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Call for an Agenda and Center for GIS Education Research

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Abstract

Despite nearly 20 years of intensive investment by higher education, industry, primary and secondary teachers, youth and community leaders, government agencies, and non-profits organizations in Geographic Information Systems (GIS) in education around the world, a GIS education research agenda has yet to be developed. This paper provides a rationale and a broad background for a GIS education research agenda and describes what that agenda should include. This agenda identifies research progress made in:

student learning and outcomes
instructor professional development
technical development, to identify where major gaps still exist.

In so doing, it is hoped that this agenda will serve as a focal point of communication for the GIS education research community and encourage additional and deeper research into these and related topics so that future directions in GIS education will have a sound research base on which to build.

Keywords: geographic information systems, GIS, educational reform, spatial thinking, geotechnology

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The need for research in GIS education

Geographic information system (GIS) technology is used as an inquiry-driven, problem-solving, standards-based set of tasks that incorporates fieldwork (Louv, 2006) and provides career pathways that are increasingly in demand. It helps students think critically, use authentic data, and connects them to their own community. It does so in informal, primary, secondary, and university settings and appeals to today's visual learners. GIS helps students understand content in a variety of disciplines, in geography, history, mathematics, language arts, environmental studies, chemistry, biology, civics, and many others (Theo, 2011; Liu et al., 2010; Shin, 2006; Wigglesworth, 2003; Wiegand, 2003; Baker and White, 2003; Aladag, 2010). Using GIS provides a way of exploring not only a body of content knowledge, but provides a way of thinking about the world (Bednarz, 2004; Kerski, 2008).

In its landmark report entitled *Learning to Think Spatially*, the National Research Council (2006) stated that "Spatial thinking can and should be taught in American schools" and that "we must foster a generation of students who are spatially literate" because "spatial thinking is a fundamental and necessary mode of thought applicable across the life span." The report, which summarized five years of investigation into the need for spatial thinking and GIS technologies in the classroom, has made the need for further research in this field even more obvious. The NAS committee stated that

> *"Students need formal training in specific spatial thinking skills…We also need an educational process that leads to a fundamental understanding of spatial thinking in general […] more than a set of specific skills tailored to a particular discipline or school subject. Currently there are no standards for how we should think or learn spatially and no standards for how spatial thinking can be taught and assessed."*

Research is needed to define what spatial literacy is, how it can be translated into educational content standards, how, when, and where it can be tested, and the difference that GIS tools and methods can make in teaching and learning. This would meet the National Academy of Sciences' goal of transferring generalizable spatial thinking skills across domains of knowledge in the K-12 curriculum, thus enhancing learning across the curriculum.

Educational investments rely on empirically based research for direction and assessment of learning effectiveness. Despite the advances made in curriculum, professional development, and technical development, a cohesive and comprehensive GIS education research agenda has yet to be developed. Downs (1994) bluntly suggested that educational research needs to move away from ad hoc studies to a systematic research approach as "The need for research in geography education: it would be nice to have some data." Nearly 20 years later, we make an identical call applied to GIS in education.

"There is a need to develop a cogent, focused research agenda in K-16 GIS education" (Baker and Bednarz,, 2003, p.233). Emerging research in GIS education is young yet needs to be deeper and broader. Advancement in any field depends upon a sound research base, for research informs and drives development. In GIS education, research drives new technological tools, new teaching methods and models, new assessment methods, and much more. Research brings together the community around common themes and connects the research base with interdisciplinary efforts. The importance of a research agenda is that it provides direction to the greater community and to encourage collaborative partnerships to realize larger gains.

This call for a robust and extensive research plan is echoed around the world, in associations and in the events that they sponsor, including the Association of American Geographers, the National Council for Geographic Education, the Royal Geographical Society, the Geographical Association, the International Geographical Union, the International Society of the Digital Earth, HERODOT, and the National Science Teachers Association. In addition, the call is heard outside the field of geography and GIScience, at the Association for Supervision and Curriculum Development and the American Educational Research Association. The call is no less substantial in studies that focus on the continual need for data generated from original research studies in the field, and has been echoed by psychologists in the spatial cognition field.

Purpose and background

The purpose of this paper is to provide a rationale and the required background to call for the formation of a GIS education research agenda by exploring four topics. First, we define GIS and describe the growing importance of GIS and other geospatial technologies to society broadly and to educators specifically. Next, we describe GIS education as it exists today and briefly define and introduce research in GIS education and seminal events in its development. In the following section, we review GIS education research in greater detail outlining key research questions which remain to be answered. We conclude by summarizing the gaps in research and arguing for the development of a collaborative research community and a comprehensive research agenda.

What is GIS?

GIS combines computerized maps of different phenomena, from local to global, together with computer software that allows a user to create, interact with, and analyse the mapped data to make decisions based on spatial patterns. Because the computer maps are databases of spatial information, the user focuses on analysing spatial patterns, relationships, and trends. Spatial analysis involves the investigation of anything that can be displayed on maps, databases, images of the Earth's surface, graphs, and in other ways, that can be studied geographically.

Why is GIS Important?

For 40 years, GIS has quietly transformed how decisions are made in universities, government, and industry by bringing digital spatial datasets and geographic analysis to the computer environment. Through the application of spatial statistics and spatial analysis to a large and diverse set of spatial data, researchers and decision-makers could identify social and physical patterns in a way that was not possible before the advent of

GIS. Have you been asked for your zip or postal code at the cash register? Have you been asked what city you are from while visiting a 'visitor's information' booth? Any information that can identify where you are on the Earth's surface can be used to create maps showing patterns. These include everything from shopping patterns to national voting trends.

More recently, the rapid advent of geotechnologies used by the public from digital maps to GPS-enabled devices, services on handheld devices such as in vehicles and on mobile phones, and web mapping services have heightened the notion of the interconnectedness of the planet and the importance of maps and images. These technologies, hastened by news and images of ice shelf breakup, political instability, hurricanes, and other jarring reminders of our dynamic planet have raised public awareness that the pervasive problems of our world need solutions that call for a holistic and geographic approach. As issues of biodiversity loss, urban sprawl, water quality and availability, energy, climate change, sustainable agriculture, and natural hazards become more widespread but also affect individuals' everyday lives, people are coming to realise that every one of these issues has a spatial, or geographic, component, and can be visualized and understood through spatial analyses with GIS tools.

These concerns have made their way into education under the heading of 'spatial thinking'. Calls by researchers and practitioners to support spatial thinking and practice in education have been increasingly echoed by legislators and the general public (Gersmehl and Gersmehl, 2006). It is believed that the use of GIS in education best embodies 'spatial thinking in practice'.

What is GIS education?

The field of GIS education is concerned in part with teaching about GIS, chiefly in the fields of GIScience, career skill, and technology courses. Teaching about GIS focuses on how geographic information is represented and how it can be analysed, and prepares learners for a career in the GISciences. The field is also concerned with teaching with GIS, to solve problems and understand concepts in disciplines such as environmental studies, geography, history, mathematics, biology, chemistry, language arts, Earth science, and others. Teaching with GIS focuses on using the spatial analysis functions to analyse patterns, relationships, and trends in spatial phenomena in a variety of different fields.

Not long after GIS was created, educators realized that a massive training effort was needed to equip people with the skills needed to effectively use GIS software, to model the world in a GIS, and to think spatially. Teaching about GIS provides a theoretical and practical foundation for careers in geographic information sciences, including such topics as database design and practical problem solving. By 2007, GIS courses, degree programs, and certificates were available at nearly every major university around the world, at many technical colleges, and in hundreds of online programs. They are taken by over 100,000 students annually (Phoenix, 2004) from different disciplines. Teaching about GIS dominates in higher education, although GIS courses are increasingly appearing at the secondary level and in informal educational programs. In 2004, the US

Secretary of Labour named geotechnologies as one of the three fields most in demand for 21st century decision-making (Gewin, 2004).

To enable instructors and educators to use GIS, a substantial investment has been made over the past 15 years by higher education, industry, primary and secondary teachers, youth and community leaders, government agencies, and non-profit organisations around the world. The purpose of this investment is to enable educators and their students to effectively use GIS software, spatial analysis methods, and the spatial perspective to increase their skills, content knowledge, and career marketability. Targeted skills range from educational (such as critical thinking, inquiry, and peer mentoring) to GIS-related (such as creating spatial data, changing its map projection, overlaying it with other data, and applying geostatistical analysis to the dataset). Content knowledge instruction ranges from core topics to the broader field of geographic information science (GIScience), such as the representation of spatial data and managing spatial data error, to knowledge that forms the core field that GIS is applied to (in geography, for example, issues of scale, spatial relationships, biodiversity, regions, and human-environment interaction). An equally significant part of the investment in GIS education has been to enable students to pursue careers in GIScience, cognate sciences, business marketing and management, education, government, and elsewhere.

As GIS became easier and more practical to use, other educators began to use it in their own disciplines, such as biology, geography, chemistry, history, mathematics, Earth science, environmental studies, language arts, and others. Teaching with GIS began at the primary and secondary level from educators seeking to teach about plate tectonics, biomes, climate, migration, history, or other geographic topics and issues, but has been spreading across science and math related departments at the university level and on university campuses (Sui, 1995). This was followed by diffusion into other departments, including business, sociology, and engineering. Even though GIS is increasingly taught in departments outside of the geography department, most research is on setting up and teaching GIS courses, rather than on how GIS affects research and teaching in other courses. GIS education research is primarily focused on whether GIS influences student learning. But, what is most needed is research on how and under what conditions such tools can be effective (Segall and Helfenbein, 2008) to advance the research agenda.

GIS has expanded because of its interdisciplinary nature, straddling the boundaries of geography, mathematics, literacy, Earth science, cartography, remote sensing, cognitive psychology, biology, computer science, education, and other fields. Moreover, GIS education sets a platform for researchers in these individual fields by establishing a common dialogue centred on themes of critical thinking, spatial thinking and analysis, technology-based education, and scientific inquiry.

What is GIS education research?

GIS education research focuses on how and what educators and students learn with spatial data, spatial analysis methods, and GIS tools. It includes but is not limited to how attitudes and the professional and community engagement of educators and students may change as a result of using GIS as differentiated from the use of traditional tools (such as paper maps and atlases) and traditional instructional methods (such as lecture, and drill and practice). It also includes the design of the tools themselves.

The research, however, lags far behind the development and investment in GIS education. Without research, how will we know if the time and monetary investments have been 'worth it'? How can we measure the effectiveness of these commitments so that we will know whether the investments met user demands and were cost-effective?

While GIS education research may seem rather specialized to readers and researchers new to the field, the field is actually quite extensive in scope. As education, society, and technologies all undergo rapid change, GIS education research has evolved, addressing the impact of broader changes on its own field, thus it is reflective and introspective in the process.

In some ways, GIS education research has slowly emerged as its own field in a similar way that GIScience emerged at the dawn of the 1990s, drawing from existing disciplines and yet distinctive from and more than the sum of its parts. GIScience seeks to redefine geographic concepts and their use in the context of geographic information and the digital age (NCGIA, 1996) and can be thought of as the set of theories and societal issues that underlie GISystems. If one argues that it is premature to call GIS education research its own field, at the very least, it is a small but cohesive, distinct community of researchers with parallel and intersecting inquiries. The GIS education community of which the research group is a part shows even more signs of evolving into an international geospatial education community with a wide breadth of interests.

A review of the literature (Esri, 2010) indicates that GIS educators are concerned about the implementation of GIS in informal education (museums, libraries, after-school clubs, outdoor programs, and elsewhere), in formal education (primary, secondary, and university-level), and in career and technology-training centres. Researchers in the field are concerned with the implementation of GIS in different cultures as well as different educational contexts, both at the micro-scale of individual classrooms, instructors, lessons, and students, but also at the macro-scale of disciplines and regions. It is concerned with how the technology and methods associated with GIS are implemented, the effectiveness of instruction, and the impact on attitudes and behaviours. The research on GIS education occurs in individual institutions around the world and also compares implementation between regions within a country as well as between countries.

In the research, pedagogical models are postulated, tested, and reworked. In the context of GIS education research, exploration of how content standards, national curricula, current events, societal trends, and the educational culture impacts drivers for spatial thinking and geotechnology initiatives in education are examined. GIS education research is also deeply concerned with the effectiveness of thinking spatially with geotechnologies, on teacher professional development, on student content knowledge, and on teacher and student technical skills, drawing on wide research methodologies.

These include methodologies ranging from ethnographies, surveys, case studies, experimental studies, instructional design, and others.

Behind the research lies a common desire to analyze and address challenges in the implementation and effectiveness of GIS in education. The GIS education community's goal is to foster partnerships, programs, and additional research to promote teaching and learning about local communities, regions, and the world through GIS technologies grounded in a spatially based instructional framework. Despite their enthusiasm and advocacy of spatial approaches in education, the community is keenly aware of the need for objectivity in their own research.

The research efforts summarized here illustrate only some of the topics that GIS education researchers are concerned with. An exhaustive list is not possible because the new frontiers of GIS education research are yet to be conceptualized, hence the need for this agenda to make explicit such a research focus.

A fair number of research results have been published over the past 20 years in this field, including at least 50 theses and dissertations, hundreds of articles, dozens of book chapters, and several books. However, some limitations exist. For example, the research tends to be small in scale, is disconnected from other studies, is missing key segments, and lacks an overall direction. A number of seminal works are described in detail below.

Key milestones for GIS education research

Several key documents and events have created the groundwork for research in this field. While this list is intentionally targetted, it should be clearly noted that many other milestones in closely related fields, such as spatial cognition, GIScience, pedagogical practice, computer-based learning, and others should also be considered by the informed researcher.

- 1990: *National Centre for Geographic Information and Analysis GIS Core Curriculum*. This comprehensive document was written key university researchers and practitioners in the three universities who had secured the first large GIS education grant. Its 75 units served as the blueprint for university-level teaching for the next decade until the core curriculum was partly revised in 2000.
- 1994: *First National Conference on the Educational Applications of GIS (EdGIS): Conference Report*. Published and organized by TERC, this first gathering of approximately 60 educators concerned with teaching with and about GIS set the stage for the network of researchers and practitioners that became the international GIS education community (Barstow et al., 1994).
- 2003: *Special issue of the Journal of Geography* (National Council for Geographic Education, 2003), 'Research on GIS in education', edited by Baker and Bednarz, this highlighted relevant research in the field of GIS education but also pointed out that much remained to be done.
- 2006: *Learning to Think Spatially: the Incorporation of Geographic Information Science across the K-12 Curriculum*. This report was issued by the National Academy of Sciences after a five-year series of discussion and development by

leaders in the field. Published by National Academies Press, this situated teaching with GIS into a broader context of spatial thinking, discussed ways to think spatially, and recommended that spatial thinking and GIS be embedded throughout all levels and in many disciplines throughout the educational system.

- 2008: *Digital Geography: Geospatial Technologies in the Social Studies Classroom*, edited by Milson and Alibrandi (2008). Published by Information Age. This book illustrated the diversity of GIS education research, professional development, and curriculum development as applied to the secondary and university level and in inservice and pre-service instructor education.
- 2012: *International Perspectives on Teaching and Learning with GIS in Secondary Schools*, edited by Milson, Demirci and Kerski (2012), published by Springer. Stories from 33 countries in this book illustrate that the use of GIS has become a worldwide phenomenon, spearheaded by educators who have overcome challenges and who push the frontiers forward in both research and practice.

Progress and gaps in GIS education research

In this section, we examine GIS education research in greater depth, followed by suggested research questions which remain to be answered, collectively forming the basis of a research agenda.

The special issue of the 2003 *Journal of Geography* indicated at least three research themes that have appeared within GIS education:

- Student learning and outcomes – identifying changes in student achievement, cognitive skills, or other affective indicators.
- Teacher training – documenting training methodologies and teacher
- Implementation
- Technical development – studying the value and effectiveness of various software functionalities and interface elements.

These research themes remain the focal points for GIS education research today and serve as a useful way of organising the past 20 years of studies. The matrix below was modified from Joyce and Weil's (1996) technique in Models of Teaching. The authors recognise that the organization scheme may be improved and that many studies fall and should fall into multiple themes.

Table 1.
Technical Development

TECHNICAL DEVELOPMENT ELEMENTS (As A MEASURABLE OUTCOME)	Digital Globes (e.g. Google Earth, ArcGIS Explorer, Whirlwind)	Data Explorers (e.g. AEJEE)	Desktop GIS (e.g. ArcView, MyWorld)	Web-based Mapping/Internet GIS	GIS (unspecified)
Interface	Wang ea, 2008		Edelson, 2004	Curtis ea, 1999	Radke, 1997 Huang, 2011 Kinzel, 2009
Functionality	Siegle, 2007 Zangerl, 2007	Sanders, 1999	Edelson, 2004	Komarkova ea, 2010	Fontanieu ea, 2007 Johansson, 2008
Audience /Age Appropriateness		Balram & Dragicevic, 2008			
General Usability	Patterson, 2007 Schneider & Davis, 2007 Stahley, 2006 Zangerl, 2007	Sanders, 1999 DeMers & Vincent, 2007	Edelson, 2004	Curtis ea, 1999	
Body of Knowledge(AAGU CGIS)/Geospatial Technology Competency Model					Johnson & Sullivan 2010; DiBiase ea 2010
Data	Schultz ea, 2008		Merchant, 2007		Johansson, 2008 Wright ea 1997

Table 2.
Teacher Training

TEACHER TRAINING	**Digital Globes (e.g. Google Earth, ArcGIS Explorer, Whirlwind)**	**Data Explorers (e.g. AEJEE)**	**Desktop GIS (e.g. ArcView, MyWorld)**	**Web-based Mapping/GIS**	**GIS (unspecified)**
PROGRAM ELEMENTS (As A MEASURABLE OUTCOME)					
Training Duration/Time/Organization	Crews, 2008		Alibrandi & Palmer-Moloney, 2001 Audet & Paris, 1997	Henry & Semple, 2012	Johansson, 2008
GIS implementation (pre/post)		Baker ea, 2009	Baker ea, 2009		
Pre-service vs In-service			Bednarz & Audet, 1999, Johansson, 2003; McClurg & Buss, 2007		
Curriculum Materials Implemented (pre/post)			Baker ea, 2009		
Classroom Assessments Implemented (pre/post)					
PEDAGOGICAL MODEL (AS A MEASURABLE OUTCOME ONLY)*					
Cooperative Learning					
Role Playing					
Project/Problem/Case Based Learning			Bryant, 2010		
Discussion/Socratic					
Concept Attainment					
Scientific Inquiry (5E, learning cycle)			Coulter, 2005		
Mastery Learning/Programmed					

Direct Instruction/Presentations			Doering, 2002		
Simulation					
Computer Aided Instruction			Gatrell, 2004		
Independent/Individualized					
Guided Generation			Doering, 2002		
Structured Problem Solving			Doering, 2002		
CURRICULM/SUBJECT (AS A MEASURABLE OUTCOME ONLY)					
World Geography					
Human Geography					
Biology/Life Sciences			Coulter & Polman, 2004		
Environmental Science					
Earth Science/Physical Geography					
Sociology					
Computer Science					
Business/Marketing/Finance			Brickley ea, 2006		
Civics/Ethics					
Mathematics			Coulter & Kerski, 2005		
Architecture/Engineering					
Language Arts					
AFFECT (AS A MEASURABLE OUTCOME ONLY)					
Attitude			White, 2005		Morrell, 2006; Johansson, 2008

Motivation					Morrell, 2006
Self-Efficacy					
Community Connectedness					Yu ea, 2011
Citizenship					
PROCESS SKILLS (AS A MEASURABLE OUTCOME ONLY)					
Spatial Thinking NAS Identified Items					
Spatial Thinking Gersmehl Scaffold					
Scientific Inquiry Skills					
Geographic Inquiry Skills			Goldstein, 2010		Schubert & Uphues, 2009
TECHNICAL SKILLS (AS A MEASURABLE OUTCOME)					
Desktop GIS (e.g. ArcView, MyWorld)	Crews, 2008				
Desktop Data Explorers (e.g. AEJEE)					
Digital Globes (e.g. Google Earth, AGX))	Patterson, 2007		Crews, 2008		
Web-based Mapping (browser-based)					

Table 3.
Student learning and outcomes

STUDENT LEARNING AND OUTCOMES (Student Developmental groupings/age as the context)	Early Primary (age 5-9 years)	Late Primary (age 10-11 years)	Early Secondary (age 12-14 years)	Late Secondary (age 15-18 years)	Undergraduate	Graduate	Adult Learner
PEDAGOGICALMODEL (AS A MEASURABLE OUTCOME ONLY)*							
Cooperative Learning			Wiegand, 2003	Wiegand, 2003	Giordano ea, 2007		Alibrandi, 1998
Role Playing			Radinsky, 2008				
Project/Problem/Case Based Learning			Huynh, 2009	Falk & Nöthen, 2005 Huynh 2009 Liu ea, 2010	Chen, 1998 ; Drennon, 2005 Durrant ea, 2004 Gatrell & Oshiro, 2001 Giordano ea, 2007 Huynh, 2009		King, 2008
Discussion/Socratic							
Concept Attainment				Demirci, 2011	Clark ea, 2007 Stout & Lee, 2004 Theo, 2011		
Scientific Inquiry (5E, learning cycle)						Hall & Post, 2008	
Mastery Learning/Programmed					Fat, 2004		
Direct Instruction/Presentations					Clark ea, 2007		

Simulation							
Computer Aided Instruction				Milson & Earle, 2007	Fuest, 2001	Werner & Stern 2003	
Independent/Individualized							
E-Learning					Clark ea, 2007 Schwarz, 2005	Szablowska-Midor, 2007	
Collaborative Learning					Jekel, Pree & Kraxberger, 2007		
CURRICULM/SUBJECT (AS A MEASURABLE OUTCOME ONLY)							
World Geography				Kerski, 2003 Patterson ea, 2003			
Human Geography	Shin, 2006		Aladag, 2007 Aladag & Aladag, 2008 Aladag, 2010				
Biology/Life Sciences			Baker, 2002				Alibrandi, 1998
Environmental Science			Hagevik, 2011 Kulo ea, 2010 Bodzin & Anastasio, 2006	Beckett & Shaffer, 2005 Flecke, 2001	Brown & Burley, 1996 Gatrell & Oshiro, 2001 Lo ea, 2002 Stewart ea, 2001		Bailey, 2006
Earth Science/Physical Geography		Purcell ea, 2006	Kulo ea, 2010	Fun, 2005 Patterson ea, 2003	Pedersen ea, 2005 Stout & Lee, 2004	Hall & Post, 2008 Post ea, 2006	
Sociology							

Computer Science							
Business/Marketing/Finance					Miller ea, 2006		
Civics/Ethics			Kerski, 2004				
Mathematics			Coulter & Kerski, 2005				
Architecture/Engineering							
Geography (general)		Klein, 2007		Demirci, 2008 Klein, 2007			
History				Schäfer ea, 2008			
AFFECT (AS A MEASURABLE OUTCOME ONLY)							
Attitude		Klein, 2007	Baker, 2002 Baker & White, 2003 Klein, 2007 Goldstein, 2010	Klein, 2007 Schäfer ea, 2008 West, 2003 Artvinli, 2010	Pedersen ea, 2005 West, 2003 Ugurlu, 2007	Szablowska-M, 2007	
Motivation		Keiper, 1999	Aladag, 2007 Aladag & Aladag, 2008	Falk & Nöthen, 2005 Klein, 2005 West, 2003 Kerski, 2008	Jekel ea, 2007 West, 2003		
Self-Efficacy			Baker, 2002 Baker & White, 2003	Audet & Abegg, 1996	Songer, 2010		Audet & Abegg, 1996
Conceptualization of GIS			White, 2005	West, 2008			
PROCESS SKILLS (AS A MEASURABLE OUTCOME ONLY)							

Spatial Thinking	Shin, 2006	Zangerl, 2007	Bednarz & Bednarz, 2008 Hagevik, 2002 Sharpe & Huynh, 2008 Wigglesworth, 2003 Zangerl, 2007	Audet & Abegg, 1996 Bednarz & Bednarz, 2008 Kerski, 2003 Klein, 2005 Zangerl, 2007	Carver ea, 2004 Lee, 2006 Sharpe & Huynh, 2008 Walsh 1992	Sharpe & Huynh, 2008	Audet & Abegg, 1996 Bailey, 2006 Zangerl, 2007
Systemic Thinking Competence				Falk & Nöthen, 2005 Klein, 2005			
Scientific Inquiry Skills	Akerson & Dickinson, 2003	Akerson & Dickinson, 2003, Baker & Case, 2000	Baker, 2002 Baker & White, 2003 Furner & Ramirez, 1999 Lucking & Christmann, 2003				
Geographic Inquiry Skills		Keiper, 1999	Aarons, 2003 Wigglesworth, 2003	Sanchez, 2007, 2008 West, 1999 Linn, Kerski, Wither, 2005	Songer, 2010		
TECHNOLOGY USE (AS A MEASURABLE OUTCOME)							
Desktop GIS (e.g. ArcView, MyWorld)	Shin, 2006	Klein, 2007	Aladag, 2007 Aladag & Aladag, 2008 Hagevik, 2003 Klein, 2007	Audet & Abegg, 1996 Demirci, 2008 Falk & Nöthen, 2005 Flecke, 2001 Klein, 2007			Audet & Abegg, 1996
Desktop Data Explorers			Aarons, 2003	Sanchez, 2008			

(e.g. AEJEE)			Baker, 2002				
Digital Globes (e.g. Google Earth, AGX))	Bodzin, 2008	Klein, 2007 Zangerl, 2007	Klein, 2007 Zangerl, 2007	Klein, 2007 Wallentin ea, 2008 Zangerl, 2007	Jekel ea, 2007		Zangerl, 2007
Web-based Mapping (browser-based)	Bodzin, 2008	Klein, 2007	Klein, 2007	Klein, 2007 Milson & Earle, 2007	Carver ea, 2004 Hall-Wallace & McAuliffe, 2002 Pedersen ea, 2005		
GIS (unspecified)			Sharpe & Huynh, 2008		Clark ea, 2007 Schwarz, 2005 Sharpe & Huynh, 2008	Sharpe & Huynh, 2008	

Of the three GIS education research themes, the majority of published research has focused on student learning and outcomes. Most of the research in this area has targeted early secondary, late secondary, and undergraduate education (Huynh, 2009; Milson and Earle, 2007; Wiegand, 2003). Primary-age education and graduate education have seen only a handful of studies (Hall and Post, 2008; Shin, 2006). A wide variety of instructional models have been studied, with a slightly heavier concentration of studies examining project-based, problem-based, inquiry-driven learning. From a subject-specific perspective, most of the studies have examined Earth science, environmental science, or geography (Aladag 2007; Bodzin and Anastasio, 2006). Despite national surveys and case studies that indicated that biology and chemistry teachers were among the early adopters in GIS (Kerski, 2003; Baker et al., 2009; Baker and Kerski, in press), those fields and the students in them have been paid scant attention.

From these matrices, six research gaps in the field of GIS education can be identified and described.

1. Learning with and about GIS

This area of research focuses on student learning with GIS and spatial analysis.

Selected research questions: What are the challenges and benefits to the use of GIS in education? How does GIS diffusion in education compare to the diffusion and implementation of other technologies? What impact does using GIS in primary and secondary education have on students' GIS skills at the university level or in the workforce? What connection does GIS in education have to inquiry-based learning? What difference does the use of GIS have on the ways that students learn, as compared to the use of traditional instructional methods and traditional paper maps and atlases? What are the tasks that GIS is best suited to? What effect does the use of GIS have on standardised test scores?

Some studies have compared the implementation of GIS to other models of technology diffusion, most notably Everett Rogers' diffusion of innovations theory (White, 2008), but the number of such studies is few. Several studies have focused on the effect of GIS on standardised test scores (Goldstein, 2010). As a result of renewed attention to STEM and careers, recent research has been applied to using GIS to teach these skills (DiBiase et al., 2010; Lubinski, 2010).

2. Measurement of GIS knowledge and application

This area of research seeks to measure how teachers teach with GIS and the degree to which students acquire knowledge and skills.

Selected Research Questions: How can GIS-based instruction are assessed? How do standardized tests assess content, attitudes, and skills that students acquire when using GIS? In what ways are standardized tests inadequate to capture what students gain when using GIS? How can effective GIS-based curricula be developed and assessed? How can we define "effective" in terms of GIS-based instruction? Does the use of GIS foster spatial thinking, and how can it be measured? How can GIS-based instruction be assessed? How do assessment instruments affect the outcomes of the research? How can assessment instruments that other disciplines have been developed be adapted to GIS in education?

This area has received continued attention in the community although it is still lacking in terms of the number of studies, both in specific disciplines, key stages in the curriculum, and across international boundaries. Nonetheless, some notable studies have been conducted including in science (Hogrebe et al., 2008), geography (Yap et al., 2008), and GIS (DeMers, 2009).

3. Implications of GIS on learning

This area focuses on how and what students learn with GIS and its implications for instruction.

Selected research questions: What impact does GIS have on the ability to think critically, not only in geography, but in other disciplines? Does GIS in education impact skills that are measurable in any type of assessment, standardised or otherwise? How effective is GIS for males versus females, for special needs students, for students where the software or instruction is not in their native language, for at-risk students? Is it better to relegate GIS education to on-the-job training, or is an investment in primary, secondary, and university-level training beneficial? Are there ways to make GIS education more effective?

In terms of affect, student self-efficacy, attitude, and motivation have been examined by several researchers (Baker, 2002; Artvinli, 2010). While a handful of studies have examined spatial thinking and GIS, considerably more work is needed in the area. The rise in attention of the concept of 'spatial thinking' (National Research Council, 2006) in the last few years amplifies the gap between completed research and needed research. In addition, despite government and industry reports identifying geospatial technologies as one of the three key fields for the 21st century, most of the resulting grants have made great strides in professional development and curriculum development, particularly at the community (two-year) college level (such as the integrated geospatial education and technology training (http://igett.delmar.edu), and the GeoTech Centre (http://www.geotechcenter.org), with only a modest attention given to research. Over the past ten years, a substantial amount of GIS-based curriculum has been developed, but almost nobody has undertaken a rigorous assessment of the effectiveness of these materials or other styles or types of curricula at any level. Finally, even though after-school and other informal educational initiatives such the ESRI geospatial program for national 4-H in the USA (http://www.esri.com/4h) have attracted hundreds of students and spawned dozens of programs, little educational research has been conducted within these programs. The same is true with communities that have evolved around environmental concerns, such as EnviroSchools New Zealand (http://www.enviroschools.org.nz) and other components of what is becoming the 'Digital Earth' community.

4. Citizenship formation through GIS use

This area of research focuses on the connection that students make with their community and country as a result of GIS-based projects.

Selected research questions: What difference does the use of GIS have on how students perceive the world, their country, their region, and their community? Does GIS have any impact on citizenship education and student involvement in the issues in their own community? How can GIS education be most effectively delivered? What themes, scales, and lesson formats are most effective? At what ages is it appropriate for students to tackle which tasks? What impact does GIS have on student attitudes about their own role in society and about environmental issues? Is GIS complementary with outdoor education? Is GIS more effective inside or outside formal education institutions? Does the use of GIS at the secondary level affect graduation rates and participation in higher education? What differences exist in the implementation and effectiveness of GIS education among different countries around the world, and why? What impact do educational practices and educational and GIS policies have on the adoption of GIS in education?

Of the approximately 20 published studies examining teacher training and GIS, the bulk of the work has attempted to document the effects of varied instruction on either teacher attitude and motivation (Johansson, 2008; Morrell, 2006) or change in instructional practice. Several of the studies in this area are case studies or ethnologies which are valuable but few relatively large-scale surveys exist (exceptions being Schubert and Uphues, 2009; Baker et al., 2009). Somewhat different from student learning and outcomes, most of the curriculum-based instructor-based studies have focused on the sciences, but there is little overall research. Almost no attention has been paid to teacher technical skills, student technical skills, or process skills such as observation, communication, organisation, comparisons, inferring relationships, and other aspects (one exception being Doering, 2002).

In addition, while some research has focused on pre-service teacher education (Hagevik et al., 2010; Kaufman, 2004), research is needed in this area, due in part to the potential for large-scale implementation of any technology through teacher education programs. The lack of geotechnologies in university education methods courses no doubt contributes to the paucity of research. It is through the methods courses where new educators learn how to teach, but the content of these important courses is already crowded and changes are difficult to make in them, much less add any content such as spatial analysis through geotechnologies. The result is that most GIS training takes place with in-service teachers, rather than pre-service teachers, hindering the implementation of teaching with GIS across the primary and secondary curriculum.

5. GIS education for educators

This area of research focuses on professional development for educators who seek to use GIS in the classroom.

Selected research questions: What difference does the use of GIS have on teacher engagement in the education profession? Does the use of GIS change teachers' instructional styles? What are the instructional differences between teaching with GIS and teaching about GIS? How does GIS affect instructors' computer skills? What impact does the use of GIS with pre-service educators have versus the use of GIS with inservice educators? How can effective instructor training in GIS be designed and assessed, and what are the best practices in instructor training? How can the use of GIS with youth and community leaders inform formal educators? What impact do rigorous implementation of standardised content and skills and associated high-stakes testing have on implementation of GIS? What are the differences between how primary, secondary, and university educators use GIS in their instruction?

It can be argued that technical development is the most difficult area to study, given the rapid changes in technology and the need to create software in order to study effects. The availability of web-enabled GIS with relatively easy application programming interfaces could offer improved access to software development for researchers. To date, most of the research under this theme has emerged from grant-funded efforts that resulted in educationally-targeted software, such as GEODESY during the 1990s (Radke, 1997) and MyWorld GIS a decade later (Edelson, 2004). Studies examining GIS functionality, interface design, and data accessibility are the most prominent under this theme with a host of research emerging in the last two years around digital globes, such as Google Earth, ESRI's ArcGIS Explorer, and NASA's WorldWind. By contrast, no studies have examined the effectiveness or implementation of open source GIS (although Wang et al. 2008 examined it under educational policy).

The recent increase in web-GIS also affords rich investigations into the differences in teacher training and student learning in desktop GIS versus web-GIS. Web-based GIS increasingly offers some of the same functions as desktop GIS without additional software or tools to learn. Few studies have compared the benefits and challenges that web-GIS offers to desktop GIS. Few studies have examined the differences between the type and methods of GIS education needed by the professional GIS community versus that needed by GIS educators [with a notable exception by Golledge et al. (2008)]. Despite the importance of data to the whole enterprise of using GIS, how data are accessed, used, and represented has not been extensively researched. By investing more effort into the technical development of GIS for use in education, researchers would likely be better positioned to inform software developers as to the most important and effective tools that could be created for instruction.

6. Technical design of GIS for users

Research in this area focuses on instructional design and the technology behind GIS and its educational use.

Selected research questions: How can instructional design influence GIS in education? (Huang, 2011). Should instructional design influence GIS in education? What differences exist between the use of professional-grade GIS software in education versus the use of GIS software that is specifically created for education? What do educators need to do with GIS software that is different than what GIS professionals need? What are the best investments that industry could make in terms of fostering GIS in education? What do educators need to do with GIS that is not currently possible? How could GIS be used effectively with computer games and virtual reality environments? What linkages need to be built between GIS technology and other technologies? What benefits and challenges exist between teaching with desktop GIS versus web-based GIS, and what is the difference on instructors and students? What impact are recreational uses of GPS, volunteered geographic information, and the proliferation of web-mapping tools and virtual globes having on the educational uses of GIS?

Again, with few exceptions (such as Edelson, 2004, and the National Research Council, 2006), most of these topics lie unexplored. Indeed, the progress made in educators using GIS has been remarkable, and can in part be attributed to close communication among secondary education, higher education, industry, and non-profit and government agencies to meet the collective needs of the community. GIS education suffers from similar issues as geography education. Geography education has been criticised on similar grounds such as inward-looking, disconnected from educational research in other disciplines, lacking in scale, with a lack of replication studies and interdisciplinary approaches (Lambert, 2010).

A call for research in GIS education

While each of the three themes of GIS educational research has shown great promise and some diversity, the themes are investigated by a fairly narrow set of researchers. Much of the focus has been on student learning and outcomes, and the field lacks the connections with such fields as information technology and spatial cognition that could inform and deepen it. Perhaps because of differences in technological implementation, educational content standards, the educational culture in different societies around the world, and research interests of their authors, one limitation in the field is that published studies are somewhat loosely related. This leaves the body of GIS education research with little core theory to draw upon and limits the number of connections that can be made between findings. A second limitation in GIS education research is that many studies do not allow replicable methods, and even those that do allow replication oftentimes have not yet been replicated. Without replicable studies, little core knowledge can be built and theories cannot be postulated and tested. How can we increase the rigour, reliability, and replicability in the research designs? Following Henri Poincaré's concept of building science from a foundation of integrated findings, one might liken the current state of GIS education research as an accumulation of facts that is no more knowledge than a pile of bricks is a house.

If, as many in education and society predict, environmental science will amplify in presence and impact over the next generation, GIS education researchers would serve well by increasing the number and scope of studies in student learning and teacher training in this field. Furthermore, with increasing attention paid not only to the value but critical need to take advantage of outdoor education and fieldwork opportunities throughout life, the GIS education community needs to provide the linkages. More attention needs to be paid to the impact that general public and student engagement with geotechnologies has on student learning and technical development (including volunteered geographic information). This includes a necessary examination of how students develop critical thinking skills about data. It is particularly needed with mapped data, in a world where maps have become commonplace and the data behind them taken for granted in terms of quality and currency. Similarly, the continued popularity of computer games presents another opportunity for the researcher to investigate how such skills as critical thinking and spatial thinking can be fostered through such activities. A substantial amount of GIS-based curriculum has been developed over the past 20 years, but almost nobody has undertaken a rigorous assessment of the effectiveness of these curricular pieces. Through all future research, the community needs to be objective, studying challenges as well as benefits. What needs to be done in GIS education to achieve this agenda? If we are to draw from education literature, these are six guiding principles that underlie education research:

1. pose significant questions that can be investigated empirically
2. link research to relevant theory
3. use methods that permit direct investigation of the question
4. provide a coherent and explicit chain of reasoning
5. replicate and generalise across studies
6. disclose research to encourage professional scrutiny and critique (National Research Council, 2002).

The GIS education community needs to work more closely with others in instructional technology and instructional psychology. If GIS in education is continued to be perceived as a 'niche' technology, rather than fundamental to student learning and 21st century skills, then its implementation will remain small and it will never receive large grants for more rigorous studies. In addition, the GIS education community needs to use existing noteworthy studies such as *Learning To Think Spatially* and the AAG's Body of Knowledge as a framework for examining instructors, students, and technical aspects.

There exists a serious need for studies that utilise empirical data and result in high-quality, replicable data and analysis. Part of the needed results is informed, peer-reviewed guidelines for best practices in instructor training, introducing students to spatial thinking and GIS, how to assess students using GIS, and other core topics. The result is that inefficiency occurs with multiple people recreating items that have already been created. The field also critically needs an analysis of the gaps in the research and an examination of unexplored fields that is much more rigorous than what is attempted in this paper. Most early studies in GIS education examined individual classrooms and students. While there is certainly room for more, studies are also needed at the macro-scale, including school districts/local education authorities, states/provinces, and countries. A set of linkages between spatial analysis skills and content knowledge to content standards in different countries is needed. Some do exist for a few countries such as the USA and Denmark, as well as a book comparing GIS in secondary education in over 30 countries (Milson et al. 2012) but no rigorous research efforts exist between countries that would shed light on how standards can foster or hinder the amount and depth of spatial analysis with GIS in those countries. Given today's educational climate of increased dependence on national standards in content and skills, such studies would be valued by many.

GIS education studies are investigated by scholars in over 20 countries, and have increased in number and diversity particularly over the past five years. While this is encouraging, studies are also needed that compare and contrast how societal and educational forces, such as educational technology, national curricula, content standards, and the presence of geography in the educational system, serve to both drive and challenge the implementation of GIS among different countries.

Much of the research seems to be time-sensitive: given the fact that technologies evolve into more powerful and efficient tools over time, it may be a reasonable assumption that research results may need to be re-examined periodically. Similarly, at the same time that GIS has evolved, instructors and students alike have become much more technologically proficient in some of the basic tasks fundamental to successful GIS use. These include the manipulation of graphics, data and file management, and downloading and formatting data from the internet. How do these technical competencies affect the ability to use GIS in instruction? Finally, longitudinal studies of individual educators and students would inform those who teach with and those who teach about GIS to know the long-term impact of their efforts, and where to concentrate their efforts in the future.

For GIS to take hold in education at a much more rapid pace than at present, several things need to occur. While changing embedded structures in society and education is a major task, the part that the community has more influence over is the quality, amount, and impact of research in GIS education. The value of the spatial approach to interdisciplinary education needs to be demonstrated for instructors and institutions to embrace it. With any new technology, development outpaces research. Research in GIS education remains far behind technological development, hindering educators' and administrators' acceptance that GIS is a tool to foster interdisciplinary learning. Rather, the perception by some is that GIS education is a 'niche' field.

A proposed center for GIS education research

The awarding of the National Centre for Geographic Information and Analysis to three universities solidified the research foundation of GIScience during the 1990s. NSF's award of $5 million to Del Mar College and its partners to establish a National Geospatial Technology Centre of Excellence in 2008 (http://www.geotechcenter.org) will make an impact on GIS curriculum and career pathways for two-year colleges. In a similar way, GIS education research needs to be funded at a level where a substantial group of scholars can be supported through a 'Center for GIS Education Research' (CGER). It is recommended that these scholars would be interdisciplinary and international in scope, include researchers and developers, and encompass informal and formal education at all levels from primary to university learners.

The need for a CGER has existed for at least a decade, but the development of the international geospatial education community (Kerski, 2008), has made the need critical. CGER would support GIS in education at a deep level and at a broad level, at a scale that spans countries but also at a detailed scale of the individual classroom. At CGER, GIS education research could be discovered, linked, nurtured, and supported. In it, a growing network of researchers could share and compare research results but also could compare the research methods. CGER would act as a network of researchers to guide GIS education research to accomplish focused tasks:

1. Network: to establish an international research network on GIS education
2. Peer review: to encourage peer review and replication of studies
3. Collaboration: to establish and nurture collaboration of research across national borders.
4. Guidance: to guide large scale research questions that span the globe
5. knowledge base: to provide a repository of GIS education knowledge through an online library, including a research bibliography, assessment tools, and GIS-based curriculum
6. Applications: to consolidate and build on fragmented findings to draw out applications of a wider scope that will address gaps in the theory of GIS learning and teaching knowledge
7. Multi-lingual: to make findings and research studies available in multiple languages.

CGER should be funded and supported through no more than ten institutions, a combination of educational non-profit organisations, for-profit institutions, and institutions of higher education. These lead institutions will be responsible for reporting to the funding agency and carrying out the CGER mission. CGER should not be housed in one physical institution but should be an online centre for the benefit of all in the field. Technological tools now make it possible for a diverse group of researchers around the planet to collaborate on GIS education research. At the core of CGER will be an online social networking set of tools where researchers around the world can find each other, find research results, write joint papers, find conferences, summits, workshops, and other events, discover new developments in geotechnologies and in the application of geotechnologies to education, and publish and discover GIS-based curriculum, assessment tools, and other resources. It is recommended that CGER be funded for an initial five-year period from 2011 to 2016 with a re-evaluation upon the conclusion of the five years.

Concluding Thoughts

The National Research Council (2006) listed five elements critical to ensuring that GIS as a spatial thinking tool is supported throughout education. They stated that there should be programs to provide material support (hardware, software, and network access), logistical support (installation, and upgrades), instructional support (pre-service and inservice training), curriculum support (goals, lessons, and so on), and community support (recognition of the educational value of the support system). We argue that a sixth element is needed, and that is the research support. Without these studies, the other support pieces will develop at a slower pace, and the pieces implemented will not be as effective. We therefore advocate that the sixth recommendation that the National Research Council (2006, p. 235) be implemented as quickly as possible through our proposed research centre: “With funding from either a government agency (such as NSF or the US Department of Education) or a private philanthropy, a research program should be developed to see whether or not an understanding of GIS improves academic achievement across the curriculum. Without credible assessment of results, the value of GIS and other support systems for spatial thinking cannot be evaluated".

It is hoped that this call for a research agenda will serve as a focal point of communication for the GIS education research community and encourage additional and deeper research into these and other areas so that future directions in GIS education will have a sound research base on which to build. Despite some substantive advancement, the field of GIS is still relatively unexplored, and is wide open for researchers to investigate new directions or to build on the past 20 years of research and development. Clearly, there is much work to be done.

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