May, 2013

Placing GIS in sustainability education

Sungsoon Hwang, *DePaul University*

Journal of Geography in Higher Education
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/cjgh20

Placing GIS in sustainability education

Sungsoon Hwang [a]
[a] Department of Geography, DePaul University, 990 W Fullerton Ave, Suite 4500, Chicago, IL, 60614, USA
Published online: 20 Mar 2013.

To cite this article: Sungsoon Hwang (2013): Placing GIS in sustainability education, Journal of Geography in Higher Education, 37:2, 276-291

To link to this article: http://dx.doi.org/10.1080/03098265.2013.769090

Journal of Geography in Higher Education, 2013
Vol. 37, No. 2, 276–291, http://dx.doi.org/10.1080/03098265.2013.769090

Placing GIS in sustainability education

Sungsoon Hwang*

Department of Geography, DePaul University, 990 W Fullerton Ave, Suite 4500, Chicago, IL 60614, USA

(*Received 22 March 2012; final version accepted 6 December 2012*)

As public awareness about sustainability grows and as higher education advances sustainability more comprehensively, geographers have an opportunity to take a role in sustainability education. This article examines (1) what constitutes sustainability education, (2) how geographic concepts and Geographic Information System (GIS) are relevant to sustainability education, and (3) how geospatial thinking can be incorporated into the sustainability curriculum using GIS. This research proposes five geospatial inquiries that students can make to explore sustainability issues using GIS, which are spatial distribution, spatial interactions, spatial relationships, spatial comparisons, and temporal relationships. Definition, examples, and uses of these five geospatial inquiries supported by GIS are provided.

Keywords: GIS; sustainability; sustainability education; GIS education; spatial thinking

Introduction

Sustainability, "meeting fundamental human needs while preserving the life-support systems of planet Earth" (Kates et al., 2001, p. 641), has become an important concern for colleges. The number of books, scientific articles, and media coverage on the topic has exploded (Walters, 2011); with that explosion, the number of sustainability-related jobs has also increased (Light, 2011). Sixty-nine percent of 8200 college applicants who participated in a recent survey said a college's commitment to the environment would impact their decision to apply to or attend a school (Iovino, 2011). Sustainability-related academic programs have been increasing (Association for Advancement of Sustainability in Higher Education [AASHE], 2012). Furthermore, US higher education has made concerted efforts to advance sustainability – as witnessed in the development and rapid adoption of the Sustainability Tracking Assessment & Rating System (Liu, 2011).

Despite the progress that has been made, work toward a sustainable future is surrounded by many barriers. Public understanding of sustainability is limited (McLoughlin, 2004). A gap exists between knowledge and action in which complex factors are at play (Kollmus & Agyeman, 2002; Macnaghten & Jacobs, 1997). And although higher education is considered an ideal place for providing education for sustainability (Cortese, 2003), divisions among disciplines have hindered implementing sustainability education (Jones, Selby, & Sterling, 2010). The current situation presents opportunity for researchers to refine sustainability concepts and for educators to promote them.

Society has started to recognize the value of GIS as an educational tool in higher education (Sinton, 2009; Sinton & Lund, 2007; Tsou & Yanow, 2010) and K12 education (Bednarz, 2004; Kerski, 2003; Napoleon & Brook, 2008). The recent publication of

* Email: shwang9@depaul.edu

Learning to think spatially (National Research Council [NRC], 2006) has served to direct further attention to the role of spatial thinking and GIS in education. Research suggests that a spatial training program might help students to enter the fields of Science, Technology, Engineering, and Math (Uttal et al., 2012; Wai, Lubinski, & Benbow, 2009) that are widely perceived in crisis (NRC, 2010). Exposure to GIS has shown to improve spatial thinking or awareness (Lee & Bednarz, 2009; Perkins, Hazelton, Erickson, & Allan, 2010). For GIS to become an effective supportive system for spatial thinking, students need to have some understanding of spatial concepts (Marsh, Golledge, & Battersby, 2007). Indeed, inadequate understanding about spatial concepts has been one of the barriers to integrating GIS into the K-12 curriculum (Kerski, 2007). Aligning logically sequenced spatial concepts with task that students can perform may be a promising avenue for the effective use of GIS in the classroom (Golledge, Marsh, & Battersby, 2008).

Although opportunities abound for using GIS as a tool for advancing sustainability, the role of GIS and geography in advancing sustainability *education* has not been discussed widely (Bednarz, 2006; Chalkley, Blumhof, & Ragnarsdttir, 2010; Liu, 2011). The case for using GIS in promoting sustainability is based mostly on case studies rather than on a comprehensive review (Campagna, 2006; Tan & Rose, 2007). Furthermore, the link between geographic concepts and GIS is not always made explicit in discussing the contribution of geographic perspectives to sustainability (Inkpen, 2009; Purvis & Grainger, 2004; Whitehead, 2006; Wilbanks, 1994). This article attempts to overcome these limitations and to further the discourse on the role of GIS in sustainability education.

The remainder of this article is organized as follows. First, this article discusses the role of education in creating a sustainable future after synthesizing definitions of sustainability. Second, it discusses what should be among learning goals of sustainability education. Third, it presents key geographic concepts pertaining to sustainability education. Fourth, it examines the potentials of GIS in advancing sustainability. Fifth, it discusses the framework for integrating spatial thinking and GIS into the sustainability curriculum. Finally, this study concludes with a summary of this article's findings and a discussion on future research.

The role of education in creating a sustainable future

The origin of sustainability discourse can be traced to a recognition of the environmental consequences of economic growth that exceeds the carrying capacity of the planet (Carson, 1962; International Union for the Conservation of Nature and Natural Resources [IUCN], 1980; Meadows, Meadows, Randers, & Behrens, 1972). The process of negotiating a global response to an ecological crisis engenders a contested and ambiguous notion of sustainability. This is reflected in the definition of sustainability (or sustainable development) as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission, 1987, p. 24). This can be interpreted as meeting needs of the poor while acknowledging ecological limits (Purvis & Grainger, 2004; United Nations [UN], 1992). Experiences – such as those of the Green Belt Movement (Maathai, 2003) – show that two goals of sustainability, protecting the environment and meeting human needs, are not necessarily conflicting, but rather may be mutually reinforcing. The UN (2002, p. 8) defines sustainability as "the integration of…economic development, social development and environmental protection as interdependent and mutually reinforcing pillars." It reflects a new focus on the human–environmental interaction, one of the four traditions of geography (Pattison, 1964) leading to the birth of sustainability science (Clark & Dickson, 2003; Kates et al., 2001).

Education can be held partially responsible for both problems and solutions in creating a sustainable future. Orr (1992) points out that the sustainability challenge is not attributed to a crisis *in* education (i.e., that we are not doing enough), but rather a crisis *of* education (i.e., that we are part of the problem). Tracing the genesis of the modern education system to the enlightenment and industrialization, he argues that this system has served to emphasize both logical reasoning over affective understanding and efficiency over equity.

Nonetheless, education is recognized as crucial to creating a sustainable future because the ideal of sustainability cannot be realized without changes in behaviors (e.g. to responsible consumption) and world view (e.g. to raise space–time horizons in response to sustainability challenges) (Meadows et al., 1972). Scholars emphasize that political economy should take account of long-term environmental costs (Daly, 1973; Hardin, 1968) and nature should be conceived as something to be preserved for and to coexist with humans (Mumford, 1974; White, 1967). Education can accelerate these changes in behaviors; higher education can inculcate in students the thinking skills required to achieve sustainability (Cortese, 2003; Orr, 2004).

Recognizing the link between sustainability and transformative change, it is worthwhile to consider the perspectives of organizational change (Bartunek & Moch, 1987), shallow versus deep ecology (Naess, 1973), and systems theory (Meadows, 2008). Different orders of change can be noted in the progression of change, from first-order change to third-order change. First-order change is adaptive and self-corrective, characterized by negative feedback loops in which the main goal is to maintain stability; second-order change is deeper and meaning-making, characterized by positive feedback loops in which the main goal is to attain a new state; and third-order change transforms the current system.

Applying these types of change to education, it is possible to divide sustainability education into three levels: education *about* sustainability, education *for* sustainability, and education *as* sustainability (Sterling, 2004). Education about sustainability (which applies first-order learning) increases knowledge about human–environmental interaction, paving the way for higher levels of sustainability education (Sterling, 2004). Education for sustainability (which applies second-order learning) bridges knowledge and action to create changes necessary to achieve sustainability (Sterling, 2004). Education as sustainability couples knowledge and action into a frame of mind that can bring about transformative change (Bonnet, 2002). These three levels of sustainability education can be characterized as "doing things better," "doing better things," and "seeing things differently," respectively (Sterling, 2004, p. 56).

Learning goals of sustainability education

Scholars suggest that we address the following questions in contemplating the road toward a sustainable future, which are as follows: (a) what are the mechanisms of the society–nature relation? (b) is the planet on a sustainable path?, and (c) what does interconnection among places mean to sustainability of the planet? In other words, it is important to recognize three aspects of sustainability that are *relational* (attributes), *directional* (time), and *distributional* (space). Climate change research illustrates the importance of understanding *relational* aspects of sustainability. Findings from climate change research demonstrate that climate change has a predominantly anthropogenic origin (Intergovernmental Panel on Climate Change [IPCC], 2007), and has implications for public health (Githeko, Lindsay, Calfalonieri, & Patz, 2000) and food security (Schmidhuber & Tubiello, 2007). This complex human–environmental interaction calls for attention to interdisciplinary inquiries across natural and social sciences.

With regard to *directional* aspects of sustainability, Boulding (1966) depicts Earth as a spaceship on an unknown path with limited resources. Since the 1980s, the earth's ecological footprint (human demand) has exceeded the planet's ecological capacity (Wackernagel et al., 2002). Environmental economists theorize that the planet is on a sustainable path when capital as a whole (i.e., natural capital and human capital) is not declining (Pearce & Atkinson, 1993); this suggests that achieving sustainability requires a two-pronged approach: developing human capital that leads the planet to sustain itself (e.g. development of alternative energy) while maintaining ecological integrity.

Understanding *distributional* aspects of sustainability may be crucial to behavioral changes since an understanding of connections among places often precedes the assumption of shared responsibility. For example, socially disadvantaged neighborhoods bear a disproportionate burden of environmental costs because the current political economy does not internalize those costs (Cutter, 1995). Environmental degradation in developing countries is not attributable solely to poverty and over-exploitation of land by farmers, but also to colonial land policies and exploitation by large multinational corporations (Blaike, 1985).

The primacy of these three aspects of sustainability is reflected in the literature on learning outcomes of sustainability education (American College Personnel Association [ACPA], 2006; Luther College, 2010; Svanström, Lozano-García, & Rowe, 2008), as well as on definitions and indicators of sustainability (Brundtland Commission, 1987; IUCN, 1980; Kates, Parris, & Leiserowitz, 2005; Maclaren, 1996; NRC, 1999; Pearce, Markandya, & Barbier, 1989; UN, 2002, 2007). An understanding of these three aspects should be among the learning goals of sustainability education. Educators can develop a sustainability curriculum that helps students (a) understand the interaction among the coupled natural and human systems; (b) build the capacity for non-declining (natural and human) capital stock; and (c) discern interdependence among places across geographic scales. In short, sustainability education is aimed at cultivating a sense of relation, path, and place (National Council for Science and the Environment [NCSE], 2003).

Geographic concepts relevant to sustainability education

It may be reasonable to consider geography as an appropriate home for sustainability education given the very nature of the discipline (Martin, 2005). Sustainability has increasingly become a research focus in geography (Yarnal & Neff, 2004). Geography as a discipline can benefit from changing educational landscape, including the sustainability movement (Erickson, 2012); yet, geographers are not exploiting this opportunity (Bednarz, 2006; Liu, 2011). This may be hampered by the discipline's structural division into physical and human geography (McManus, 2004). To assess the relevance of geography to sustainability discourse, it will be necessary to examine key geographic concepts instrumental in understanding and addressing sustainability challenges.

Scale: Tackling sustainability challenges requires collaborative efforts across jurisdictions at different geographic scales. Sustainability issues occur at multiple geographic scales. Climate change is a global event with varying consequences at the local level. The processes that shape sustainability are organized "more characteristically at some scales than others" (Wilbanks, 2007, p. 279). For example, dynamics of stream ecosystems can be best observed in watersheds at particular geographic scales (continental, regional, and local) rather than across the continuum of scales (continental to local). Boundary organizations (Guston, 2001) – designed to facilitate collaboration between involved communities – can manage forests better than organizations formed

without regard to a biome. A mismatch between the scale of an operation and the scale of a phenomenon often causes ineffective responses to sustainability challenges (Whitehead, 2006). Sustainability issues interact across scales. Research shows that land use change models that incorporate scale interaction outperform models that do not (Veldkamp & Fresco, 1996). Scale interaction allows analysts to integrate global generality and local idiosyncrasy. In summary, the concept of scale helps elucidate holistic notions of sustainability.

Place and region: Sustainability challenges can be observed most profoundly by a consideration of place and region. Place is location experienced. A region is an area that exhibits a high degree of homogeneity (e.g. a metropolitan area or a watershed) (Natoli, 1994). One can correct a mistaken view that sustainability issues are distribution free (i.e., without spatial variation) by using places and regions as the unit of analysis. Furthermore, places and regions provide an appropriate context in which to assess sustainability because they share history and neighbors. Indeed, sustainability science promotes place-based analysis that examines "spatially continuous or coupled human-environment systems" over places at multiple geographic scales (Turner et al., 2003, p. 8076). Exploring spatial, temporal, and spatiotemporal patterns through place-based analysis can help analysts uncover place-specific processes that underlie patterns (Nagendra, Munroe, & Southworth, 2004). In sum, the concept of place/region helps us understand context-specific notions of sustainability.

Interaction: Sustainability can be understood in terms of interactions (or interdependence). Those interactions can be thematic, spatial, and temporal. These three dimensions of interactions can be visualized using a Geographic Matrix (Berry, 1964) (Figure 1) that synthesizes subject areas of geography; columns represent regions, rows represent characteristics (or attributes) of a region, and each matrix represents time. In short, geographers study attributes of regions at different scales over time. Thematic interactions refer to how different attributes interact, as shown by a vertical link in Figure 1 (e.g. the effect of air quality on health). Spatial interactions (SIs) refer to how a certain attribute interacts among regions, as shown by a horizontal link in Figure 1 (e.g. dispersion

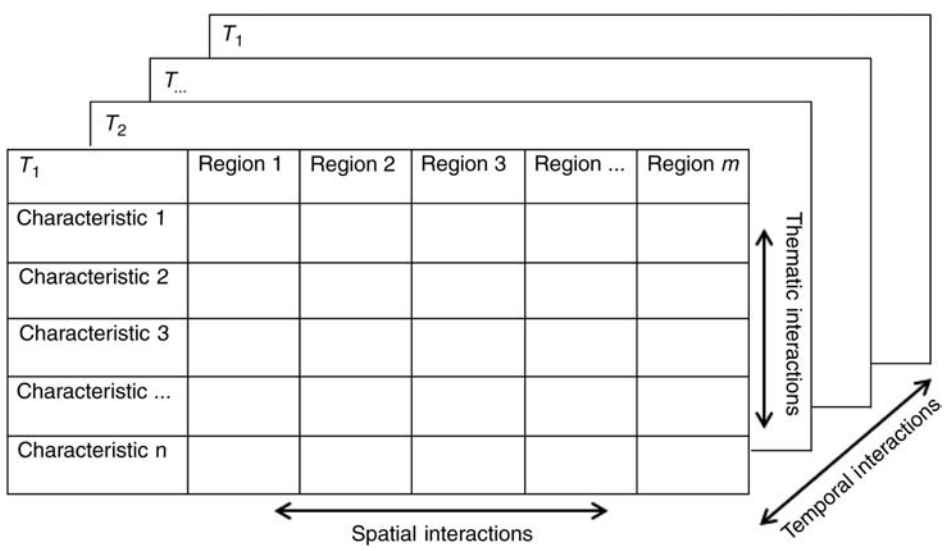

Figure 1. Three dimensions of interactions in the Geographic Matrix.

of air pollution). Temporal interactions refer to how attributes of regions interact over time, as depicted by an oblique link in Figure 1 (e.g. change in air quality).

Interactions in one dimension depend on interactions in other dimensions. For example, how environmental degradation interacts with social developments (thematic interactions) depends on historic trajectories (temporal interactions) and interdependence of regions (SIs); exploitation of natural resources in the developing world does not necessarily mitigate (but rather exacerbates) social problems such as poverty, given agriculture-based (undiversified) and postcolonial political economies (Bryant, 1998; Maathai, 2003). The relationship among (social, economic, and environmental) components of sustainability cannot be generalized as fixed, but rather as emergent, given varying spatiotemporal contexts. The concept of interactions sheds light on the interconnected aspects of sustainability. It should be noted that these concepts (scale, place/region, and interaction) are not mutually exclusive, but rather intricately related.

Potentials of GIS in advancing sustainability

GIS is well suited to accelerate efforts to understand and address sustainability challenges in several ways. First, GIS enables users to organize and integrate data pertaining to exploring sustainability issues. In GIS, similar themes are organized into layers (e.g. ozone, transportation network, and aquifer) and data layers can be integrated vertically (thematically), horizontally (spatially), and temporally (NRC, 1997) (Figure 2). *Vertical integration* combines layers (attributes) given a geographic area. *Horizontal integration* merges layers among geographic areas. *Temporal integration* puts together layers over time. Given this, one can do the following: (a) explore the relationship among attributes (e.g. climate change and hydrological hazards); (b) examine issues that cut across regions (e.g. water pollution); and (c) monitor how these issues evolve over time (e.g. change in patterns and processes of flooding). Hence, GIS can be used to reveal three aspects of sustainability (relational, distributional, and directional) altogether.

Second, sustainability issues are now monitored with greater efficiency than ever due to advances in geospatial technology and Information and Communication Technology (such as remote sensing, Global Navigation Satellite Systems, sensor networks, and cloud computing). Hyper-spectral remote sensing has great potential to advance knowledge about ever-changing physicochemical properties of the planet (Jensen, 2007). Mobile GIS users can freely upload geo-tagged multimedia data as events unfold (such as wildfires, earthquakes, and flooding) (Haklay, Singleton, & Parker, 2008). We live in an age in

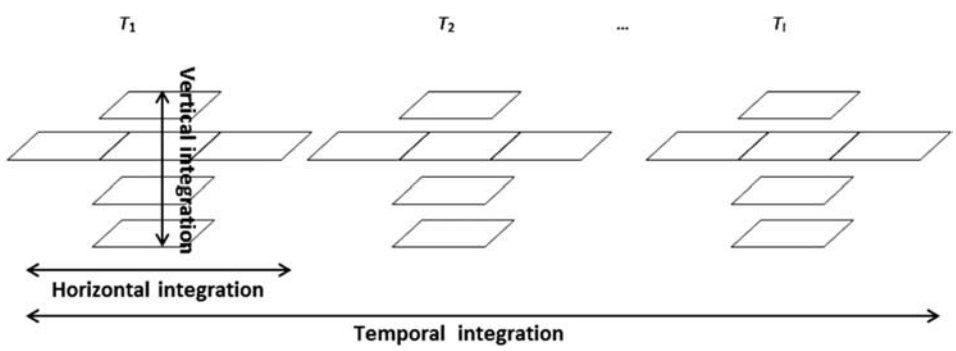

Figure 2. Data integration in GIS.

which human senses augmented by technology continuously feed us information about the planet. This improvement in quantity and quality of geographic data furthers our ability to advance the understanding of sustainability challenges.

Third, the visual analytic capabilities of GIS can facilitate the process of gaining insights into sustainability challenges. One difficulty in understanding these challenges lies in the complexity of relevant data. GIS is equipped with interactive geographic visualization and analysis techniques in multiple views – tables, graphs, statistics, and maps – that are dynamically linked (Andrienko & Andrienko, 2006; Anselin, 2005; MacEachren, 1995) and can enable users to visualize spatial distribution (SD) and identify spatial patterns or outliers. This taps into the human capacity for pattern recognition and helps users understand sustainability issues. GIS provides a universal medium – maps empowered by computation and geared toward the human brain – that can facilitate cognition about complex sustainability issues.

The ways in which data are organized, acquired, and presented in GIS – as mentioned above – are conducive to promoting a common understanding of complex problems among different stakeholders. Thus, GIS has the potential to promote interdisciplinary research (Moore, 2008; Nigrelli & Audisio, 2010), interdisciplinary education (Borden et al., 2007), and participatory decision-making (Ahamed et al., 2009; Nyerges & Jankowski, 2009; Vanderpost & McFarlane, 2007) geared toward addressing sustainability challenges. Research suggests that sustainability can be achieved effectively by bringing together appropriate disciplines (Jones et al., 2010) and organizational units (Guston, 2001). GIS is neither confined to one discipline nor bound by one organizational unit. Hence, GIS is well suited to support interdisciplinary inquiry across organizational boundaries essential to achieving sustainability.

Incorporating spatial thinking into the sustainability curriculum using GIS

Although concept-based learning may be an appropriate structure for teachers, research shows that task-based or problem-based pedagogy has been effective for students' learning (Golledge et al., 2008). Students can be guided to explore sustainability issues by making geospatial inquiries; these inquiries (a) are aligned with learning goals of sustainability education (i.e., understanding relational, directional, and distributional aspects of sustainability); (b) incorporate geographic concepts (scale, place/region, and interaction); and (c) are supported by GIS. Geospatial inquiries can be organized into five types: *SD*, *SIs*, *spatial relationships (SRs)*, *spatial comparisons (SCs)*, and *temporal relationships* (TRs) in order of complexity (from simple to complex).

Definition of five geospatial inquiries

The working definition of and hierarchy among these geospatial inquiries is provided in Figure 3. In this working definition, the term *place/region* is a domain-specific multi-scalar construct as discussed earlier; for instance, economic regions can be defined specific to the domain of economy at local, regional, and international scales. The term *thing* is used as an umbrella term to refer to objects (spatially discrete phenomena such as land parcels and roads), fields (spatially continuous phenomena such as temperature and elevation), and events (dynamic phenomena such as earthquakes and crime incidents) (Goodchild, Yuan, & Cova, 2007).

SD inquiry involves recognizing the identity of a spatial entity (e.g. what is a watershed?) and identifying the location (or extent) of the spatial entity (e.g. where is a

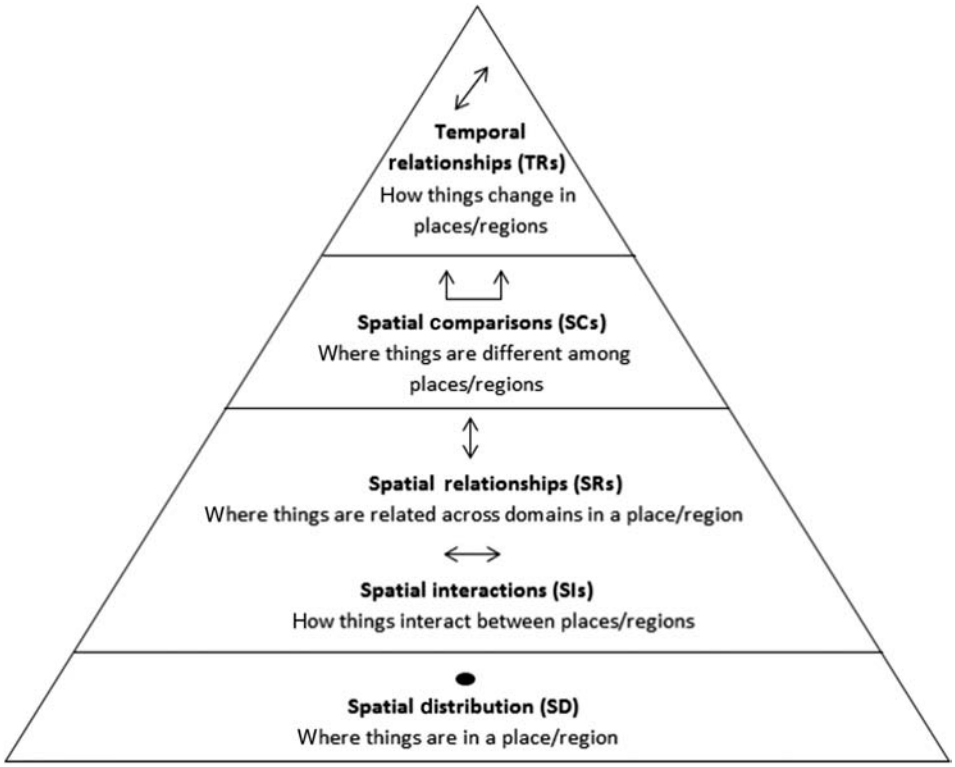

Figure 3. Definition of and hierarchy among five geospatial inquiries.

watershed?). SD serves as a building block for further inquiries. SIs inquiry involves recognizing how entities are connected among places/regions (e.g. how is watershed A connected to watershed B?). SI is equivalent to the concept of flow and movement from one place/region to another. SRs inquiry concerns noting how entities of one domain are associated with entities of another domain (e.g. how is a runoff level associated with land cover types in a watershed?). SR is equivalent to the concept of correlation (i.e., relationship among variables) or thematic interaction in Figure 1. Hence, SD can be denoted as a cell, SI as a horizontal link, and SR as a vertical link in Figures 3 and 4.

SCs focus on differences between places/regions (e.g. how is economic region A different from economic region B?); SI focuses on connection between places/regions (e.g. how does economic region A interact with economic region B?). SC deals with multiple places/regions to reveal what is particular about a place/region over another; SR places emphasis on correlation while controlling for places/regions. SC can embed SD, SI, and SR – that is, differences in SD, SI and SC among places/regions can be examined. For example, the rate of knowledge transfer (as an example of SI) in the Silicon Valley can be compared to other economic regions. Differences in social vulnerability to environmental change (as an example of SR) can be examined among different coastal regions; this is equivalent to the concept of spatial nonstationarity (i.e., relationship between variables varies by location). TRs are the most complex inquiry as they can embed other inquiries. In other words, one can examine changes in SD, SI, SR, and SC. For example, changes in regional inequality (as an example of SC) can be monitored. SC is denoted as a horizontal pair, and TR is denoted as an oblique link in Figures 3 and 4.

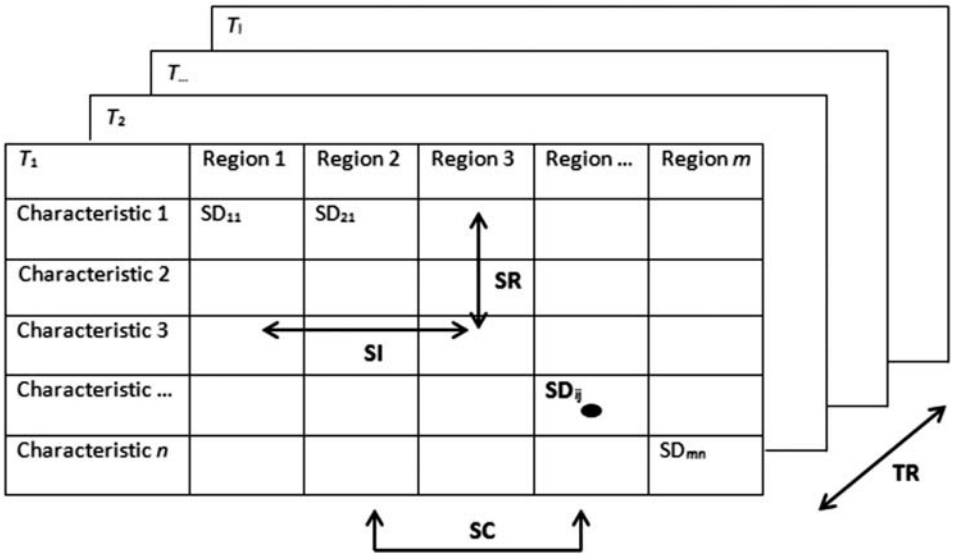

Figure 4. Five geospatial inquiries in the Geographic Matrix.

Learning sustainability spatially with GIS

Sustainability curricula can be designed in a way that inquiries of a high-order category build on inquiries of a low-order category (Figure 3). For instance, students begin with recognizing components and patterns of water systems (SD). Then they can learn to model flow in water systems (SI), and examine human impacts on water systems (SR). Building on the inquiries above, students can then compare how human impacts on water systems differ across regions (SC) and change over time (TR). SI is important to understanding how places are interconnected (meeting the "distributional" goal of sustainability education). SR encourages students to make connections across domains (meeting the "relational" goal of sustainability education). A complete set of geospatial inquiries in sequence enables learners to identify place-specific processes and determine whether communities of their interest are on a sustainable path (meeting the "directional" goal of sustainability education). Below, I provide more examples of these inquiries relevant to sustainability education, and discuss how GIS can be used to support these inquiries.

Spatial distribution: One can discern how attributes are similar and dissimilar over locations (spatial dependence and spatial heterogeneity) by interpreting whether there is an even or uneven SD of a phenomenon at various geographic scales. This can lead students to ask why (e.g. why there is a high level of ozone in that area) and encourage them to link patterns to processes. For example, students can identify the location of power plants, detect crime hot spots, and explore spatial concentrations of toxic emissions. Various mapping techniques are available to support this inquiry. Point maps can be used to show the location of objects and events; proportional symbol maps depict magnitude associated with objects and events (spatially discrete data); dot density or choropleth maps portray SD of attributes aggregated by areal units such as census (spatially aggregate data); and isarithmic (isoline) maps visualize SD of attributes interpolated from sample field data such as temperature (spatially continuous data).

Spatial interactions: The interconnections among places (the SIs) should be recognized, for such recognition broadens our geographic horizons; it provides foundation for collaborative responses to sustainability challenges. To promote SI inquiry, students can be instructed to investigate water flows in a local watershed and commuting flows in a metropolitan region. Students can map where food comes from and discuss sustainability implications of space–time compression (Harvey, 1990). Students can make desire lines (or spider diagrams) and flow maps to visualize flow among places and regions. With a hydrologic modeling tool, one can trace the path of water pollution by delineating a least-cost path and watersheds. One can analyze commodity flows among economic regions by constructing an origin–destination matrix with a network analysis tool. *Horizontal integration* supports this inquiry and can be performed using GIS data processing tools. These days, online data distribution services provide flexible ways of downloading data by geographic areas. For instance, Internet users can download public-domain geographic data by reference areas (such as administrative boundaries and watersheds) or by a particular user-defined map extent through the National Map Viewer (http://viewer.nationalmap.gov/viewer/).

Spatial relationships: Inquiries about SRs are essential to understanding sustainability challenges, for sustainability challenges are inherently cross-cutting. In analyzing SRs among variables involved in a sustainability challenge, different ways of organizing sustainability indicators can be considered – the issue or theme (environmental, economic, and social) oriented framework (UN, 2007) and capital framework (Meadows, 1998). Public health officials may want to know how ozone levels affect the occurrence of asthma. Farmers and environmental policy-makers may wonder what influences nitrogen-based fertilizers have on organic matter in soil. This type of analysis can be complemented by correlation analysis. If one wants to know how corruption relates to exploitation of natural resources in the developing world, one can construct a scatter plot and calculate a correlation coefficient from appropriate indicators.

Spatial comparison: Indigenous people and their communities can play an important role in responding to sustainability challenges given their historical relationship with their lands (UN, 1992). Sustainability initiatives that are effective in some places are not necessarily transferable to other places due to the idiosyncrasy or path dependence of places. For instance, the rate in which green building is adopted varies by metropolitan areas. A degree of economic integration (SIs) differs among economic regions. Ecological resilience in response to development (SRs) is not uniform across places. By interpreting the difference among regions, one can uncover the different processes that underlie varying manifestations of a phenomenon. This inquiry can be best utilized when spatial heterogeneity (i.e., attributes of places are different due to the intrinsic uniqueness of a place) (Anselin, 1988; Hartshorne, 1959) is in operation. GIS techniques mentioned earlier can be used to support this inquiry.

Temporal relationships: Given our concerns with ensuring that the planet is on a sustainable path, understanding environmental changes and the evolving human-environmental interaction can alert us to planetary unsustainability. This will also ensure that societal responses to sustainability challenges are corrected and adapted in an informed manner. Students may be interested in changes in a forest reserve, a water runoff level, an ecological footprint, and community resilience. With GIS, students can map data at different points in time (e.g. SD of pervious land cover in 1990 and 2010); map changes over time (e.g. what surface areas have become impervious from 1990 to 2010); and animate changes during a period (e.g. has runoff increased, and if so where in particular; are there any spatial patterns in flooding over time).

Conclusions

This paper examines how GIS can be used to support sustainability education. A sustainability curriculum should be framed to bring about changes in behaviors and world view, and it can be developed in consideration of three levels of sustainability education – education about sustainability, education for sustainability, and education as sustainability. The curriculum should focus on elucidating humans' coexistence with nature (relational) in the interconnected world (distributional) beyond the time horizon of the present (directional). Geographic concepts are conducive to advancing an understanding of sustainability challenges, and these can be incorporated into the sustainability curriculum.

To elevate the role of geography and GIS in sustainability education, I present a framework for teaching spatially explicit (or geospatial) sustainability using GIS. I delineate five geospatial inquiries that meet the learning goals of sustainability education (cultivating a sense of relation, place, and path), and incorporate key geographic concepts (scale, place/region, and interaction). Using GIS, students can explore where things are (SD); how things interact between regions (SIs); how things are related across domains (SRs); how things are different across regions (SCs); and how things change over time (TRs). These inquiries can help students to explore spatial patterns, relationships, and changes, and uncover place-specific processes.

GIS supports the spatial thinking mentioned above by providing ways to organize, integrate, visualize, and analyze data germane to exploring sustainability issues. GIS helps manage the complexity inherent in sustainability challenges through interactive geographic visualization and analysis techniques. GIS enables an evidence-based investigation of sustainability in a holistic manner. Hence, GIS has two broad appeals with respect to overcoming barriers to advancing sustainability in higher education – a limited understanding of sustainability and divisions among disciplines. Students can substantiate abstract and ambiguous notions of sustainability by working through concrete constructs (such as maps, graphs, and statistics) created by GIS. Although sustainability has been increasingly incorporated across disciplines, efforts to bring together different disciplines are still lacking. GIS can potentially serve as an educational tool that weaves together knowledge about our planet. As GIS has become easier to use and more accessible to the public (Schultz, Kerski, & Patterson, 2008), it will become feasible to use GIS as a tool that enables interdisciplinary education for sustainability.

Given growing demands for a geospatial workforce (Department of Labor Employment and Training Administration [DOLETA], 2010; Gaudet, Annulis, & Carr, 2003), greater impetus in higher education to participate in advancing sustainability, and the expanding use of GIS across curricula, it is conceivable to deploy GIS in university curricula so that diverse audiences can develop sustainability literacy utilizing the framework presented in this article. Given that sustainability is being added to general education requirements in universities, geographers can offer a general education course on sustainability of the planet using GIS.

Future research will be necessary to assess the pedagogical value of the framework presented in this paper. More specifically, what effects does spatial thinking have on developing sustainability literacy among a broad audience? What aspects of GIS enable or impede achieving specific learning goals of sustainability education? This paper focuses on the role of GIS in furthering education *about* sustainability and emphasizes GIS as a positivistic mode of observation (or a tool for quantitative research). Thus, it may be worthwhile looking into in what ways this framework can be pedagogically engineered toward education *for* sustainability.

References

Ahamed, T., Khan, M. I. N., Takigawa, T., Koike, M., Tasnim, F., & Zaman, J. M. Q. (2009). Resource management for sustainable development: A community- and GIS-based approach. *Environmental Development and Sustainability*, *11*(5), 933–954.

American College Personnel Association (ACPA) College Student Educators International (2006). Sustainability taskforce student learning outcomes. Retrieved November, 2012, from http://www.myacpa.org/task-force/sustainability/docs/Learning_Outcomes_Sustainability_Map.pdf

Andrienko, N., & Andrienko, G. (2006). *Exploratory analysis of spatial and temporal data: A systematic approach*. Berlin, New York: Springer.

Anselin, L. (1988). *Spatial econometrics: Methods and models*. Dordrecht: Kluwer Academic Publishers.

Anselin, L. (2005). Interactive techniques and exploratory spatial data analysis. In P. A. Longley, M. F. Goodchild, D. J. Maguire & D. W. Rhind (Eds.), *GIS: Principles, techniques, management and applications* (pp. 253–266). Hoboken, NJ: Wiley.

Association for Advancement of Sustainability in Higher Education (AASHE) (2012). Sustainability-focused academic degree programs. Retrieved November, 2012, from http://www.aashe.org/resources/academic-programs

Bartunek, J. M., & Moch, M. K. (1987). First-order, second-order, and third-order change and organization development interventions: A cognitive approach. *Journal of Applied Behavioral Science*, *23*(4), 483–500.

Bednarz, R. S. (2006). Environmental research and education in US geography. *Journal of Geography in Higher Education*, *30*(2), 237–250.

Bednarz, S. W. (2004). Geographic information systems: A tool to support geography and environmental education? *GeoJournal*, *60*, 191–199.

Berry, B. J. L. (1964). Approaches to regional analysis: A synthesis. *Annals of the Association of American Geographers*, *54*(1), 2–11.

Blaike, P. M. (1985). *The political economy of soil erosion in developing countries*. Harlow, Essex: Longman.

Bonnet, M. (2002). Education for sustainability as a frame of mind. *Environmental Education Research*, *8*(1), 9–20.

Borden, R. J., Cline, K. S., Hussey, T., Longsworth, G., & Mancinelli, I. (2007). A river runs through it: A college-community collaboration for watershed-based regional planning and education. *Human Ecology Review*, *14*(1), 90–100.

Boulding, K. E. (1966). The economics of the coming spaceship Earth. In H. Jarrett (Ed.), *Environmental quality in a growing economy* (pp. 3–14). Baltimore, MD: Johns Hopkins University Press.

Brundtland Commission (World Commission on Environment and Development) (1987). *Our common future*. Oxford: Oxford University Press.

Bryant, R. L. (1998). Power, knowledge and political ecology in the third world: A review. *Progress in Physical Geography*, *22*(1), 79–94.

Campagna, M. (2006). *GIS for Sustainable Development*. Boca Raton, FL: CRC Press.

Carson, R. (1962). *Silent spring*. Boston, MA: Houghton Mifflin.

Chalkley, B., Blumhof, J., & Ragnarsdttir, K. V. (2010). Geography, earth and environmental sciences: A suitable home for ESD? In P. Jones, D. Selby & S. Sterling (Eds.), *Sustainability education: Perspectives and practice across higher education* (pp. 93–108). London: Earthscan.

Clark, W. C., & Dickson, N. M. (2003). Sustainability science: The emerging research program. *Proceedings of the National Academy of Sciences*, *100*(14), 8059–8061.

Cortese, A. D. (2003). The critical role of higher education in creating a sustainable future. *Planning for Higher Education*, *31*(3), 15–22.

Cutter, S. L. (1995). Race, class and environmental justice. *Progress in Human Geography*, *19*(1), 111–122.

Daly, H. E. (1973). *Toward a steady-state economy*. San Francisco, CA: W.H. Freeman.

Department of Labor Employment and Training Administration (DOLETA) (2010). High growth industry profile – geospatial technology. Retrieved November, 2012, from http://www.doleta.gov/BRG/Indprof/geospatial_profile.cfm

Erickson, R. (2012). Geography and the changing landscape of higher education. *Journal of Geography in Higher Education*, *36*(1), 9–24.

Gaudet, C. H., Annulis, H. M., & Carr, J. C. (2003). Building the geospatial workforce. *URISA Journal*, *15*(1), 21–30.

Githeko, A. K., Lindsay, S. W., Calfalonieri, U. E., & Patz, J. A. (2000). Climate change and vector-borne diseases: A regional analysis. *Bulletin of the World Health Organization*, *78*(9), 1136–1147.

Golledge, R., Marsh, M., & Battersby, S. (2008). Matching geospatial concepts with geographic educational needs. *Geographical Research*, *46*(1), 85–98.

Goodchild, M. F., Yuan, M., & Cova, T. J. (2007). Towards a general theory of geographic representation in GIS. *International Journal of Geographical Information Science*, *21*(3), 239–260.

Guston, D. H. (2001). Boundary organizations in environmental policy and science: An introduction, Science. *Technology & Human Values*, *26*(4), 399–408.

Haklay, M., Singleton, A., & Parker, C. (2008). Web mapping 2.0: The neogeography of the GeoWeb. *Geography Compass*, *2*(6), 2011–2039.

Hardin, G. (1968). The tragedy of the commons. *Science*, *162*(3859), 1243–1248.

Hartshorne, R. (1959). *Perspective on the nature of geography*. Chicago, IL: Rand McNally & Company.

Harvey, D. (1990). *The condition of postmodernity: An enquiry into the origins of cultural change*. Cambridge, MA: Blackwell.

Inkpen, R. (2009). Development: Sustainability and physical geography. In N. Clifford, S. L. Holloway, S. P. Rice & G. Valentine (Eds.), *Key concepts in geography* (pp. 378–391). Los Angeles, CA: Sage.

Intergovernmental Panel on Climate Change (IPCC) (2007). Climate change 2007: Synthesis report. Retrieved November, 2012, from http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

International Union for the Conservation of Nature and Natural Resources (IUCN) (1980). World conservation strategy, International Union for the Conservation of Nature. Retrieved November, 2012, from http://data.iucn.org/dbtw-wpd/edocs/WCS-004.pdf

Iovino, J. (2011). The Princeton review gives 768 colleges green ratings. *The Princeton Review*, 1 August. Retrieved November, 2012, from http://www.princetonreview.com/green/press-release.aspx

Jensen, J. R. (2007). *Remote sensing of the environment: An earth resource perspective*. Upper Saddle River, NJ: Pearson Prentice Hall.

Jones, P., Selby, D., & Sterling, S. (2010). More than the sum of their parts? Interdisciplinarity and sustainability. In J. Paula, D. Selby & S. Sterling (Eds.), *Sustainability education: Perspectives and practice across higher education* (pp. 17–37). London: Earthscan.

Kates, R., Clark, W., Corell, R., Hall, J., Jaeger, C., Lowe, I., . . . , & Svedin, U. (2001). Environment and development: Sustainability science. *Science*, *292*(5517), 641–642.

Kates, R. W., Parris, T. M., & Leiserowitz, A. A. (2005). What is sustainable development? goals, indicators, values, and practice. *Environment*, *47*(3), 8–21.

Kerski, J. J. (2003). The implementation and effectiveness of geographic information systems technology and methods in secondary education. *Journal of Education*, *102*(3), 128–137.

Kerski, J. J. (2007). Geographic Information Systems in education. In J. Wilson & A. S. Fotheringham (Eds.), *The Handbook of Geographic Information Science* (pp. 540–556). Malden, MA: Wiley-Blackwell.

Kollmus, A., & Agyeman, J. (2002). Mind the map: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research*, *8*(3), 239–260.

Lee, J., & Bednarz, R. (2009). Effect of GIS learning on spatial thinking. *Journal of Geography in Higher Education*, *33*(2), 183–198.

Light, J. (2011, July 11). Sustainability jobs get green light at large firms. *The Wall Street Journal*. Retrieved November, 2012, from http://online.wsj.com/article/SB10001424052702304793504576434301780569100.html

Liu, L. (2011). Where in the world of sustainability education is US geography? *Journal of Geography in Higher Education*, *35*(2), 245–263.

Luther College (2010). Frequently asked questions about sustainability education. Retrieved November, 2012, from http://www.luther.edu/sustainability/assets/Sustainability_FAQs_III.docx

Maathai, W. (2003). *The Green Belt Movement: Sharing the approach and the experience*. New York: Lantern Books.

MacEachren, A. M. (1995). *How maps work: Representation, visualization and design*. New York: Guilford Press.

Maclaren, V. W. (1996). Urban sustainability reporting. *Journal of the American Planning Association*, *62*(2), 184–202.

Macnaghten, P., & Jacobs, M. (1997). Public identification with sustainable development: Investigating cultural barriers to participation. *Global Environmental Change*, *7*(1), 5–24.

Marsh, M., Golledge, R., & Battersby, S. E. (2007). Geospatial concept understanding and recognition in G6-college students: A preliminary argument for minimal GIS. *Annals of the Association of American Geographers*, *97*(4), 696–712.

Martin, G. J. (2005). *All possible worlds: A history of geographical idea*. Oxford: Oxford University Press.

McLoughlin, L. C. (2004). Is sustainability a breakfast cereal? Public program based research into community understandings of sustainability. *Australian Journal of Environmental Education*, *20*(1), 115–127.

McManus, P. (2004). Geography. In J. Blewitt & C. Cullingford (Eds.), *The sustainability curriculum: The challenge for higher education* (pp. 218–231). London: Earthscan.

Meadows, D. H. (1998). Indicators and information systems for sustainable development. The Sustainability Institute. Retrieved November, 2012, from http://www.biomimicryguild.com/alumni/documents/download/Indicators_and_information_systems_for_sustainable_development.pdf

Meadows, D. H. (2008). *Thinking in systems: A primer*. White River Junction, VT: Chelsea Green Publishing.

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens, W. W.III (1972). *The limits to growth*. New York: Universe Books.

Moore, C. G. (2008). Interdisciplinary research in the ecology of vector-borne diseases: Opportunities and needs. *Journal of Vector Ecology*, *33*(2), 218–224.

Mumford, L. (1974). *The pentagon of power: The myth of the machine*, *Vol. II*. New York: Harcourt Brace Jovanovich.

Naess, A. (1973). The shallow and the deep, long-range ecology movement: A summary. *Inquiry*, *16*, 95–100.

Nagendra, H., Munroe, D. K., & Southworth, J. (2004). From pattern to process: Landscape fragmentation and the analysis of land use/land cover change. *Agriculture, Ecosystems and Environment*, *101*, 111–115.

Napoleon, E., & Brook, E. (2008). *Thinking spatially using GIS*. Redlands, CA: ESRI Press.

National Council for Science and the Environment (NCSE) (2003). Recommendations for education for a sustainable and secure future: A Report of the third national conference on science, policy and the environment. Retrieved November, 2012, from http://ncseonline.org/sites/default/files/2003%20NCSE%20Conference%20Report.pdf

National Research Council (NRC) (1997). *Rediscovering geography: New relevance for science and society*. Washington, DC: National Academy Press.

National Research Council (NRC) (1999). *Our common journey*. Washington, DC: National Academy Press.

National Research Council (NRC) (2006). *Learning to think spatially: GIS as a support system in the K-12 curriculum*. Washington, DC: National Academies Press.

National Research Council (NRC) (2010). *Rising above the gathering storm, revisited: Rapidly approaching category 5*. Washington, DC: National Academies Press.

Natoli, S. J. (1994). "Guidelines for geographic education" and the fundamental themes in geography. *Journal of Geography*, *93*(1), 2–6.

Nigrelli, G., & Audisio, C. (2010). Floods in Alpine river basins (Italy): An interdisciplinary study combining historical information and hydroclimatic data. *GeograpiaFisica E Dinamica Quaternaria*, *33*(2), 205–213.

Nyerges, T. L., & Jankowski, P. (2009). *Regional and urban GIS: A decision support approach*. New York: Guilford Press.

Orr, D. W. (1992). *Ecological literacy: Education and the transition to a postmodern world*. Albany, NY: State University of New York Press.

Orr, D. W. (2004). *Earth in mind: On education, environment, and the human prospect* (10th anniversary ed.). Washington, DC: Island Press.

Pattison, W. (1964). The four traditions of geography. *Journal of Geography*, *63*(5), 211–216.

Pearce, D. W., & Atkinson, G. D. (1993). Capital theory and the measurement of sustainable development: An indicator of "weak" sustainability. *Ecological Economics*, *8*, 103–108.

Pearce, D. W., Markandya, A., & Barbier, E. (1989). *Blueprint for a green economy*. London: Earthscan.

Perkins, N., Hazelton, E., Erickson, J., & Allan, W. (2010). Place-based education and geographic information systems: Enhancing the spatial awareness of middle school students in Maine. *Journal of Geography*, *109*(5), 213–218.

Purvis, M., & Grainger, A. (2004). *Exploring sustainable development: Geographical perspectives*. London: Earthscan Publications.

Schmidhuber, J., & Tubiello, F. N. (2007). Global food security under climate change. *Proceedings of the National Academy of Sciences*, *104*(50), 19703–19708.

Schultz, R. B., Kerski, J. J., & Patterson, T. C. (2008). The use of virtual globes as a spatial teaching tool with suggestions for metadata standards. *Journal of Geography*, *107*, 27–34.

Sinton, D. (2009). Roles for GIS within higher education. *Journal of Geography in Higher Education*, *33*(S1), 7–16.

Sinton, D., & Lund, J. (2007). *Understanding place: GIS and mapping across the curriculum*. Redlands, CA: ESRI Press.

Sterling, S. (2004). Higher education, sustainability, and the role of systemic learning. In P. B. Corcoran & A. E. J. Wals (Eds.), *Higher education and the challenge of sustainability: Problematics, promise, and practice* (pp. 47–70). Dordrecht: Kluwer Academic Publishers.

Svanström, M., Lozano-García, F. J., & Rowe, D. (2008). Learning outcomes for sustainability development in higher education. *International Journal of Sustainability in Higher Education*, *9*(3), 339–351.

Tan, X., & Rose, B. (2007). A geospatial approach to sustainability study. *International Journal of Sustainable Development*, *10*(3), 214–232.

Tsou, M. -H., & Yanow, K. (2010). Enhancing general education with geographic information science and spatial literacy. *URISA Journal*, *22*(2), 45–54.

Turner, B. L. II, Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., . . . , & Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences*, *100*(14), 8074–8079.

United Nations (UN) (1992). Agenda 21. Retrieved November, 2012, http://www.un.org/esa/dsd/agenda21/

United Nations (UN) (2002, August 26–September 4). *Report of the world summit on sustainable development, Johannesburg, South Africa*. New York, NY: United Nations.

United Nations (UN) (2007). *Indicators of sustainable development: Guidelines and methodologies* (3rd ed.). Retrieved November, 2012, from http://www.un.org/esa/sustdev/natlinfo/indicators/guidelines.pdf

Uttal, D. H., Meadows, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2012, June 4). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin*, Advance online publication.

Vanderpost, C., & McFarlane, M. (2007). Groundwater investigation in semi-arid developing countries, using simple GIS tools to facilitate interdisciplinary decision making under poorly mapped conditions: The Boteti area of the Kalahari region in Bostswana. *International Journal of Applied Earth Observation and Geoinformation*, *9*(4), 343–359.

Veldkamp, A., & Fresco, L. O. (1996). CLUE-CR: An integrated multi-scale model to simulate land use change scenarios in Costa Rica. *Ecological Modelling*, *91*, 231–248.

Wackernagel, M., Schultz, N. B., Deumling, D., Linares, A. C., Jenkins, M., Kapos, V., . . . , & Randers, J. (2002). Tracking the ecological overshoot of the human economy. *Proceedings of the National Academy of Science*, *99*(14), 9266–9271.

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology*, *101*(4), 817–835.

Walters, J. S. (2011, March 13). New trends in sustainability, development issues. *Global Sherpa*. Retrieved November, 2012, from http://www.globalsherpa.org/news-trends-sustainability-development-issues

White, L. Jr (1967). The historical roots of our ecologic crisis. *Science*, *155*, 1203–1207.

Whitehead, M. (2006). *Spaces of sustainability: Geographical perspectives on the sustainable society*. New York: Routledge.

Wilbanks, T. J. (1994). "Sustainable development" in geographic perspective. *Annals of the Association of American Geographers*, *84*(4), 541–556.
Wilbanks, T. J. (2007). Scale and sustainability. *Climate Policy*, *7*(4), 278–287.
Yarnal, B., & Neff, R. (2004). Wither parity? The need for a comprehensive curriculum in human-environment geography. *Professional Geographer*, *56*(1), 28–36.