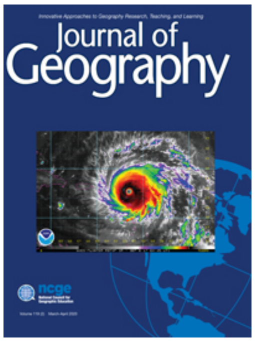

Journal of Geography

ISSN: 0022-1341 (Print) 1752-6868 (Online) Journal homepage: https://www.tandfonline.com/loi/rjog20

WebGIS Implementation and Effectiveness in Secondary Education Using the Digital Atlas for Schools

Rafael De Miguel González & Maria Luisa De Lázaro Torres

To cite this article: Rafael De Miguel González & Maria Luisa De Lázaro Torres (2020) WebGIS Implementation and Effectiveness in Secondary Education Using the Digital Atlas for Schools, Journal of Geography, 119:2, 74-85, DOI: 10.1080/00221341.2020.1726991

To link to this article: https://doi.org/10.1080/00221341.2020.1726991

Published online: 21 Feb 2020.

JOURNAL OF GEOGRAPHY
2020, VOL. 119, NO. 2, 74–85
https://doi.org/10.1080/00221341.2020.1726991

WebGIS Implementation and Effectiveness in Secondary Education Using the Digital Atlas for Schools

Rafael De Miguel González[a,b,c] and Maria Luisa De Lázaro Torres[b,c,d]

[a]Faculty of Education, University of Zaragoza, Zaragoza, Spain; [b]EUROGEO, Waardamme, Belgium; [c]Real Sociedad Geográfica, Madrid, Spain; [d]Department of Geography, UNED, Madrid, Spain

ABSTRACT

The Digital Atlas for Schools is an innovative WebGIS development contributing to the use of geospatial information in schools. Based on a story map tool, it creates a geography curriculum constructed on ArcGIS Online. This article discusses the implications of implementing geospatial technologies so that learners can acquire spatial thinking and geographical knowledge, but also develop responsible and active spatial citizenship. Based on the learning progression approach, it presents results showing the effectiveness of this instructional resource, both for secondary school students and for geography teachers in training. The article concludes with a discussion on how results confirm the need for geospatial technologies to be better incorporated into the geography curriculum at secondary schools.

KEYWORDS
WebGIS; geographical education; spatial thinking; geographical knowledge; Spain

Introduction

Besides teaching and learning methods, didactics, resources and curriculum, recent research in geographical education has focused particularly on key components of spatial thinking, geographical knowledge and, more recently, spatial citizenship. Current scientific literature argues that geospatial technologies, geographic information systems and other tools support and facilitate the acquisition of these three elements. This article illustrates the Digital Atlas for Schools, and examines its impact as an innovative and powerful tool for learning geography in school education, but also for geography teacher training. Based on the correlation between spatial thinking, geographical knowledge and spatial citizenship as a theoretical framework, this article evaluates the influence of WebGIS in geographical education. This influence is due to increasing implementation in geography classrooms and also previous empirical research that proves the effectiveness of geospatial technology for learning geography and acquiring spatial abilities. This article aims to obtain evidence for two main research questions: Do geospatial technologies foster better geography learning than conventional teaching, and, in particular, when using the Digital Atlas? Do geospatial technologies facilitate a balanced acquisition of spatial thinking ability, geographical knowledge, and spatial citizenship?

Going a step further, the purpose of this study is to examine the effectiveness of the Digital Atlas compared to conventional geography teaching and learning methods. A quasi-experimental design was used to evaluate the reliability of this new tool as a pedagogical resource to obtain improved instruction in several physical, human and regional geographical education topics. Findings and measurable results suggest a correlation between the use of the Digital Atlas and learning progressions. Does the Digital Atlas effectively contribute to better learning in geographical education and to what extent? Is the Digital Atlas equally valid for geography teacher training and for school education? These questions are explored in this article, which concludes with a discussion of implications and recommendations for the use of digital atlases in geographical education.

Background: WebGIS and effective geography learning

The rise in the use of several geospatial technologies in the classroom (virtual globes, remote sensing, GIS, WebGIS, GPS, geolocation mobile apps, and other geomedia and GeoICT resources) has transformed geography teaching practices in the past ten years. The use of active instructional practices, for example inquiry-based learning and problem-solving activities, has also increased in secondary-education classrooms, mainly in Europe and the United States (Bednarz and van der Schee 2006) but also in other parts of the world, including Asia and Latin America (Milson, Demirci, and Kerski 2012; Chen and Wang 2015; Demirci, De Miguel, and Bednarz 2018).

Although several challenges posed by the introduction of geospatial technologies in secondary school classrooms were debated around 20 years ago (ESRI 1998; Kerski 2003; Johansson 2006), the current widespread availability of geospatial data, spatial-data infrastructures, geomedia and WebGIS resources make their use indispensable for every "good and up-to-date geography lesson." Further, capacity for valuable geography teaching for the future requires a

CONTACT Rafael De Miguel González rafaelmg@unizar.es Faculty of Education, University of Zaragoza, Pedro Cerbuna 12, Zaragoza 50009, Spain

comprehensive model for an updated geography curriculum (Jo and Muñiz 2015). Specifically, the International Geographical Union has acknowledged the importance of these tools through the recent International Charter on Geographical Education by stating that "geospatial technologies offer unique opportunities to make sense of the modern world" and form an invaluable 21st-century skill set for geographical education (Stoltman, Lidstone, and Kidman 2017).

Some researchers go further and propose a change in the very nature and paradigm of geographical education, redefining it solely as digital geographical education (De Miguel, De Lázaro, and Marrón 2012; Van der Schee et al. 2015) or even digital earth education (Kerski 2008; Fargher 2013; Donert 2014; Donert 2015). In addition to the many benefits of using geospatial technologies, digital geographical education unquestionably increases students' motivation and interest in geography classes, as indicated by the previous literature. However, the main reason for using GIS in geography classrooms stems from two prominent pedagogical principles specific to our scientific discipline and school subject: spatial thinking and geographical knowledge. Uhlenwinkel (2013) underlines the differences between them, since the latter uses a subject-based approach. Nevertheless, other contributions (De Miguel 2016a; De Miguel 2016b) describe a parallel instructional sequence between spatial thinking and geographical knowledge to synthesize links within inquiry-based learning processes based on geospatial technologies. They also highlight the powerful role of geospatial technologies in addressing research challenges in geographical problems, geographical skills and geographical knowledge (De Miguel, Koutsopoulos, and Donert 2019).

Spatial thinking

Spatial thinking has been well defined by the National Research Council's Committee on Support for Thinking Spatially (2006) as a distinctive ability separate from general intelligence and as a constructive combination of cognitive skills (Metoyer and Bednarz 2017) based on a constructive amalgam of three elements: concepts of space, tools of representation, and processes of complex reasoning. Spatial visualization, spatial orientation and spatial relations are considered the three main spatial abilities of cognitive geography (Golledge and Stimson 1997; Lee and Bednarz 2009). In particular, spatial relations have been extensively outlined by several authors who establish differing taxonomies for spatial relations as a basic component of spatial thinking (Bednarz 2004; Gersmehl and Gersmehl 2007; Golledge, Marsh, and Battersby 2008; Janelle and Goodchild 2009; Jo and Bednarz 2009; Mohan and Mohan 2013; De Miguel 2016b). Recently, behavioral geography has introduced new approaches to study spatial thinking using cognitive neurosciences (Lobben and Lawrence 2015; Schinazi and Thrash, 2018).

According to Metoyer and Bednarz (2017), spatial thinking is important for academic success in geography and other sciences, for example STEM domains (Wei, Lubinski, and Benbow 2005). Using geospatial technologies and GIS allows students to improve their spatial skills and spatial thinking, develop spatial abilities, solve spatial problems and increase their spatial reasoning. Geospatial technologies include geographical scales (local, regional, national and global), spatial analysis and research, but also explicit GIScience and tools (Roche 2014). Thus, national curricula and standards in the United States (Bednarz, Heffron, and Huynh 2013) and in European countries (Donert et al. 2016) recommend the use of geospatial technologies for daily activities in geography classrooms as essential for acquiring spatial thinking.

Geographical knowledge

The difference between spatial thinking and geographical thinking involves considering the social, economic, political and cultural aspects of the human dimension (Hubbard et al. 2002) rather than merely topological aspects. In other words, geographical thinking involves applying spatial thinking to address complex geographic concepts or environmental and social problems (Metoyer and Bednarz 2017). Consequently, space, place and environment are key concepts for acquiring geographical thinking, complemented by other organizing concepts—such as scale, change, people, sustainability, interdependence, ecosystems, physical and human processes, landscape and cultural diversity, among others—included in most national geography curricula (De Miguel 2014a), particularly in England (Lambert and Morgan 2010). Geographical thinking taught using "traditional mental skills," such as memorization, has now been replaced by problem-solving, reasoning and inquiry-based approaches (Morgan 2018) in which geospatial technologies play an important role.

Inquiry-based learning was included in the *National Geography Standards* (1994) a decade after the publication of the *Guidelines for Geographic Education* (1984), which defined the five geographical skills for successful geographic inquiry-based learning: asking, acquiring, organizing, analyzing and answering geography questions. This scheme was adopted and adapted by papers describing the geo-inquiry approach in implementing geospatial technologies at school (ESRI 2003; Kerski 2011; Favier 2011; De Miguel 2013; Roberts 2013).

However, not only are geospatial technologies powerful tools for developing spatial thinking, geographical thinking or inquiry-based learning, they also provide meaningful geographical subject matter for students, since they help them understand the world by contextualizing global and local geographical issues. An approach based on the GeoCapabilities international project confirms that it is possible to acquire powerful disciplinary knowledge with the use of geospatial technologies (Lambert, Solem, and Tani 2015; Butt 2017; Fargher 2018).

Spatial citizenship

Spatial citizenship provides a third essential component in geographical education along with spatial thinking and geographical knowledge. Consequently, geography educators need to raise awareness of the world's spatial and social problems to turn learners into critical thinkers and citizens that propose actions to improve their everyday environment. The practical applications of geospatial technologies embedded in learning practices for traffic and transportation, smart-city approaches, environment, social media, and so on, contribute decisively to this instructional goal (Gryl, Jekel, and Donert 2010; Kim and Bednarz 2013; Bearman et al. 2016; Demirci, De Miguel, and Bednarz 2018; Donert, De Miguel and Lupi, 2019).

Implementation

Geospatial technologies are not merely visual resources easing geography instruction. Their myriad benefits have transformed all dimensions of geographical education, from school curriculum to pedagogies, practices and styles of teaching and learning geography in primary and secondary education (Rod, Larsen, and Nilsen 2010; Del Campo et al. 2012; Heffron and Downs 2012; De Miguel 2014a; Chen and Wang 2015). Consequently, an approach focusing on textbooks runs parallel to the use of online resources. By boosting inquiry-based learning and problem-solving activities with geospatial technologies, students can enjoy a more dialogical, collaborative and integral learning experience. These technologies further their understanding of numeracy, graphics and map integration; they contribute data and resources for study cases; and they help perform meaningful fieldwork activities. They also improve individual learning and special-needs education, and provide a more accurate learning assessment. Furthermore, as geospatial technologies allow for SMART learning—self-directed, motivated, adaptive, resource-enriched, and technology-embedded—(Kim 2017), this new approach has been introduced into geography teacher education (pre- and in-service) as a factor for professional development (Fitzpatrick 2001; Hong 2015; Bryant and Favier 2015). Several selected contributions assessing geospatial-technology implementation in the classroom at international, national or individual levels conclude that comparing "analog" geographical education to digital geographical education no longer makes any sense (Bednarz and van der Schee 2006; Milson and Earle 2008; Lam, Lai, and Wong 2009; Bodzin 2011; Milson, Demirci, and Kerski 2012; Goldstein and Alibrandi 2013; Kerski, Demirci, and Milson 2013; Hwang 2013; De Miguel 2014b; Chen and Wang 2015; Collins 2018; Chang et al. 2018; Matusch et al. 2018; Kolvoord, Keranen, and Rittenhouse 2019).

Effectiveness

Nevertheless, the effectiveness of geospatial technologies still proves rare in *geospatial education research*, which is particularly illuminating in a scientific field characterized by a paucity of empirical data and longitudinal studies. If empirical evidence based on tested and effective geography teaching models is required to shape decision-making in educational practice (Bednarz, Heffron, and Huynh 2013), then this is even more necessary for *geospatial education research* (Baker et al. 2015). For *critical geospatial education research*, one contribution (Kim and Bednarz 2013) obtains empirical evidence on links between spatial thinking and critical thinking, which we identify as spatial citizenship. Another study (De Miguel 2016a) also finds evidence of relationships between spatial thinking and geographical knowledge. Additional research, looking at the effectiveness of geospatial technologies in geography classrooms, provides evidence for the hypothesis that geospatial technologies foster stronger geography learning compared to conventional teaching (Audet and Paris 1997; Kerski 2003; Demirci 2008; Yap et al. 2008; Lee and Bednarz 2009; Lee and Bednarz 2012; Kerski, Demirci, and Milson 2013; Demirci 2015; Sharpe and Huynh 2015; Tan and Chen 2015; Höhnle et al. 2016; Metoyer and Bednarz 2017; Sinha et al. 2017). This article adds to empirical research conducted with the Digital Atlas and WebGIS to provide some answers to the balanced acquisition of the three key components aforementioned: spatial thinking, geographical knowledge and spatial citizenship.

WebGIS

Of all available geospatial technologies, WebGIS is perhaps the most powerful, analytical and overall useful tool for geographical education, particularly in secondary education (Baker 2005; Johansson 2006; Baker 2015; Jo, Hong, and Verma 2016; De Lázaro, De Miguel, and Morales 2017; Fargher 2018; Kerski and Baker 2019). This in spite of difficulties involved in using and learning GIS (Rickles, Ellul, and Haklay 2017), successful initiatives illustrate instances in which secondary students use desktop GIS for highly sophisticated work (Kolvoord, Keranen, and Rittenhouse 2019). WebGIS has almost all the functionalities of a desktop GIS and is far easier for secondary school students to use, as proven by increasing use of it (Slocum et al. 2008; Hong 2014; Manson et al. 2014; De Lázaro, Izquierdo, and González 2016).

WebGIS also has many advantages including accessibility, storage, ubiquity and speed advantages. It fosters a transdisciplinary approach to STEM education through integration and interoperability with other geospatial technologies, including mobile devices (GPS and geolocation data, open data, multi-scale data, real-time data and spatial-data infrastructures). It encourages the possibility of collaborative work combined through interface customization and personal learning. It allows for the deployment of inquiry-based learning and problem-solving activities focused on spatial analysis, the implementation of the TPACK (Technological Pedagogical Content Knowledge) instructional model (Hong and Stonier 2015); and the open dissemination of student mapping, including embedded in social media or storytelling, thus contributing to spatial citizenship and volunteered geographic information.

The Digital Atlas for school education

This article is based on research conducted using a WebGIS application for geographical education: A Digital Atlas on

ArcGIS Online, called the Digital Atlas for Schools (*Atlas Digital Escolar*, in the original version in Spanish; hereinafter, *ADE*). Atlases have always been a key instructional resource for teaching and learning geography in schools and beyond (Robert 1997). However, there are few relatively recent references to the design, use and assessment of digital atlases, virtual globes or interactive maps (Patterson 2007; DeMers and Vincent 2008; Bednarz and Bednarz 2015; De Miguel, Buzo, and De Lázaro 2016; De Miguel et al. 2016; Curtis 2019; Kerski and Baker 2019).

The team that created *ADE* comprised a mixed group of high-school and university geography teachers responsible for teacher-training programs, using ArcGIS desktop and, increasingly, ArcGIS Online, after its release in late 2012. They realized the power of this tool for creating maps collaboratively to facilitate the use of ArcGIS Online in geography courses for secondary education—both middle school and high school. The use of WebGIS software allows for a stronger pedagogical sequence in helping students to access and use geographic information. Thus, secondary school geography students can create their own maps, learn by doing, and simulate the tasks of a professional geographer through collaborative work on a project based on inquiry-based learning, instead of memorizing geographical places.

After several months of experimenting with map production, the group decided to organize a layout in several categories, in accordance with the main contents of the Spanish national geography curriculum, and to balance the number of maps for each category. They published maps in a story map/storytelling format to facilitate access to them in a user-friendly manner for secondary school students.

ADE is organized in the format of a Web-mapping application with a very simple interface. The title page includes a YouTube video explaining ArcGIS Online for beginners, an explanatory text, followed by the category index. This design facilitates intuitive use by vertical scrolling, and offers possibilities to interact with ArcGIS Online or ArcGIS Desktop to continue creating and updating the maps. In addition, information obtained from statistical or cartographic sources (Excel tables or layer metadata in WMS, etc.) can be consulted in a specific pop-up window, as a Web-map format. If students have an ArcGIS account, they can update the data, modify the visual representation (colors, shapes, ranks, etc.) or add a new layer with complementary geographic information to provide more details on the geographical place or the geographical process. Open data published by public institutions, such as the Spanish National Geographic Institute (known by its Spanish abbreviation, IGN in Spanish) and the National Institute of Statistics (known by its Spanish abbreviation, INE in Spanish) were used to create *ADE*. Data from several international organizations, such as EUROSTAT, the United Nations, World Bank or the International Monetary Fund, and many others, allowed us to obtain official data and address Europe's and the World's geographical problems.

The "Introductory Section" in the Digital Atlas provides different tools for using categories and learning geography:

1. The map itself, which covers the main screen area.
2. A pop-up window called "details" explains the map's most important characteristics for a particular geographical issue. It also provides two links: an ArcLesson supplementing each map with a key instructional resource (spatial problem to be solved, questionnaire based on the map itself) and a link to the map (Web Map) for teachers or students registered with an ArcGIS account to access the map so they can add, remove or update data layers, etc.
3. A toolbar in the upper left area; the most important element as it allows the user control over the map's interactivity, leading to potential acquisition of spatial-thinking abilities through the map legend, layering, base-map gallery, measuring (linear, surfaces), geolocation coordinates (decimal degrees or degree, minutes and seconds), sharing the map, and bookmarks.
4. Other tools for searching places, zooming and changing scale.

Each map has two versions (an app version that is closed for changes and an open Web map version) supplemented by the ArcLesson. Consequently, there are three approaches to a specific topic, allowing students a broad set of possibilities for learning geography through diverse spatial pedagogies.

After the title page and introduction, *ADE* is structured into four categories based on the main topics forming the national geography curriculum for middle school and high school in Spain. The reason for reproducing the curriculum structure in the Digital Atlas structure is to maintain the coherence in the geographical content of the national curriculum (physical geography and environment, population and settlements, human geography and economy, spatial imbalances and regional planning) and to simplify the interface for student interactivity with the maps. There is a fifth category in the *ADE* called "Experiences", showing the best maps and student outcomes based on project-based learning. The entire *ADE* consists of these five categories, each containing several maps; for example, the first category—physical geography and environment—includes maps of relief, climate, vegetation, hydrology, landscapes, etc. Around 131 maps and 478 layers of geographic information are available for consultation, as modifiable instructional resources and as a map and databases for geography inquiry-based learning. The fact that the *ADE* was published in Spanish (and many layers are uploaded in English) helped disseminate the Digital Atlas widely, not only in Spain but also in Europe and Latin America: the Digital Atlas had over 80,000 visits from late 2015 (released) to 2019.

Implementing the digital atlas to conduct geography-education research

Research design

After disseminating the Digital Atlas, geography teachers in both secondary schools and teacher-training colleges began to make large-scale use of the tool. However, the authors, as geographical education researchers, wanted to implement

Table 1. Learning progressions for the climate topic with the Digital Atlas.

Level 0	No evidence of understanding
Level 1	Students understand climate concepts
Level 2	Students can identify climate regions
Level 3	Students understand how different geographical factors determine the climate
Level 4	Students can identify which geographic factors are more or less important for climate definition
Level 5	Students understand that some world regions are more affected by climate change

Table 2. Learning progressions for the urban geography topic with the Digital Atlas.

Level 0	No evidence of understanding
Level 1	Students understand urban concepts
Level 2	Students can identify capital metropolitan regions in the world
Level 3	Students understand urbanization levels in different countries
Level 4	Students can identify urban regions based on urbanization level
Level 5	Students understand that urban population and urban network complexity is explained by economic wealth

Table 3. Learning progressions for the economy topic with the Digital Atlas.

Level 0	No evidence of understanding
Level 1	Students understand the globalization concept
Level 2	Students can identify regions with a higher export rate
Level 3	Students understand top ranked accessibility in the world's more developed regions
Level 4	Students can identify relationships between accessibility and transportation density
Level 5	Students understand the spatial complexity of the globalization concept as international exchanges of goods and services, but also capitals and information, thus reinforcing spatial dependences and hierarchies

Table 4. Learning progressions for the spatial imbalances topic with the Digital Atlas.

Level 0	No evidence of understanding
Level 1	Students understand the population growth concept
Level 2	Students can identify regions with higher population growth
Level 3	Students understand relative economic growth (below average, above average)
Level 4	Students can identify regions based on economic growth, distinguishing which are more and less dynamic
Level 5	Students understand that there are spatial relationships explaining the link between demographic and economic growth

Table 5. Learning progressions for spatial thinking with the Digital Atlas.

Level 0	No evidence of understanding
Level 1	Students can understand primitive geospatial concepts such as identity location
Level 2	Students can identify spatial distributions as a simple concept
Level 3	Students can establish geospatial relations and identify clusters in the map, a difficult concept
Level 4	Students can identify corridors and buffers in the map as complicated geospatial concepts
Level 5	Students acquire extended abstract thinking, as they can generalize complex spatial structures such as hierarchy or central place

the tool following a conventional research plan. First, a series of general objectives for the use of the Digital Atlas were defined: facilitating the acquisition of geographical knowledge following the national curriculum guidelines; encouraging critical geospatial thinking; fostering spatial analysis and spatial multicriteria assessment; taking advantage of open data; promoting learning standards and evaluation criteria; implementing civic education and lifelong learning—such as sustainable development; and, obtaining results based on evidence practices of the effectiveness of using geospatial technologies. However, besides these general objectives for any user, the research is based on the four aforementioned more specific and concrete key questions: How much better is the Digital Atlas than conventional geography learning? Can the Digital Atlas effectively contribute to learning progressions in geographical education and to what extent? Are geoinformation and the Digital Atlas equally valid for school education and for geography teacher training? Is the Digital Atlas useful for learning any kind of geography curriculum content and to what extent? Last, but not least, as mentioned previously, the research addressed the measurement of the real impact of geospatial technologies to promote better geography learning, and, moreover, some activities explored how the Digital Atlas contributes to the balanced acquisition of spatial thinking, geographical knowledge and spatial citizenship. The purpose of this study was to research future teachers' and students' awareness of geospatial technologies and obtain data on geographical knowledge learning outcomes (Tables 1–5). The results could potentially help the education community better understand how WebGIS (and, in particular, Digital Atlas) contribute to a deeper and more meaningful learning of geographical content, both in school education and in teacher training. This study followed the learning-progression-knowledge model that used a two-phased quantitative method described below.

Learning progression model

One of the main concerns surrounding GIS implementation and effectiveness in schools involves monitoring the real impact of geospatial technologies on learning. In other words, do students learn more with or without digital mapping? And what is the extent of that learning? At the beginning of the Digital Atlas design, the enthusiasm for such a visually attractive and user-friendly tool as ArcGIS Online was palpable. Many educators at several geography-education conferences relayed the motivational factor of the Web-mapping interface for students. However, this geographical learning must be compared empirically to assess validity in accordance with curriculum standards. Therefore, reliable models and instruments were needed to confirm the hypothesis that students learn more successfully with *ADE than with conventional approaches*. The authors chose learning progression model, a well-regarded theoretical framework for learning outcomes in geographical education, to conduct research on Digital Atlas implementation. Learning progression has been the research model used for flagship initiatives by several institutions, such as the Commission on Geographical Education of the International Geographical Union (Muñiz, Solem, and Boehm 2016; Solem et al. 2018), the American Association of Geographers and the National Council for Geographic Education (Bednarz, Heffron, and Huynh 2013; Solem, Huynh, and Boehm 2014; Huynh, Solem, and Bednarz 2015; Larsen and

Table 6. Learning progressions for geographical education. Source: Souto, Vercher, and Rodríguez 2014, p. 53.

SOLO levels	Students' cognitive tasks
Pre-structural	Students recognize and remember specific geographic information, but do not know how to develop, organize or structure it. They do not understand what they have studied and simply repeat meaningless information.
Unistructural	Students can connect simple and obvious spatial ideas but still do not understand the meaning.
Multistructural	Students connect concepts of different geographical areas but lack the ability to synthesize. Students can solve, apply or calculate graphs (climate, population, etc.) but do not understand the significance of the whole.
Relational	Students can appreciate the significance of the parts in relation to the whole, develop a general explanation of geographic phenomena, and synthesize and interpret a geographic subject.
Extended abstract	Students can create principles and generalize. Students prove they not only know the given subject area, but also something beyond it, and they can transfer these principles and criticize, judge, design, improve, etc.

Table 7. Spatial-thinking abilities acquired by students during the instructional intervention on smart cities.

Level 1	Location, measuring distance, layering
Level 2	Overlaying and dissolving, visualization, connecting locations, buffering, scale, comparing maps
Level 3	Assessing similarity, associating and correlating spatially distributed phenomena, regionalizing
Level 4	Forming hierarchies, defining networks, identifying spatial patterns, recalling and representing layouts, evaluating regularity, recognizing spatial distribution, determining clusters
Level 5	Evaluating randomness, determining dispersion, identifying spatial dependences, sketching maps, constructing gradients

Harrington 2018), the European Association of Geographers, EUROGEO (Zwartjes 2014; Donert et al. 2016) but also by researchers in the UK (Weeden 2013), and Spain. Learning progression has also been an important research model for natural and environmental sciences education (Gunkel et al. 2012).

The Road Map for 21st Century Geography Education Project recommended "*that geography education researchers engage in systematic efforts to identify learning progressions in geography both within and across grade bands*" and stated that "*the Committee believes that empirical research that tests hypothetical learning progressions will advance our understanding of student learning and provide guidance to the design of standards, assessments, and shared tasks and activities*" (Bednarz, Heffron, and Huynh 2013, 56–57). This was also applied in Spain in two studies, which helped define the learning progression scale for this particular research on Digital Atlas implementation. Souto, Vercher, and Rodríguez (2014) obtained some evidence on *Selectividad* results (equivalent to SAT or ACT for the US or A levels in the UK) applying the revised Structured Observed Learning Outcomes (Anderson and Krathwohl 2013) taxonomy, and adapted to geographical knowledge and skills (Table 6). Other classroom research with middle-school students (De Miguel 2016a) verified the effectiveness of the Digital Atlas for teaching smart cities and improving spatial thinking (Table 7). This table identified the five steps of Bloom's taxonomy to five learning progression levels of spatial thinking (Golledge, Marsh, and Battersby 2008) and

Table 8. Participant distribution score from all the questionnaires (percentage).

Sample group		
All	Pretest	Post-test
n = 83, score 5.0	1.2%	14.5%
n = 83, score 4.9-4.0	25.3%	59.0%
n = 83, score 3.9-3.0	46.9%	25.3%
n = 83, score 2.9-2.0	20.5%	1.2%
n = 83, score 1.9-1.4	6.1%	0.0%
Graduate students		
n = 40, score 5.0	2.5%	30.0%
n = 40, score. 4.9-4.0	40.0%	62.5%
n = 40, score 3.9-3.0	55.0%	7.5%
n = 40, score 2.9-2.0	2.0%	0.0%
n = 40, score 1.9-1.4	0.0%	0.0%
Secondary students		
n = 43, score 5.0	0.0%	0.0
n = 43, score 4.9-4.0	11.6%	55.8%
n = 43, score 3.9-3.0	39.5%	41.9%
n = 43, score 2.9-2.0	37.3%	2.3%
n = 43, score 1.9-1.4	11.6%	0.0%

it has been confirmed as a valid and useful empirical tool for obtaining results from the educational implementation of the Digital Atlas, as part of the research described below.

To investigate implementation and effectiveness of the Digital Atlas, the authors defined five scales of five levels as the key instrument for measuring learning outcomes and progressions. This followed an argument from analogy regarding five SOLO levels: one for each thematic section of the Digital Atlas (climate, urban geography, economy, spatial imbalances) plus one for spatial thinking and spatial citizenship (Tables 1–5). In particular, Table 5 combines the joint assessment of learning practices in spatial thinking and spatial citizenship using geoinformation as three highly connected concepts (Shin and Bednarz 2019). The two last items from the questionnaire included spatial-thinking abilities—as aforementioned in Table 7 (spatial patterns, spatial dependences, and so on)—and also spatial citizenship skills such as raising awareness of sustainable ways for urban mobility, civic participation and communication about traffic and transit, engagement in community facilities, etc.

Methodology: Participants, instrument, and procedure

The study was set in two contexts: a high school and a college of education. The number of secondary students was almost the same (n = 43) as the number of college students (n = 40). The background, ethnicity and gender composition did not vary greatly across the total participants (n = 83), except for the difference between the two groups. One group comprised two classes recruited for this study from *tercero de la ESO* (equivalent to 9th Grade in the US, i.e., freshman at high school) and the other was one class studying for the Master's Degree for Teacher Training in Secondary Education. Despite the age difference between these two groups (secondary school students aged 14–15, and master's degree students usually aged 22), both were intentionally utilized to verify the contradictory status of geography teaching in Spain. As in France, Italy and several Latin American countries, secondary education in Spain does not include a geography course per se, since it is integrated in social sciences.

Consequently, geography is taught at the same time as history, art history and civic education, although the national curriculum includes more geographical content in *tercero de la* ESO (9th grade in the US), while mostly history content are in the curriculum in *cuarto de la ESO* (10th grade in the US). As this situation continues in undergraduate programs, most people starting a master's degree to become a secondary school teacher of social sciences only studied history at high school or in undergraduate programs. In other words, future teachers of social sciences (geography and history) stop learning geography from the age of 14–15 until the beginning of the master's degree program, when they take two courses: one of general geography (physical, human and regional) and one of geographical education and didactics (De Miguel 2016a). This is the case not only for 40-person study sample but also for thousands of students enrolled in postgraduate teacher-training programs at any Spanish university.

The researchers obtained data through five questionnaires, one for each of the five aforementioned categories: climate, urban geography, economy, spatial imbalances and spatial thinking. As each questionnaire included five progressive items, in accordance with the criteria given in Tables 1–5, checking the learning level and learning progression outcomes was easy. Consequently, each student (both graduate and secondary, n = 83) had to complete 25 items twice (pre- and post-test), which provided 4,150 empirical data items. The questionnaires were validated in a quantitative-qualitative mixed sequential approach. First, the questionnaire was presented and discussed at several conferences on geographical education organized by the aforementioned institutions: Commission on Geographical Education of the International Geographical Union, AAG Annual Meeting, EUROGEO Conference, Spanish Geographers Conference. The ESRI educational team also surveyed the Digital Atlas, its implementation and the questionnaire. Instrument reliability and validity were addressed by the Cronbach's alpha quantitative index. *The responses to the Likert-scale items indicated a strong internal consistency (Cronbach's α = 0.85).*

The questionnaire was first administered as a pretest after teaching geography with analog or conventional educational resources, such as a printed atlas, textbooks and wall maps in a more teacher-centered way of teaching. The second administration (post-test) consisted of completing the questionnaire after several learning activities with the Digital Atlas. It also helped in obtaining empirical data to measure learning progressions absolutely, from the first to the fifth established levels, and relatively, seeking differences between the pre- and the post-test, i.e., between an analog and a digital approach for teaching and learning geography.

Results

Global results

The overall result from the data analysis showed an average student score of 3.40 (based on the five levels of SOLO taxonomy in Table 6) in the pretest versus a score of 4.31 in the post-test. This means an increase of 0.91 from non-digital to digital geography teaching (18.2% increase). These differences are further accentuated in the secondary school students: 2.95 in the pretest versus 4.02 in the post-test (an increase of 1.07, 21.4%). Among the graduate students, the scores were 3.88 (pretest) versus 4.61 (post-test), which is an increase of 0.73 (14.6%). First aggregate data showed that the graduate students obtained a higher level of knowledge, but that the secondary school students gained more benefits from learning using the Digital Atlas. The number of students with improved learning after the post-test confirms this: 62% of the total participants increased at least one level in any of the five questionnaires versus 38% of students that did not demonstrate any increase between the pre- and post-tests. Almost two out of three participants in the empirical research confirmed the effectiveness of the Digital Atlas after its implementation. These data also differ for the secondary school students (70% show an improvement versus 30% with the same score) and the graduate students (53% show an improvement versus 47% with the same score).

The student distribution of learning outcomes reveals these trends: 14.5% of the graduate students (n = 40) attained the maximum score, level 5, for all the questionnaires, that is, extended abstract knowledge and skills in climate, urban geography, economy, spatial imbalances and spatial thinking. None of the secondary school students (n = 43) obtained the top score of 5 in the five questionnaires, but three (6.9%) acquired a score of 5 in four questionnaires plus a level 4 in the fifth questionnaire, which makes an average score of 4.8 for these three students. On the other side of the scale, no graduate student obtained a score below level 3 (multistructural) and only one secondary school student obtained an average score of level 2.6 (between unistructural and multistructural). The vast majority of the graduate students (92.5%) exceeded relational knowledge (level 4) while the smaller majority of the secondary school students (55.8%) exceeded this relational knowledge (level 4), although 83.7% of the school students achieved a score above level 3.4 (Table 8).

Concerning standard deviation, the amount of variation or dispersion in the pretest (σ = 0.85) is a bit higher than in the post-test (σ = 0.58). This confirms the validity of the results and indicates that the scores after doing activities with the Digital Atlas tend to be closer to the mean. This is especially evident for the graduate students, although other standard deviation results are not much higher, so scores are not really spread out over the range of values (Table 9).

Results by map and questionnaire

The results disaggregated by questionnaire and map (Table 10) indicate that climate obtained the highest score (n = 83: 4.49) per participant in all groups for the post-test, followed by spatial imbalances (4.44), spatial thinking (4.31), economy (4.29) and urban geography (4.01). Although spatial thinking is one of the most difficult topics in research education—as expressed by many of the aforementioned authors in their publications on spatial-ability tests, for example Lee and

Table 9. Participants' average score by topic.

	Sample group		
	All n = 83	Graduate students n = 40	Secondary students n = 43
Climate			
Average pretest score	3.83	*4.30*	3.39
Average post-test score	4.49	*4.72*	4.27
Pre- and post-test difference	0.66	0.42	0.88
Urban geography			
Average pretest score	3.10	3.60	2.63
Average post-test score	4.01	4.37	*3.67*
Pre- and post-test difference	0.91	0.70	1.04
Economy			
Average pretest score	3.49	4.05	2.98
Average post-test score	4.29	4.65	3.95
Pre- and post-test difference	0.80	0.60	0.97
Spatial imbalances			
Average pretest score	3.66	4.12	3.23
Average post-test score	4.44	4.72	4.18
Pre- and post-test difference	0.78	0.60	0.95
Spatial thinking			
Average pretest score	2.90	3.35	*2.48*
Average post-test score	4.31	4.60	*4.04*
Pre- and post-test difference	1.41	1.25	1.56

Table 10. Number of learning progression levels improved between the pre- and post-tests, by topic (percentage).

	n = 83	n = 40	n = 43
Climate			
0	48.2	65.0	32.6
1	41.0	27.5	53.5
2	8.4	7.5	9.3
3	1.2	0.0	2.3
4	1,2	0.0	2.3
Urban geography			
0	38.6	45.0	32.6
1	34.9	37.5	32.6
2	21.7	12.5	30.2
3	4.8	5.0	4.7
Economy			
0	43.4	50.0	37.2
1	37.3	40.0	34.9
2	15.7	10.0	20.9
3	3.6	0.0	7.0
Spatial imbalances			
0	45.8	52.5	39.5
1	32.5	35.0	30.2
2	19.3	12.5	25.6
3	2.4	0.0	4.7
Spatial thiniking			
0	16.9	25.0	9.3
1	38.6	37.5	39.5
2	32.5	27.5	37.2
3	10.8	7.5	14.0
4	1.2	2.5	0.0

Bednarz 2012—research proves that the Digital Atlas is more effective in this particular aspect. Data confirm that spatial thinking had the lowest scores in the pretest (2.90) and exceeded the economy and urban geography topics at the end of the intervention, thus implying the highest improvement difference between the pre- and post-tests: 1.41 (n = 83), 1.25 (n = 40) and 1.56 (n = 43). On the contrary, climate and spatial imbalances showed the lowest improvement due to their high initial (pretest) score, for example, 0.42 points of difference between both climate tests for n = 40. In other words, the Digital Atlas resulted far more effective for teaching spatial thinking to school students than teaching climate to graduate students. Furthermore, the fact that the average score for the fifth questionnaire was 4.31 (n = 83), but 4.60 for graduate students and 4.04 for freshman secondary students, means that the vast majority of participants (83%) attained one of the two items—levels four and five—also related to spatial citizenship. And, in particular, 69% of graduate students (adults) achieved five out of five items, while only 38% of secondary school students did.

The number of learning progression levels improved by the students after implementing the Digital Atlas also confirms this trend. Table 9 shows that very few students from both groups, secondary and graduates, (16.9%) failed to experience any increase between the pre- and post-tests in the spatial-thinking questionnaire. The other topics with the highest rate evidence of no improvement between the pre- and post-tests were: 48.2% climate, 45.8% spatial imbalances, 43.4% economy, and 38.6% urban geography. Furthermore, spatial thinking had the highest rate of evidence of students improving three or more levels between the pre- and post-tests (12%) versus any other topics (5% of students improved three or more levels in climate, urban geography and spatial imbalances).

Discussion

Results provide evidence for the two main research questions discussed at the beginning of this article. Digital Atlas is a powerful tool to learn geography as it fosters more meaningful learning than conventional instructional resources. Besides this, Digital Atlas help in the goal of balance between spatial thinking, geographical knowledge and spatial citizenship. The responses to the questionnaires suggest that both school and higher education participants experienced effective learning from implementing the Digital Atlas, although this was more marked in the secondary school geography students. Nevertheless, this approach has also proved to be an important instrument for consolidating knowledge and raising awareness during teacher training, especially in the spatial citizenship questions. Although the adults obtained a higher learning outcome level than the teenagers (in absolute terms of knowledge and skills acquisition), an indisputable outcome of this research is that relative learning, that is, an increase in learning progressions and cognitive tasks based on the five Structured Observed Learning Outcomes (SOLO) categories, is most important in school students.

The experience was also positive for most participants. Notwithstanding the size of the sample or the questionnaire structure, two thirds of the students (graduate and high school) demonstrated improved geography learning, but particularly the 9th grade students. One reason for this might be the use of geospatial technologies as they are more visual, facilitate learning-by-doing processes, and, therefore, are more motivating for geography learners, who tend to be more comfortable working and living with multimedia devices.

Results also reveal the possibilities of this geospatial approach in a comprehensive teaching model as it was useful for pupils seeking excellence and for students with learning difficulties, and, in particular, with difficulties in acquiring spatial thinking. Otherwise, a large percentage of participants in both categories reached a medium-high learning progression level. Since over 90% of the graduate students were able to create geographical principles, generalize, and transfer those principles from the specific topic to a large geographical process, their status was between upper relational and extended abstract. Over 80% of secondary school participants also exceeded the multistructural level, as they can discern spatial relationships, provide a general explanation of geographic phenomena, and synthesize a geographic subject. However, in some subjects, such as urban geography or economy, students show more difficulty in understanding the complexity of spatial organization.

Conclusion

The study conducted at a high school and a university has provided a deeper understanding of the benefits of using WebGIS for geography teaching and learning. The questionnaires were completed by 83 people to show their learning progressions without (pretest) and with (post-test) geospatial technologies for the purpose of comparing learning outcomes. This research has shown that a rational implementation of the Digital Atlas is more effective than conventional methods of teaching geography. It is more effective in absolute terms for graduate students (they achieve the highest levels), and more effective in relative terms for secondary school students (they achieve higher learning progressions). The more WebGIS is used, the longer the learning line progression is.

The research has some limitations: geography is not compulsory in Spain at high school in 10th, 11th or 12th grades; secondary school teachers only use the Digital Atlas occasionally for particular lessons (versus questionnaires throughout the entire curriculum); the graduate students have a weak geographical background; the shortage of empirical researchers; and the lack of teacher engagement at high school. A larger sample could have broadened the number of participants, and, therefore, the statistics. Nevertheless, the visual appeal of the maps in the Digital Atlas, and the implementation of the learning-by-doing and independent-task method increased the motivation of almost all participants. In the case of the graduate students in pre-service teacher training, the experience proved extremely positive. Many stated they would need more training (pre and in-service) to acquire suitable geospatial-technology skills to master WebGIS as a key instructional resource in their future professional development.

This study has demonstrated the effectiveness of geospatial technologies in enhancing students' knowledge, skills and values. Thus, the research confirms that WebGIS has many educational advantages for students and teachers at secondary schools, especially in geographical education. Quantitative research findings have also shown how the three key components in geographical education—spatial thinking, geographical knowledge and spatial citizenship—have developed, especially in the case of geographical knowledge. Since the Spanish curriculum is rigid and discipline-focused, teachers and students are more used to performing activities related to descriptive geographical knowledge than to learning-by-doing spatial thinking or spatial citizenship tasks.

Despite these limitations, the research has managed to answer the initial questions and, in particular, show how geospatial technologies contribute to spatial citizenship to raise awareness of spatial values, civic engagement, and democratic participation. This research illustrated a balance in student understanding of the three components in the five analysis categories. All participants experienced higher learning progressions with geospatial technologies in spatial thinking, geographical knowledge (in particular through powerful urban and economic geography concepts), but also in spatial citizenship. Climate change and spatial imbalances questionnaires demonstrated spatial empathy among students for geographical and social problems (for example, temperature rises and social injustices by comparing two territories) and, consequently, they have considered Web-mapping as an empowering tool for expressing and disseminating their own ideas, solutions or suggestions to improve spatial conditions. Some maps from the Digital Atlas were even used later by teachers and students to raise awareness of the UN 2030 Sustainable Development Goals.

Connections between geospatial technologies and spatial awareness could be a supplementary research topic. Further qualitative research (interviews, focus groups, etc.) might help in understanding why the Digital Atlas allows students to gain experience through constructivist learning. Spatial-thinking ability tests or other standardized tests (such as the AP Human Geography exam) can provide more easily quantitative data, but spatial citizenship research would require another approach. These lines of research and others—for example, inquiring in detail why one out of three could not gain any benefit from using the Digital Atlas—will open new possibilities for future instructional interventions with the Digital Atlas, or any other similar WebGIS tool.

This article contributes to the body of empirical evidence of meaningful, concrete and measurable learning, and reinforces research on geospatial-learning technologies. While this research on the Digital Atlas obtained similar results to the papers mentioned earlier, (Baker et al. 2015; Bednarz, Heffron, and Huynh 2013), it strengthens the argument for a structured methodology to conduct reliable research, in this case, both for learning activities with students (inquiry-based instructional learning approach) and for the research design itself (learning progressions).

As for the students that did not experience benefits after using the Digital Atlas, this seemed a result of rejection of the spatial technologies by students and trainee teachers more used to paper atlases, textbooks or transmissive lectures. Difficulties, biases and misconceptions could be causes of the lack of effectiveness. This merits further research, perhaps considering interoperability between mobile apps/

devices and WebGIS, which is increasingly useful for fieldwork and outdoor learning.

Nonetheless, it is evident that, in the last decade, an increased awareness of the educational benefits of geospatial technologies in the classroom, especially in secondary education as they offer such a wide diversity of motivating instructional resources, strategies, and methodologies for learners exists among the geography education community. The US Road Map for Geography Education and the IGU International Charter on Geographical Education underline the challenges geographical education faces in the 21st century, in particular, expanding skills compared with many decades ago. How to deal with this geospatial-technology boom in a smart way is key to achieving an integral geographical education, as this research has tried to illustrate with the use of the Digital Atlas.

Funding

IUCA-UNIZAR. Institute of Research into Environmental Sciences of Aragon.

Notes on contributors

Rafael De Miguel González is an Associate Senior Professor at the University of Zaragoza, where he is also Executive Associate Dean. Dr. De Miguel González President of EUROGEO, the European Association of Geographers.

María Luisa De Lázaro Torres is an Associate Senior Professor at the Geography Department (Universidad Nacional de Educación a Distancia, UNED) and the Vice-President of EUROGEO.

References

Anderson, W., and D. Krathwohl, eds. 2013. *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. Boston: Allyn&Bacon.

Audet, R. H., and J. Paris. 1997. GIS implementation model for schools: Assessing the critical concerns. *Journal of Geography* 96 (6): 293–300. doi: 10.1080/00221349708978810.

Baker, T. R. 2005. Internet-based GIS mapping in support of K–12 education. *The Professional Geographer* 57 (1):44–50.

Baker, T. R. 2015. WebGIS in education. In *Geospatial technologies and geography education in a changing world: Geospatial practices and lessons learned*, ed. O. Muñiz, A. Demirci, and J. van der Schee, 105–15. Japan: Springer.

Baker, T., S. Battersby, S. W. Bednarz, A. M. Bodzin, B. Kolvoord, S. Moore, D. Sinton, and D. Uttal. 2015. A research agenda for geospatial technologies and learning. *Journal of Geography* 114 (3):118–30. doi: 10.1080/00221341.2014.950684.

Bearman, N., N. Jones, I. André, H. A. Cachinho, and M. DeMers. 2016. The future role of GIS education in creating critical spatial thinkers. *Journal of Geography in Higher Education* 40 (3):394–408. doi: 10.1080/03098265.2016.1144729.

Bednarz, S., et al. 1994. Geography for life: National geography standards, 1994. Washington, D.C.: National Geographic Research and Exploration.

Bednarz, S. W. 2004. Geographic information systems: A tool to support geography and environmental education? *GeoJournal* 60 (2):191–9.

Bednarz, S. W., and R. Bednarz. 2015. Brave new world: Citizenship in a geospatially enriched environment. *GI_Forum* 1:230–40. doi: 10.1553/giscience2015s230. http://austriaca.at/0xc1aa5576_0x00324a21.pdf

Bednarz, S. W., S. Heffron and N. T. Huynh, eds. 2013. *A road map for 21st century geography education: Geography education research (A report from the Geography Education Research Committee of the Road Map for 21st Century Geography Education Project).* Washington, DC: Association of American Geographers.

Bednarz, S. W., and J. van der Schee. 2006. Europe and the United States: The implementation of geographic information systems in secondary education in two contexts. *Technology, Pedagogy and Education* 15 (2):191–205. doi: 10.1080/14759390600769573.

Bodzin, A. 2011. The implementation of a geospatial information technology (GIT)-supported land use change curriculum with urban middle school learners to promote spatial thinking. *Journal of Research in Science Teaching* 48 (3):281–300. doi: 10.1002/tea.20409.

Bryant, L., and T. Favier. 2015. Professional development focusing on inquiry-based learning using GIS. *In Geospatial technologies and geography education in a changing world: Geospatial practices and lessons learned*, ed. O. Muñiz, A. Demirci, and J. van der Schee, 127–37. Japan: Springer.

Butt, G. 2017. Debating the place of knowledge within geography education: Reinstatement, reclamation or recovery? *In The power of geographical thinking*, ed. C. Brooks, G. Butt and M. Fargher, 13–26. Dordrecht: Springer.

Collins, L. 2018. The impact of paper versus digital map technology on students' spatial thinking skill acquisition. *Journal of Geography* 117 (4):137–52. doi: 10.1080/00221341.2017.1374990.

Chang, C. H., B. S. Wu, T. Seow, and K. Irvine, eds. 2018. *Learning geography beyond the traditional classroom*. Dordrecht: Springer.

Chen, C., and Y. Wang. 2015. Geospatial education in high schools: Curricula, methodologies and practices. In *Geospatial technologies and geography education in a changing world: Geospatial practices and lessons learned*, ed. O. Muñiz, A. Demirci, and J. van der Schee, 67–76. Japan: Springer.

Curtis, M. 2019. Professional technologies in schools: The role of pedagogical knowledge in teaching with geospatial technologies. *Journal of Geography* 118 (3):130–42. doi: 10.1080/00221341.2018.1544267.

De Lázaro, M. L., S. Izquierdo, and M. J. González. 2016. Geodatos y paisaje: De la nube al aula universitaria. *Boletín de la Asociación de Geógrafos Españoles* 70:371–91. doi: 10.21138/bage.2175.

De Lázaro, M. L., R. De Miguel, and F. J. Morales. 2017. WebGIS and geospatial technologies for landscape education on personalized learning contexts. *ISPRS International Journal of Geo-Information* 6 (11):350. 10.3390/ijgi6110350.

De Miguel, R. 2013. Aprendizaje por descubrimiento, enseñanza activa y geoinformación: Hacia una didáctica de la geografía innovadora. *Didáctica Geográfica* 14:17–36.

De Miguel, R. 2014a. Innovative learning approaches to secondary school geography in Europe: New challenges in the curriculum. In *Innovative learning geography. New challenges for the 21st century*, ed. R. De Miguel and K. Donert, 21–38. Newcastle-Upon-Tyne: Cambridge Scholars Publishing.

De Miguel, R. 2014b. Concepciones y usos de las tecnologías de información geográfica en las aulas de ciencias sociales. Diagnóstico sobre innovación en didáctica de la geografía en centros de secundaria de Zaragoza. *Iber, Didáctica de Las Ciencias Sociales, Geografía e Historia* 76:60–71.

De Miguel, R. 2016a. Spain. Learning progressions: From compulsory to non-compulsory geography education. In *Learning progressions in geography education. International perspectives*, ed. O. Muñiz, M. Solem, and R. Boehm, 91–110. Dordrecht: Springer.

De Miguel, R. 2016b. Pensamiento espacial y conocimiento geográfico en los nuevos estilos de aprendizaje. In *Nativos digitales y geografía en el siglo XXI: Educación geográfica y estilos de aprendizaje*, ed. R. Iglesias, 11–39. Sevilla: Asociación de Geógrafos Españoles.

De Miguel, R., I. Buzo, and M. L. De Lázaro. 2016. New challenges for geographical education and research: The Digital School Atlas. In *Crisis, globalization and social and regional imbalances in Spain*, ed. T. Albert, 187–97. Madrid: Spanish Committee IGU.

De Miguel, R., K. Koutsopoulos, and K. Donert. 2019. Key challenges in geography research with geospatial technologies. In *Geospatial challenges in the 21st century*, ed. K. Koutsopoulos, R. De Miguel, and K. Donert, 1–8. Dordrecht: Springer.

De Miguel, R., M. L. De Lázaro, J. Velilla, I. Buzo, and C. Guallart. 2016. Atlas Digital Escolar: Internet, geografía y educación. *Ar@cne.*

Revista Electrónica de Recursos de Internet sobre Geografía y Ciencias Sociales, Ciencias Sociales 212.

De Miguel, R., M. L. De Lázaro and M.J. Marrón, eds. 2012. *La educación geográfica digital*. Zaragoza: Asociación de Geógrafos Españoles.

Del Campo, A., C. Romera, J. Capdevila, J. A. Nieto, and M. L. Lázaro. 2012. Spain: Institutional initiatives for improving geography teaching with GIS. In *International perspectives on teaching and learning with GIS in secondary schools*, ed. A. J. Milson, A. Demirci, and J. J. Kerski, 125–30. New York: Springer.

DeMers, M. N., and J. S. Vincent. 2008. ArcAtlas in the classroom: Pattern identification, description, and explanation. *Journal of Geography* 106 (6):277–84. doi: 10.1080/00221340701851225.

Demirci, A. 2015. The effectiveness of geospatial practices in education. In *Geospatial technologies and geography education in a changing world: Geospatial practices and lessons learned*, ed. O. Muñiz, A. Demirci, and J. van der Schee, 141–53. Japan: Springer.

Demirci, A. 2008. Evaluating the implementation and effectiveness of GIS-based application in secondary school geography lessons. *American Journal of Applied Sciences* 5 (3):169–78. doi: 10.3844/ajassp.2008.169.178.

Demirci, A., R. De Miguel and S. W. Bednarz, eds. 2018. *Geography education for global understanding*. Dordrecht, Netherlands: Springer.

Donert, K. 2015. Digital Earth – Digital World: Strategies for geospatial technologies in twenty-first century education. In *Geospatial technologies and geography education in a changing world: Geospatial practices and lessons learned*, ed. O. Muñiz, A. Demirci, and J. van der Schee, 195–204. Japan: Springer.

Donert, K. 2014. Building capacity for Digital-Earth education in Europe. In *Innovative learning geography. New challenges for the 21st Century*, ed. R. De Miguel and K. Donert, 9–20. Newcastle-Upon-Tyne: Cambridge Scholars Publishing.

Donert, K., R. De Miguel, and A. Lupi. 2019. YouthMetre: Open data to empower young people to engage in democracy and policy-making. In *Geospatial technology in geography education*, ed. R. De Miguel, K. Donert and K. Koutsopoulos, 87–101. Dordrecht, Netherlands: Springer.

Donert, K., F. Desmidt, M. L. de Lázaro y Torres, R. D. M. González, M. Lindner-Fally, A. Parkinson, D. Prodan, E. Woloszynska-Wisniewska, and L. Zwartjes. 2016. The GI-learner approach: Learning lines for geospatial thinking in secondary schools. *GI_Forum* 2:134–46. doi: 10.1553/giscience2016_02_s134.

ESRI. 1998. *GIS in K–12 education. An ESRI white paper*. Redlands: ESRI.

ESRI. 2003. *Geographic inquiry: Thinking geographically*. Redlands: Environmental Systems Research Institute Inc.

Fargher, M. 2013. Geographic information (GI)? How could it be used? In *Debates in geography education*, ed. D. Lambert and M. Jones, 206–18. London: Routledge.

Fargher, M. 2018. WebGIS for geography education: Towards a Geocapabilities approach. *ISPRS International Journal of Geo-Information* 7 (3):111. doi: 10.3390/ijgi7030111.

Favier, T. 2011. *Geographic information systems in inquiry-based secondary geography education*. Enschede, Netherlands: Ipskamp.

Fitzpatrick, C. 2001. A trainer's view of GIS in schools. *International Research in Geographical and Environmental Education* 10 (1):85–7. doi: 10.1080/10382040108667426.

Gersmehl, P. J., and C. A. Gersmehl. 2007. Spatial thinking by young children: Neurologic evidence for early development and "educability". *Journal of Geography* 106 (5):181–91. doi: 10.1080/00221340701809108.

Goldstein, D., and M. Alibrandi. 2013. Integrating GIS in the middle school curriculum: Impacts on diverse students' standardized test scores. *Journal of Geography* 112 (2):68–74. doi: 10.1080/00221341.2012.692703.

Golledge, R. G., M. Marsh, and S. Battersby. 2008. Matching geospatial concepts with geographic educational needs. *Geographical Research* 46 (1):85–98. doi: 10.1111/j.1745-5871.2007.00494.x.

Golledge, R. G., and R. J. Stimson. 1997. *Spatial behavior: A geographic perspective*. New York: Guilford Press.

Gunkel, K., B. Covitt, I. Salinas, and C. Andreson. 2012. A learning progression for water in socio-ecological systems. *Journal of Research in Science Teaching* 49 (7):843–68. doi: 10.1002/tea.21024.

Gryl, I., T. Jekel, and K. Donert. 2010. GI and spatial citizenship. In *Learning with Geoinformation V – Lerner mit Geoinformation V*, ed. T. Jekel, A. Koller, K. Donert, and R. Vogler, 2–11. Berlin: Wichmann Verlag.

Heffron, S. G., and R. M. Downs, eds. 2012. *Geography for life: National geography standards*, 2nd ed. Washington, DC: National Council for Geographic Education.

Höhnle, S., J. Fogele, R. Mehren, and J. C. Schubert. 2016. GIS teacher training: Empirically-based indicators of effectiveness. *Journal of Geography* 115 (1):12–23. doi: 10.1080/00221341.2015.1016546.

Hong, J. E. 2014. Promoting teacher adoption of GIS using teacher-centered and teacher-friendly design. *Journal of Geography* 113 (4): 139–50. doi: 10.1080/00221341.2013.872171.

Hong, J. E. 2015. Teaching GIS and other geospatial technologies to in-service teachers. In *Geospatial technologies and geography education in a changing world: Geospatial practices and lessons learned*, ed. O. Muñiz, A. Demirci, and J. van der Schee, 117–26. Japan: Springer.

Hong, J. E., and F. Stonier. 2015. GIS in-service teacher training based on TPACK. *Journal of Geography* 114 (3):108–17. doi: 10.1080/00221341.2014.947381.

Hubbard, P., R. Kitchin, B. Bartley, and D. Fuller. 2002. *Thinking geographically: Space, theory and contemporary human geography*. London: Continuum.

Huynh, N., M. Solem, and S.W. Bednarz. 2015. A Road Map for Learning Progressions Research in Geography. *Journal of Geography* 114 (2):69–79. doi: 10.1080/00221341.2014.935799.

Hwang, S. 2013. Placing GIS in sustainability education. *Journal of Geography in Higher Education* 37 (2):276–91. doi: 10.1080/03098265.2013.769090.

Janelle, D. G., and M. F. Goodchild. 2009. Location across disciplines: Reflection on the CSISS experience. In *Geospatial technology and the role of location in science*, ed. H. J. Scholten, N. van Manen, and R. Velde, 15–29. Dordrecht, Netherlands: Springer.

Jo, I., and S. W. Bednarz. 2009. Evaluating geography text-book questions from a spatial perspective: Using concepts of space, tools of representation, and cognitive processes to evaluate spatiality. *Journal of Geography* 108 (1):4–13. doi: 10.1080/00221340902758401.

Jo, I., J. E. Hong, and K. Verma. 2016. Facilitating spatial thinking in world geography using Web-based GIS. *Journal of Geography in Higher Education* 40 (3):442–59. doi: 10.1080/03098265.2016.1150439.

Jo, I., and O. Muñiz. 2015. An agenda of GST in geography education for the future. In *Geospatial technologies and geography education in a changing world: Geospatial practices and lessons learned*, ed. O. Muñiz, A. Demirci, and J. van der Schee, 205–21. Japan: Springer.

Johansson, T., ed. 2006. *GISAS project: Geographical information systems applications for schools*. Helsinki: University of Helsinki.

Kerski, J. J. 2003. The implementation and effectiveness of geographic information systems technology and methods in secondary education. *Journal of Geography* 102 (3):128–37. doi: 10.1080/00221340308978534.

Kerski, J. J. 2008. The role of GIS in digital earth education. *International Journal of Digital Earth* 1 (4):326–46. doi: 10.1080/17538940802420879.

Kerski, J. J. 2011. Sleepwalking into the future. The case for spatial analysis throughout education. In *Learning with GI 2011*, ed. T. Jekel, A. Koller, K. Donert, and R. Vogler, 2–11. Berlin: Wichmann.

Kerski, J. J., and T. Baker. 2019. Infusing educational practice with Web GIS. In *Geospatial technology in geography education*, ed. R. De Miguel, K. Donert and K. Koutsopoulos, 3–19. Dordrecht, Netherlands: Springer.

Kerski, J. J., A. Demirci, and A. Milson. 2013. The global landscape of GIS in Secondary Education. *Journal of Geography* 112 (6):232–47. doi: 10.1080/00221341.2013.801506.

Kim, M., and R. Bednarz. 2013. Development of critical spatial thinking through GIS learning. *Journal of Geography in Higher Education* 37 (3):350–66. doi: 10.1080/03098265.2013.769091.

Kim, S. Y. 2017. Smart learning: Approaches and materials for language learning. *Multimedia-Assisted Language Learning* 20 (3):62–83.
Kolvoord, B., K. Keranen, and S. Rittenhouse. 2019. The geospatial semester: Concurrent enrollment in geospatial technologies. *Journal of Geography* 118 (1):3–10. doi: 10.1080/00221341.2018.1483961.
Lam, C., E. Lai, and J. Wong. 2009. Implementation of geographic information system (GIS) in secondary geography curriculum in Hong Kong: Current situations and future directions. *International Research in Geographical and Environmental Education* 18 (1):57–74. doi: 10.1080/10382040802591555.
Lambert, D., and J. Morgan. 2010. *Teaching geography 11-18. A conceptual approach*. Maidenhead: Open University Press.
Lambert, D., M. Solem, and S. Tani. 2015. Achieving human potential through geography education: A capabilities approach to curriculum making in schools. *Annals of the Association of American Geographers* 105 (4):723–35. doi: 10.1080/00045608.2015.1022128.
Larsen, T., and J. Harrington. 2018. Developing a learning progression for place. *Journal of Geography* 117 (3):100–18. doi: 10.1080/00221341.2017.1337212.
Lee, J., and R. Bednarz. 2009. Effect of GIS learning on spatial thinking. *Journal of Geography in Higher Education* 33 (2):183–98. doi: 10.1080/03098260802276714.
Lee, J., and R. Bednarz. 2012. Components of spatial thinking: Evidence from a spatial thinking ability test. *Journal of Geography* 111 (1):15–26. doi: 10.1080/00221341.2011.583262.
Lobben, A., and M. Lawrence. 2015. Synthesized model of geospatial thinking. *The Professional Geographer* 67 (3):307–18. doi: 10.1080/00330124.2014.935155.
Manson, S., J. Shannon, S. Eria, L. Kne, K. Dyke, S. Nelson, L. Batra, D. Bonsal, M. Kernik, J. Immich, et al. 2014. Resource needs and pedagogical value of Web mapping for spatial thinking. *Journal of Geography* 113 (3):107–17. doi: 10.1080/00221341.2013.790915.
Matusch, T., A. Schneibel, L. Dannwolf, and A. Siegmund. 2018. Implementing a modern e-learning strategy in an interdisciplinary environment—Empowering UNESCO stakeholders to use earth observation. *Geosciences* 8 (12):432. doi: 10.3390/geosciences8120432.
Metoyer, S., and R. Bednarz. 2017. Spatial thinking assists geographic thinking: Evidence from a study exploring the effects of geospatial technology. *Journal of Geography* 116 (1):20–33. doi: 10.1080/00221341.2016.1175495.
Milson, A. J., A. Demirci, and J. J. Kerski, eds. 2012. *International perspectives on teaching and learning with GIS in secondary schools*. New York: Springer.
Milson, A. J., and B. D. Earle. 2008. Internet-based GIS in an inductive learning environment: A case study of ninth grade geography students. *Journal of Geography* 106 (6):227–37. doi: 10.1080/00221340701851274.
Mohan, A., and L. Mohan. 2013. Spatial thinking about maps: Development of concepts and skills across the early school years. Report prepared for National Geographic Education Programs.
Morgan, J. 2018. Are we thinking geographically? In *Debates in geography education*, ed. D. Lambert and M. Jones, 2nd ed., 287–96. London: Routledge.
Muñiz, O., M. Solem, and R. Boehm (eds.) 2016. *Learning progressions in geography education. International perspectives*. Dordrecht: Springer.
National Research Council's Committee on the Support for Thinking Spatially. 2006. *Learning to think spatially: GIS as a support system in the K–12 curriculum*. Washington, DC: The National Academies Press.
Patterson, T.C. 2007. Google Earth as a (not just) geography education tool. *Journal of Geography* 106 (4):145–52. doi: 10.1080/00221340701678032.
Rickles, P., C. Ellul, and M. Haklay. 2017. A suggested framework and guidelines for learning GIS in interdisciplinary research. *Geo: Geography and Environment* 4 (2):e00046. doi: 10.1002/geo2.46.
Robert, B. 1997. The ecosystem approach to the development of a school Atlas. *International Research in Geographical and Environmental Education* 6 (1):68–71. doi: 10.1080/10382046.1997.9965025.
Roberts, M. 2013. *Geography through enquiry: Approaches to teaching and learning in the secondary school*. Sheffield: The Geographical Association.
Roche, S. 2014. Geographic information science I: Why does a smart city need to be spatially enabled? *Progress in Human Geography* 38 (5):703–11. doi: 10.1177/0309132513517365.
Rod, J., W. Larsen, and E. Nilsen. 2010. Learning geography with GIS: Integrating GIS into upper secondary school geography curricula. *Norsk Geografisk Tidsskrift - Norwegian Journal of Geography* 64 (1): 21–35. doi: 10.1080/00291950903561250.
Schinazi, V., and T. Thrash. 2018. Cognitive neuroscience of spatial and geographic thinking. In *Handbook of behavioral and cognitive geography*, ed. D. Montello, 154–74. Cheltenham: Edward Elgar Publishing.
Sharpe, B., and N. Huynh. 2015. A review of geospatial thinking assessment in high schools. In *Geospatial technologies and geography education in a changing world: Geospatial practices and lessons learned*, ed. O. Muñiz, A. Demirci, and J. van der Schee, 169–80. Japan: Springer.
Shin, E., and S. Bednarz, eds. 2019. *Spatial citizenship education. Citizenship through geography*. New York: Routledge.
Sinha, G., T. A. Smucker, E. J. Lovell, K. Velempini, S. A. Miller, D. Weiner, and E. E. Wangui. 2017. The pedagogical benefits of participatory GIS for geographic education. *Journal of Geography* 116 (4): 165–79. doi: 10.1080/00221341.2016.1215488.
Slocum, T. A., R.B. Mcmaster, F.C. Kessler, H.H. Howard, and R. B. Mc Master. 2008. Web mapping. In *Thematic cartography and geovisualization*, 3rd ed., ed. T. Slocum, 441–59. Upper Saddle River, NJ: Pearson/Prentice Hall.
Solem, M., N. Huynh and R. Boehm, eds. 2014. *Learning progressions for maps, geospatial technology, and spatial thinking: A research handbook*. Washington, DC: Association of American Geographers.
Solem, M., J. Stoltman, R. Lane, T. Bourke, C.H. Chang, and K. Viehrig. 2018. An assessment framework and methodology for a Trends in International Geography Assessment Study (TIGAS). *Geographical Education* 31:7–15.
Souto, X.M., V. Vercher, and M. Rodríguez. 2014. Is it possible to improve spatial learning with the PAU? A case study: The PAU of Geography, Valencia 2012. *Didáctica de Las Ciencias Experimentales y Sociales* 28:43–63. doi: 10.7203/dces.28.3743.
Stoltman, J., J. Lidstone, and G. Kidman. 2017. The 2016 International Charter on Geographical Education. *International Research in Geographical and Environmental Education* 26 (1):1–2. doi: 10.1080/10382046.2017.1272849.
Tan, I., and J. Chen. 2015. An assessment of the use of GIS in teaching. In *Geospatial technologies and geography education in a changing world: Geospatial practices and lessons learned*, ed. O. Muñiz, A. Demirci, and J. van der Schee, 155–67. Japan: Springer.
Uhlenwinkel, A. 2013. Spatial thinking or thinking geographically? On the importance of avoiding maps without meaning. In *GI_Forum 2013. Creating the GISociety*, ed. T. Jekel, A. Car, J. Strobl, and G. Griesebner, 294–305. Berlín: Herbert Wichmann Verlag.
Van der Schee, J., H. Trimp, T. Beneker, and T. Favier. 2015. Digital geography education in the twenty-first century: Needs and opportunities. *In Geospatial technologies and geography education in a changing world: Geospatial practices and lessons learned*, ed. O. Muñiz, A. Demirci, and J. van der Schee, 11–20. Japan: Springer.
Wei, J., D. Lubinski, and C. P. Benbow. 2005. Creativity and occupational accomplishments among intellectually precocious youth: An age 13 to age 33 longitudinal study. *Journal of Educational Psychology* 94:785–94. doi: 10.1037/0022-0663.97.3.484.
Weeden, P. 2013. How do we link assessment to making progress in geography? In *Debates in geography education*, ed. D. Lambert and M. Jones, 143–54. London: Routledge.
Yap, L.Y., I. Tan, X. Zhu, and M. Wettasinghe. 2008. An assessment of the use of geographical information systems (GIS) in teaching geography in Singapore schools. *Journal of Geography* 107 (2):52–60. doi: 10.1080/00221340802202047.
Zwartjes, L. 2014. The need for a learning line for spatial thinking using GIS in education. In *Innovative learning geography. New challenges for the 21st Century*, ed. R. De Miguel and K. Donert, 39–63. Newcastle-Upon-Tyne: Cambridge Scholars Publishing