press (www.esripress.esri.com). Materials could

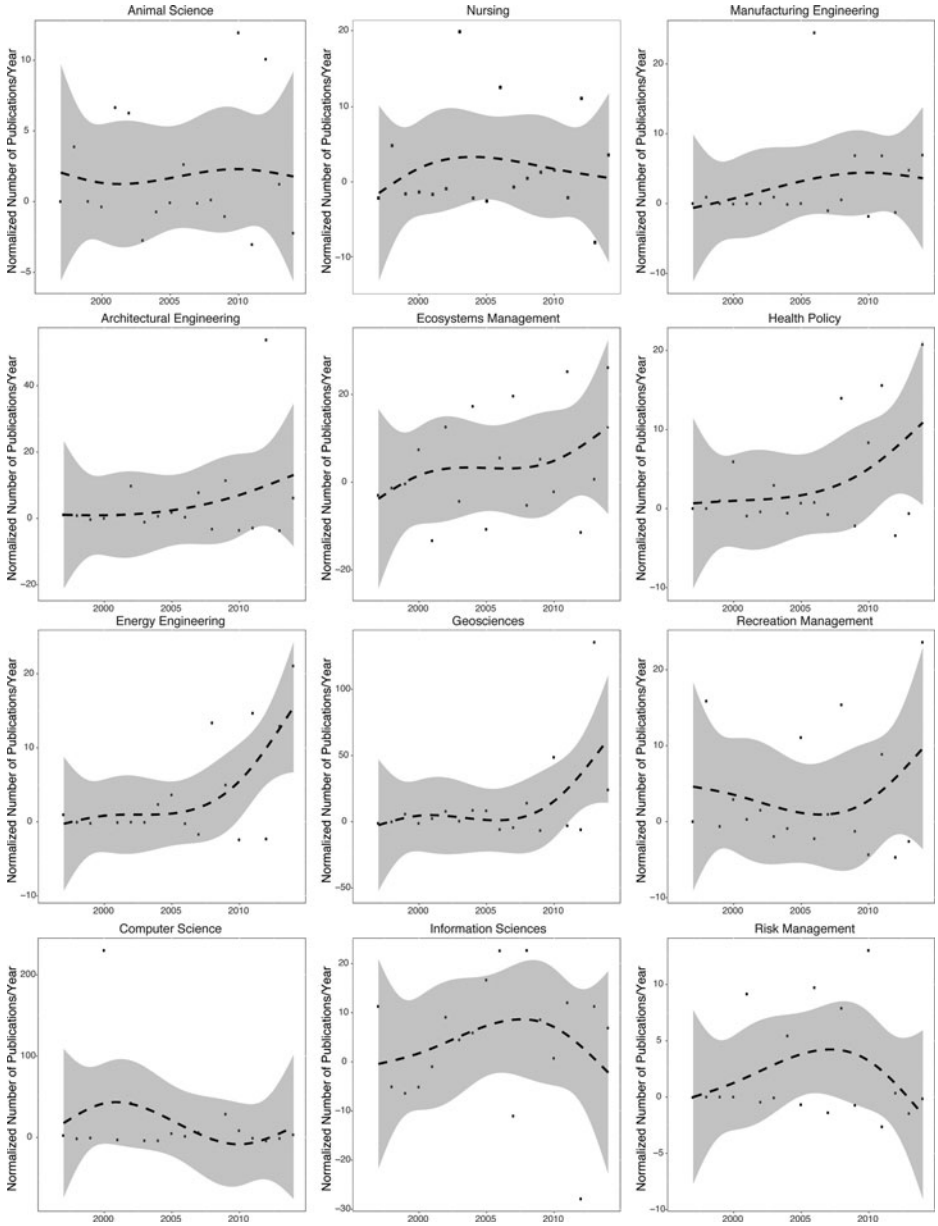

FIGURE 3 Graphs of examples of different search results. Each row illustrates three examples from each phase of innovation. The first row is the innovation phase. The second row is the early adoption phase. The third row is the takeoff phase. The fourth row is the saturation phase.

be delivered through a variety of formal and informal methods, and at a minimum we suggest a research seminar and workshop series (e.g., Guan and Bol 2012). To develop a research seminar, library-based GIS service providers can examine the list of publications produced from the bibliometric analysis for the most interesting and impactful GIS projects that have been published in each discipline. Impact here can be defined as the publications that have received the most citations and/or views depending on what the publisher's database reports. A seminar presentation that describes the methods used to identify departments (i.e., describing this article), and a number of discipline specific examples of GIS applications would likely be a presentation that is both interesting and engaging for a departmental audience. Many academic departments host weekly or monthly research seminar series, and these could be an ideal venue for library-based GIS service providers to begin sharing ideas with target departments. The liaison-librarian and faculty partners could assist with the development of seminar content, logistics, and delivery. Building on the interest generated from a research seminar, one or more skills-based workshops could be developed for a faculty and student audience. Skills workshops could provide conceptual and foundational knowledge training as well as develop reconstructions of the GIS methods that were used in the projects presented in the research seminar. The workflow may also engage attendees who would then likely become future patrons of individual-focused library based GIS services.

RESULTS

The total number of publications produced by the bibliometric analysis of all disciplines was 39,495. Of the 133 discipline specific searches, 34 disciplines were found to be in the innovation phase, 41 in the early adoption phase, 11 in the takeoff phase, 10 in the saturation phase, and 35 averaged less than one publication per year and were excluded from the results due to lack of data. Figure 3 shows representative examples of the four innovation phases. Those identified as being in the take-off phase, and therefore potentially worthy of being targeted for education and outreach activities, were agricultural economics, civil engineering, crime, energy engineering, geosciences, health administration, human development, materials science, medieval studies, psychology, and recreation management.

DISCUSSION

Results of the bibliometric analysis helped library-based GIS service providers to wade through a large body of literature to identify potentially innovative uses of GIS across an array of disciplines in a data-driven, defensible, and repeatable way. Through research and trial–and-error, we encountered a number of implementation challenges for the proposed methods and workflow. A discussion of some of the challenges follows.

Refining Search Terms

We found the keyword "GIS" was the most encompassing search term that produced the most desirable results. Other search terms that did not work as well included "spatial," "geographic," "geographic information systems," and "geographic information." Although in geography the term GIS can be used both to speak to the science and the systems (Goodchild 2004), GIS as an acronym for 'geographic information systems' is more consistently used outside the field of geography to mean a technological tool used in research. Liu et al. (2016) noted the problems with using the term "GIS"; however, in keyword searching publication databases it was found to be more useful than other search terms. Additionally, the Scopus journal categories were helpful in limiting results to only the subset that was most relevant to the discipline searched.

Limitations of Keyword Searching

In some cases, the name of the discipline used in keyword searching was misconstrued as having multiple meanings. For example, Comparative Literature as a discipline refers to literature across different cultures, languages, and nationalities. However, other disciplines compare within and across their own literature, and the term "comparative literature" produced some unexpected publication results. This challenge was remedied in part by limiting the search to journals within a journal category domain. In the case of Comparative Literature, we limited to the Scopus journal category of "Arts and Humanities."

Once a list of publications was compiled and potential target disciplines identified, it was necessary to validate that the results were applicable to leveraging GIS as a technological innovation as applied to research problems of the discipline in question. To assess validity, we examined the most common journal names produced by search results as well as read titles, abstracts, and in some cases, portions of articles. This examination of search results served a twofold purpose—-to validate, as well as to familiarize ourselves with the ways that GIS was being used in particular disciplines. In our validation of search results, we identified a method that when searching with an acronym keyword (i.e., "GIS"), produced undesirable results—by being confused with other acronyms of the same letter combination(s). A minority of results for the disciplines "Health Administration" and "Health

Development" were actually about the gastrointestinal (GI) tract of the human body (e.g., Cook et al. 2012) and one was about war veterans and the military Servicemen's Readjustment Act (informally known as the G.I. bill) (Ellison et al. 2012). One other publication included in the results of health-related disciplines was about river health, as opposed to human health that is the focus of academic departments (Xia et al. 2014). While not all publications were relevant to the discipline searched, a surprising many detailed novel and interesting ways that researchers were using GIS in their work. Among health-related search results were also publications about GIS being used to identify populations in need of better access to health care services (e.g., Hansson et al. 2013), and national scale studies linking environmental factors with human health disorders (Al-Hamdan et al. 2014).

In another example of undesirable search results, more than half of the publications for "Material Science" detailed valid applications of GIS, but they were arguably more relevant to another academic discipline such as the risks and hazards subfield often found in departments of civil engineering or geography. Although we do note that some publications were relevant to the materials science discipline like one on a GIS-based tool to help users interpret X-ray maps that are often used in material science applications (Ortolan et al. 2014). In sum, not all results produced by keyword searching were found to be applicable to GIS and the discipline searched, and the quality of results likely varies for each discipline searched and publication database used. Of the eleven disciplines identified in the present study to be in the take-off phase, four of the searches contained undesirable results (the three already discussed plus psychology). However, the remaining seven disciplines produced keyword search results that were highly relevant to applications of GIS that may be considered innovative in the academic fields searched.

Different Forms of Scholarly Work

We used the assessment tool SciVal, which searched the Scopus database that contains publications from many disciplines, but is specifically tailored towards the social, natural, and health sciences. In our experience, the Scopus database appeared to index a broad selection of journals; however, business, arts, humanities, and education journals and/or publications seemed to be underrepresented. Future research could benefit from searching other publication databases that may better represent nonscience disciplines than does Scopus. Additionally, certain disciplines are perhaps underrepresented in publication databases in general due to the nonpublication nature of their scholarly output. For example, faculty in the arts and humanities may not publish their work in the form of journal articles, but still may find GIS to be an interesting and useful tool. The rapidly evolving field of digital humanities provides an example of a discipline that is not likely

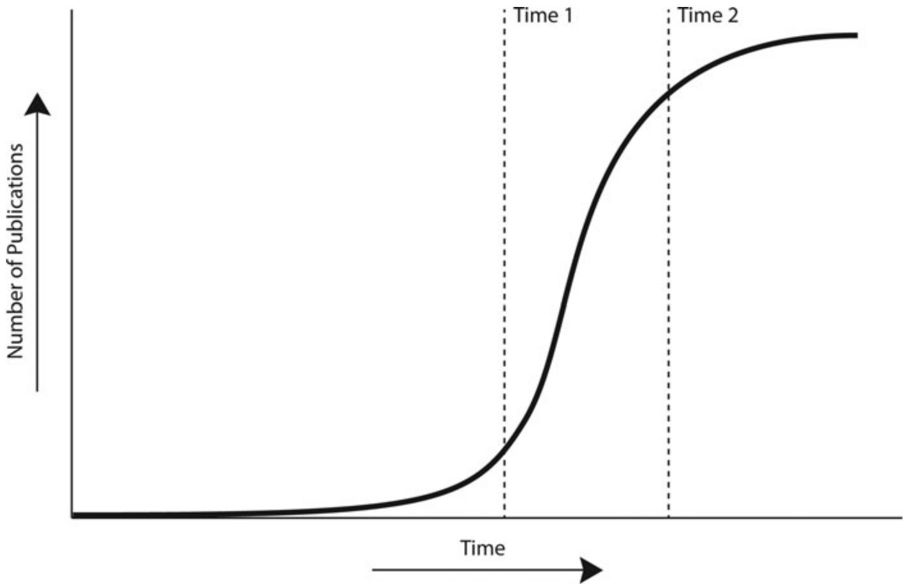

FIGURE 4 Illustration of how, depending on when the bibliometric analysis is conducted within the diffusion of innovation, one might be unable to identify a discipline as having potential before the "takeoff" phase. Time 1 illustrates what the trend may look like before the takeoff period, while Time 2 indicates how different the graph looks once the takeoff period has commenced.

well-represented in publication databases and yet is rapidly adopting GIS technology.

Emerging Fields and the Publication Time-Lag

While the present analysis proved to be a useful way to identify disciplines where there was an acceleration in the adoption of GIS across the study period, it was harder to distinguish a discipline that was in the early adoption phase of the diffusion of innovation (Figure 4, Time 1) due to the small number of publications in search results and a time-lag in academic publishing.

Emerging fields with few publications tended to vary from having some to none year to year over the study period, making it difficult to differentiate publication trends from noise. The challenge of identifying emerging fields was exacerbated by the sometimes long time-lag between when the work was actually performed and when it was published. Given that it also takes time to develop discipline-specific outreach and educational materials, it may be that disciplines that are targeted as a result of the proposed analysis and workflow are closer to the late-adoption phase of innovation by the time the workflow is completed.

We discussed here a number of challenges in producing and interpreting the results of a bibliometric analysis in the context of a majority of results that were highly desirable and informative. Although keyword searching in a bibliometric analysis is an imperfect method, its value is that it is: *defensible* in terms of library-based geospatial service providers being able to justify the focus of their education and outreach efforts on certain departments and not others; and *repeatable* in that it is a method that can be repeated at different institutions as well as at the same institution through time.

The Workflow as a Self-Selective Process

Moving beyond the bibliometric analysis step of the proposed workflow requires a further narrowing of focus on just a few disciplines and the voluntary participation of others who may or may not see the benefit of collaborating with GIS service providers. Those that do see the benefits of collaboration, or are more inclined to collaborate in general, likely represent the most productive partnerships for library-based GIS service providers to engage. In this way, moving through the workflow itself is a selective process that leads from a universe of potential disciplines to target for GIS outreach and education, to a subset of disciplines that show the most promise based on bibliometric analysis, to only those disciplines for which keyword searching worked well, to only those disciplines that have a willing liaison-librarian and departmental collaborator at a given institution. Although in implementing the workflow it is still possible to end up with more promising disciplines than GIS service providers have the resources to engage, this would represent a positive result that could further justify the dedication of resources to library-based GIS services.

CONCLUSIONS

Library-based GIS service providers have a need to identify and engage potential new users of GIS in their academic communities as a way of demonstrating and maximizing the impact of their services. In the absence of well-established practices to identify and reach this group, we drew on the Diffusion of Innovation Theory to propose a set of methods and workflow. The methods and workflow leveraged bibliometric analysis in a way that is strategic, defensible, and reproducible in focusing on disciplines that stand to benefit the most from adoption of GIS tools and methods. Moving through the proposed workflow, GIS service providers can connect with liaison-librarians as potential change agents and engage departmental opinion leaders. In doing so, library-based GIS service providers can enable the adoption of spatial thinking, incorporation of spatial data, and the use of GIS as an innovative research tool in a multitude of new disciplines. Rather than being formulaic, we hope that the proposed methods and workflow provide a starting point of discussion and an inspiration towards more investigation into how to maximize the impact of library-based GIS services at academic institutions across the country and around the world.

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