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The future role of GIS education in creating critical spatial thinkers

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ABSTRACT

Teaching of critical spatial thinking in higher education empowers graduates to effectively engage with spatial data. Geographic information systems (GIS) and science are taught to undergraduates across many disciplines; we evaluate how this contributes to critical spatial thinking. The discipline of GIS covers the whole process of spatial decision-making, but GIS modules often ignore the context setting of spatial problems, and just cover the technical aspects of how to use GIS software. We outline how some existing GIS practicals could be improved to focus on the development of critical spatial thinking skills, competences and abilities that are valuable to graduates.

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Introduction

Providing students with critical spatial thinking skills, abilities and knowledge is a key aspect of any geography degree (Whyatt, Clark, & Davies, 2011), and employers look for an understanding of and ability to debate multiscale issues from the global to the local in all graduates (Swyngedouw, 1992). The presence of critical spatial thinking skills in geography is important because it helps students to be able to access and make sense of (geo)information (Gryl, Jelk, & Donert, 2010) in order to understand the complexities of many of the spatial problems that face our world today (e.g. understanding of rapid world transformations, for instance, or the tensions in Mediterranean region; it is not “good people against bad people”, there is not an “axis of evil”). Geography is a science that emphasizes interconnections and inter-scaling, both in geography as a whole (e.g. Allen & Massey, 1995; Hardwick & Holtgrieve, 1996) and within specific disciplines; for example, transport (Hay, 1977), geomorphology (Cantón et al., 2011) and economics (Dicken, 1986). These are vital concepts and there is a need to focus on this both in the research we do as well as the material we teach (Del Casino, 2004; Moseley, 2009).

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These interconnections are equally relevant to geographic information systems (GIS) as well as geography, particularly when considering GIS in the light of the recent developments of the digital earth (Goodchild, 2008) and the development of quantitative geography (Longley, 2000). Geobrowsers (such as Google Earth) have developed a new type of GIS, making spatial data available to a much wider range of people than before. Goodchild (2008) describes how geobrowsers have been developed, taking an approach that looked at what could be done technically, rather than focusing on meeting the needs of the planned user community. Whilst this has made spatial data easier to access, it could also be argued that the advent of geobrowsers has reduced the level of spatial literacy among those who use spatial data, endangering these skills of critical spatial thinking. The increased availability of geodata has opened up the potential of applying GIS and geocomputation techniques to a wide variety of areas, but a lack of sufficient geospatial skills and low levels of spatial literacy have severely inhibited this in the UK (ESRC, 2013). Klein and Laurin (2005) testify how the frailties of spatial literacy in Quebec have affected the social relevance of geography, particularly at the level of people's identity and the training of citizens with territorial consciousness. That is why several authors including National Research Council (NRC, 2006), Goodchild and Janelle (2010), Jarvis (2011), Favier (2011) and Goodchild (2011, 2014) emphasize the need for the focus on critical GIScience, even with all of the developments that have occurred since the early 1990s, because GIS is about how we use the technology to answer these spatial questions, as well as being about the technology itself.

Geography degrees are in an ideal position to provide this spatial literacy training, of which GIS can form a key component. Geography is the knowledge and understanding of spatial phenomena and processes as well as the meaning of spatial units from the global scale to the microlocal (Jackson, 2006; National Research Council [NRC], 1997). GIS can integrate the various scales related to phenomena, processes and meanings. Many different modules of a geography degree look at very specialized domains (e.g. housing, mobility, territorial cohesion, hydrology, fluvial geomorphology, etc.), but there are relatively few that can be used to teach students the links between these different areas. Both the theoretical framework as well as the GIS itself are tools that can be used to gain understanding of the links between different elements. Geography as a subject is a good setting for GIS because it provides the basis for establishing these interconnections (Kemp, Goodchild, & Dodson, 1992). However, we have limited understanding about how individual students develop their own conceptual understanding, with different students having different approaches (Madsen & Rump, 2012).

Unfortunately, GIS modules can often spend more time on developing the technical skills associated with using ArcGIS,¹ QGIS² or any other piece of GIS software, rather than developing the theoretical understanding of spatial problems, the science behind this (i.e. Geographic Information Science) and the usefulness of spatial data (see Table 1 from Sui, 1995). As a result of this focus on the technical skills, GIS courses can attract the more technologically able due to the heavy reliance on computer technology. As a result, this reliance on computer literacy results in those familiar with computers progressing with GIS more easily than those who are not. This current situation is likely to be a result of the fact that previously GIS used to be limited by the technology available, i.e. computer processing limitations, data storage limits, etc. Therefore, the focus was on "how can we get the technology to do what we want?" rather than "what do we want the technology to do?" This focused the teaching on technical competence rather than critical spatial thinking.

Table 1. GIS teaching topics from a variety of attendees at INLT writing retreat.

Topic description	GIS integrated within wider module?	GIS analysis?
Tropical rainforest deforestation of Amazon/Peru: pattern links to process multiply across scale to give varied interpretation	No	No
Construction of the Mathora Relief road across the R. Yamona, Vrindavan, India. Clash of ideas about “development”, local vs. regional, heritage conservation, religion and social class/caste	No	No
Health outcomes as a measure of physical and social capital	No	No
The power of maps literature (Haneyl Woods). Critical recording of politics of map making. Have use version with students looking at OS Maps/Google Maps, etc.	No	No
Introducing geog class where students recorded experience of a recent earthquake and plotted results on overlay of geology	Yes	No
Flood hazard risk in and around Aberystwyth and how this impacts on Ceredigion County Council Planning Policy	Yes	Unsure
Regeneration of Dublin Docklands area: political (big politics and local/community politics), economic, social and environmental issues	No	No
Local/tourist experience of city of Birmingham as a global city and through different parts of the city	No	No
Deer use of landscape and impact on conservation habitats and rare species. How far does each impact spread? How does each species and/or range effect each user?	Yes	No
Flooding in Exeter and Chichester: causative primary and secondary factors, downstream influences, application and critique of LIS flood model, some links between flood model and GIS	Yes	Yes
Teaching development issues by researching a problem space and its access – i.e. the space of health. Recognizing that health involves gender, water, growth, etc. Can be at individual scale, village, regional, national, global, etc. Identifying the useful scale of analysis, temporal content and appropriate lens	No	No
Census data – correlations at different scales, understanding interactions and explanations	No	No
Compare different representations of the same space in the arts, or in the literature and try to explain the differences or commonalities	No	No
Analyse the possible environmental impacts of changes to a National Park, and of the increase in traffic to the area due to greater access. This requires them to consider the interactions of people, soil, water, animals, plants and air (and pollution) within the existing preserve which is an active volcanic zone that also experiences periodic and often devastating fires and volcanic uplift and sulphur venting	No	No
Production of a Flood Risk Management Plan, using GIS to carry out hydrological analysis ^a	Yes	Yes
Site selection of paint factory, using GIS ^b	No	Yes

^aTopic from author (NJ) experience.

^bTopic from author (NB) experience.

Now these restrictions are fewer because of the developments in technology, allowing us to focus on the “what” question rather than the “how”.

This emphasis on the technology rather than the spatial data is also compounded by the fact that most of the basic cartographic courses in universities across the world have been replaced by GIS courses (Kessler & Slocum, 2011), and as Srivastava and Tait (2012, p. 528) put it, “maps are no longer necessarily created by experts, but instead by software”, highlighting the focus on IT skills rather than spatial literacy. Cartographic courses typically covered a range of aspects on critical spatial thinking as well as map design, and if these have been replaced by GIS courses that do not cover critical spatial thinking or map design (Field, 2014), then students will not be taught the skills they need to be able to critically interpret maps and spatial data.

Even with the lifting in restrictions the developments in technology allow us, the perception of GIS being a technical subject still lingers, and anecdotal evidence shows that IT skills are still important in being able to effectively use GIS and progress efficiently through a course (Appleton, 2012, personal communication; Bearman, Munday, & McAvoy, 2015; McLennan & Gibbs, 2008). This may also be the case because academic staff who have been using GIS for a number of years are still focused on GIS from a “technology first” point of view, potentially because that is where their experience or skill set is, or because of the fact that changing their teaching material would take significant time and effort. When designing a GIS curriculum, it is often the case that some of the theoretical aspects are dropped in favour of the practical technical sessions. This is common in courses at college and university levels across the UK, the USA, Portugal and in many other teaching settings (Sui, 1995).

In our (the authors’) experience, GIS modules can often be very problem specific or problem focused. For example, in many GIS practical sessions, the student is often given a data-set and given instructions on how to use the GIS to process the data to get the final analysis output. This approach develops the student’s ability to use the software in question, but it is debatable whether this approach adds much to their knowledge about the types of question that a GIS can answer, or how to apply the tools available to other data-sets. There is also the risk of developing a “cookbook” type approach to the practicals, where students just follow the instructions without understanding what they mean (Pye, 2014, personal communication). In our experience, relatively few modules look at the whole problem-solving process, i.e. problem identification, data finding, data loading, GIS analysis, GIS output evaluation and GIS output presentation. One of the reasons for this is likely to be because just teaching the GIS analysis and GIS output evaluation is much easier than completing the whole problem-solving process. Additionally, it can be difficult to achieve the breadth of the whole process and the depth of GIS analysis required for the module in the time available. Also, because the universities have never been able to surpass the paradigm based on a technical rationale, disciplines tend to be organized on the basis of content and teaching is invariably centred on the transmission of knowledge rather than on questioning and problem-solving (Cachinho, 2006). Additionally, timetabling limitations can often result in a disconnection between the lecture content and the lab setting within a GIS course (Read, 2010). This can limit the links between critical spatial thinking and technical GIS use, limiting the development of critical spatial thinking interconnections the students can make in geographical learning.

The critical spatial thinker

During the last decade, spatial thinking has attracted the attention of many researchers in geography and other disciplines. Bednarz and Lee (2011) bind this new interest in spatial thinking to the publication of *Learning to Think Spatially* from the NRC (2006) Committee on Spatial Thinking. Regardless of the influence that this study may have had, the truth is that in the following years, several authors sought to identify and assess the components of spatial thinking and the skills and abilities of critical spatial thinkers (Bednarz & Lee, 2011; Gersmehl & Gersmehl, 2007; Golledge, Marsh, & Battersby, 2008; Goodchild & Janelle, 2010; Janelle & Goodchild, 2009; Kim & Bednarz, 2013; Kuhn, 2012; Lee & Bednarz, 2009, 2012). In general, for these scholars, a critical spatial thinker should master the following key set of abilities and skills:

- Understand the effect of scale and the role of assumptions in the use of spatial data.
- Appreciate the difficulties of inferences in multidimensional data.
- Understand the implications of problems and uncertainty with spatial data.
- Apply geostatistical theory in the use of interpolation of spatio-temporal data.

These defined abilities and skills provide a foundation for this article to consider how GIS education can begin to develop the critical spatial thinkers of the twenty-first century. This was best recognized by Goodchild and Janelle (2010, p. 10) as they suggest “it is evident that students should be trained to the standards of a critical spatial thinker”. This is a challenging endeavour that needs to be taken by and integrated into GIS education. The first step is to construct a clear picture of the concept of, and characteristics of, the critical spatial thinker.

A workshop was organized by the International Network for Learning and Teaching (INLT) in Geography, held in Box Hill, Surrey, UK, at the end of August 2014 on the theme of Geography in Higher Education. The workshop was attended by the authors and provided the opportunity to gather data from the 30 international participants on their experiences of and view on critical spatial thinking. A world cafe format (Brown, Isaacs, & The World Cafe Community, 2005) was adopted to collect the data over 1 h, during which participants circulated and visited tables focused on different questions; in the case of this article, these were:

- What are the key characteristics of a critical spatial thinker?
- What teaching examples do you use critical spatial thinking skills in?

The academics involved in the discussions all had links with geography, but not necessarily with teaching GIS or researching GIS. This section of the paper makes use of answers to the first question, while the next section (Summary of Current GIS Provision) discusses answers to the second part of the question.

The results of the world cafe discussion indicate that the ideal critical spatial thinker would be someone who can critically examine and understand spatial issues in regard to three areas: (i) spatial data, (ii) spatial processing and analysis (including modelling) and (iii) spatial outputs and communication. These three areas are outlined below.

Critical thinking about spatial data comprises a number of key abilities. Firstly, the critical spatial thinker should be able to locate, filter and extract the correct data to address spatial problems. Secondly, the critical spatial thinker should understand and recognize any limitations with spatio-temporal scales and assumptions in spatial data. Thirdly, the critical spatial thinker needs to develop the ability to integrate different types of spatial data, both in terms of spatial and temporal scales. A crucial component of the critical spatial thinker should be not in mastering each of the abilities, but in the ability to apply each of them in an appropriate manner when solving a spatial problem. This ability to select the correct data links to the next skill-set of the critical spatial thinker which is in the analysis of the data.

Once the student has selected suitable data, through the consideration of the skills described above, the next stage in the process is the spatial analysis and processing of data, which requires another set of critical spatial thinking skills. These skills are themed around understanding the meaning of the spatial data used and developing understanding beyond the basic level of that offered by the data. These include:

- ability to identify, evaluate and justify the methods of spatial analysis used;
- capacity to reason spatially and understand the processes and effects of inter-scaling, from local to global;

- consider the links between physical and human processes;
- capability to move beyond Euclidean space to model phenomenological types of spaces, for example: time-space and mental-maps;
- awareness of causal dynamics, conscious of system processes, interactions and trends; and
- able to see and understand the interconnections between the different types of factors and realms: physical/human; culture/nature; society/space; and local/global.

Each of these different abilities identified through the discussions is particularly important in the defence of the methods of analysis and processing of data by a critical spatial thinker. This helps the user understand the impact that their use of this data has on the analysis they are completing. The final skill-set needed from the critical spatial thinker is in the next stage of the process of solving the problem. So far, the critical spatial thinkers have selected appropriate data for the problem they are solving and carried out suitable analysis on that data; the final step in this process is to generate relevant and useful outputs.

Critical spatial thinkers have to consider the outputs created through the process of using spatial data and analysis to solve problems. The critical spatial thinker needs to understand both the conceptual and technical aspects of the role of scale in maps as well as appreciating that there are multiple perspectives of viewing the same data. As Kim, Bednarz and Kim (2012), Bunch and Lloyd (2006) and Liben (2006), among others, point out, the map as a form of spatial representation is one of the most important communication tools of geography. Therefore, the critical spatial thinker will need to be able to visualize data in more than one way, through understanding the audience to which output is targeted. Additionally, a desire to represent spatial information in innovative, exciting and informative ways for range of perspectives will be crucial to ensure the future of development of new techniques of presenting data. Lastly, the critical spatial thinker should be to look at any outputs and be able to provide a critique of the strengths and weaknesses (Monmonier, 1996). Once the critical spatial thinker is able to consider each of these different aspects, they can create outputs to achieve the aims and objectives of the task.

A number of existing definitions of a “critical spatial thinker” do exist, including the University Consortium for Geographic Information Science, Body of Knowledge (UCGIS BoK) (DiBiase et al., 2006) which has been adopted by the Association of American Geographers as a set of standard requirements in addition to those discussed earlier. There is a section of the UCGIS BoK on conceptual foundations, which are analogous to the definition of a critical spatial thinker that was discussed above. However, there is still a significant bias to the technical skill set of GIS compared to the non-technical issues of critical spatial thinking (DeMers, 2009). Therefore, we have outlined the skills we believe are necessary, which supplement those discussed elsewhere.

Moving from current GIS thinking to critical spatial thinking

The previous section outlined the skills that a critical spatial thinker should develop, based on the literature and our discussions at the INLT liquid cafe event. This section moves on to consider how much critical spatial thinking skills are already taught to geography undergraduate students, and then discuss areas where there is the potential for improvements to be made.

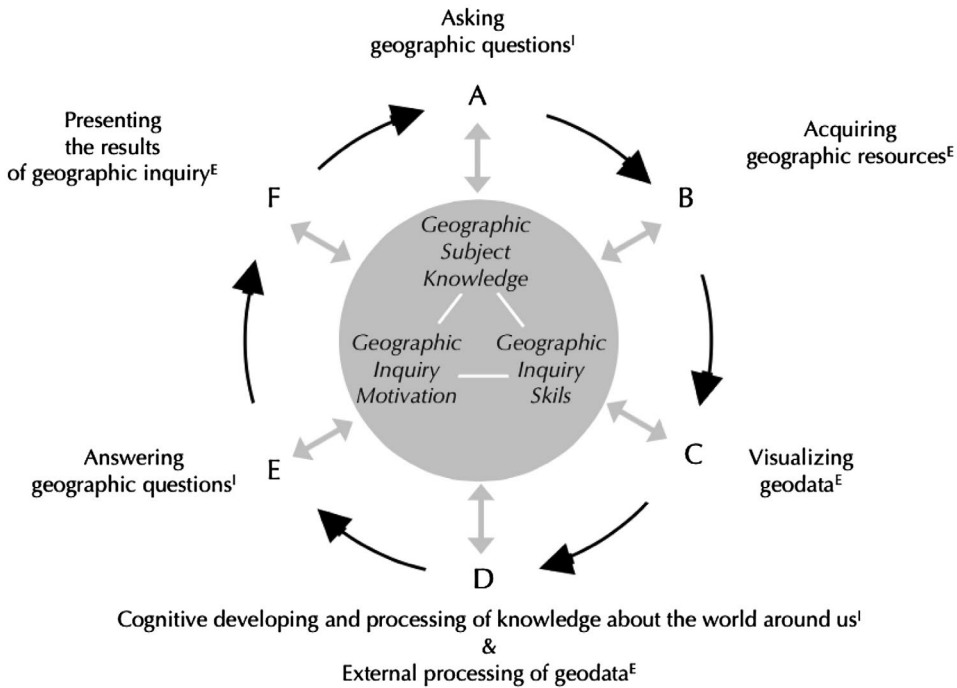


Figure 1. The processes adopted when answering geographic questions (Favier, 2011).
Notes: *i*, internal operations; *E*, external operations.

Typically, in many universities, GIS is taught as a compulsory part of a wider study skills module in the first year. After that, it is taught in a dedicated module, usually as an optional choice. A significant amount of GIS teaching is done in these stand-alone, dedicated modules, and often lacks wider integration (i.e. the GIS problem is not embedded into a specific application area). This wider integration is something that is crucial to setting the use of GIS within the wider issue and allowing the student to see how GIS integrates as part of the wider cycle of problem – evaluation – solution loop. This is shown very clearly in Figure 1, from Favier (2011).

In this, Favier adapts the model in the US National Geography Standards (National Education Standards Project, 1994), and splits these stages into six processes: (A) asking geographic questions, (B) acquiring geographic resources, (C) visualizing geodata, (D) cognitive processing of knowledge about the world around us, (E) answering geographic questions and (F) presenting the results of geographic inquiry. Critical spatial thinking requires the student to think about all of the steps in this process, and ideally their GIS teaching as well. The first step is to ask geographic questions, which need to be asked in the context of the setting of the GIS question, hence the ideal situation of locating the learning of GIS within an application-specific context. Acquiring geographic resources, exploring geographic data and analysing geographic information are all more GIS focused and can be carried out effectively within a GIS stand-alone module. However, the final stages (answering geographic questions and presenting results) require the contextual information of the case study setting, i.e. what changes are made or what recommendations are put forward to address the problem at hand. It is these first and last stages that are often excluded from

GIS teaching, and the inclusion of these will address some of the issues around critical spatial thinking.

Another aspect of this issue is the skills required to make most effective use of representing data spatially (i.e. mapping). The ESRC report (ESRC, 2013) discusses extensively the limited technical knowledge in geography, with the observation that if more geographers do not start coding, then it will be others creating the tools geographers need to use. This could be problematic if the tools that are available do not do what they need to. They also comment that different methods of representing data need to be combined: “It is important to change perspectives so that different methods are seen to be complementary, emphasizing the additive rather than divisive attributes of quantitative methods, qualitative methods and visualization (mainly GIS and cartography)” (ESRC, 2013, p. 16). This need for combination and integration, both in geography and the wider social sciences, is also echoed by Hennig (2015) and Hammett, Twyman and Graham (2015), who discuss the move away from mapping to the written form by geographers.

An informal survey was conducted with the academics who attended the INLT in Geography writing retreat. The survey was conducted after the writing retreat, allowing the academics to expand on the comments they provided in the liquid cafe session. From these comments and the survey, a range of teaching approaches to GIS emerged. They covered both the fully integrated and stand-alone GIS modules (see Table 1). Of the 16 different teaching experiences discussed, only 5 were integrated GIS modules, where there was a full case study approach, and 3 of these were simple map creation and discussion, rather than any GIS analysis per se. One of the GIS analysis modules was an application of hydrology, where a flood model was developed and critiqued within a module setting. The integration of this was limited, as there were two separate staff involved in the module without sufficient time to integrate the case study more fully. Additionally, given the limited amount of class time, the lecturers said the students needed more time dedicated to explaining the process of GIS and the model (most students having had limited experience of GIS), which limited the time available for context setting of this practical. The other integrated module with GIS analysis was a similar flooding-/hydrology-based module. The table includes two modules from the author’s experiences, which are discussed below.

In a managing rivers and coasts module at the University of the West of England, Bristol (UWE), students are required to use GIS to carry out hydrological analysis to assess flood risk on a river catchment in the South West of England. This includes learning about types of spatial data, such as Digital Elevation Models, and the limitations and assumptions that are associated with using that data for hydrological analysis. The data are utilized in a series of prescribed ArcGIS hydrology processes to prepare and use the data in hydrological analysis. The outputs of the hydrological analysis are then linked with data collected (e.g. surveys) in the field by students and combined to create a Flood Risk Management Plan for a section of river. This module links the topic of interest (rivers and coasts) with the geographic data and skills required to perform analysis in this area.

A second example of a problem-based learning GIS practical is a site selection GIS practical taught at University of East Anglia. This practical shows students how a series of criteria can be applied in a GIS (less than 500 m from a main road, more than 600 m from a river, away from infiltration zones for boreholes, etc.) to find a number of possible locations for a new paint factory. Compared to the best practice model of problem-based learning (Read, 2010), the practical is currently set up in a way where the justification of

these criteria is not explained particularly well, nor are the next steps, after performing the site selection analysis. This practical could be set within a planning or hydrology module quite effectively, allowing the students to explore and use the GIS to apply either the current planning requirements for a paint factory (e.g. distance to roads, rivers and infrastructure) or hydrology (e.g. water infiltration rates). Therefore, allowing for discussion of the reasoning behind the chosen criteria, links to relevant planning laws and policies and so on. The planning setting would also allow discussion of how to best represent the potential options to the end user/client, and what happens after the GIS analysis. If the practical remained in its current setting within a GIS module, it would be beneficial to include, or at least discuss, the reasons for the criteria chosen, and the use of the final output.

These experiences are a snapshot of views from a relatively small sample of academics. The group are self-selecting, and the views here are from those academics interested in teaching (as they attended the writing retreat on teaching and learning). So while these results are not representative, they do provide a starting platform for this discussion. The ideal would be to include students' feedback on the courses they have taken, in terms of how well they believe the course has prepared them for their future careers. This was not possible with this survey, but is something important to research in the future.

Summary of current GIS provision

The use of GIS is becoming easier with the number of tools and data-sets available much greater than five years ago. From a learning perspective, it would be ideal if GIS could be incorporated as a tool within each subject-specific module, as done with interdisciplinary learning in other subject areas, such as undergraduate health professionals who have benefited from this approach to teaching (Cooper, Carlisle, Gibbs, & Watkins, 2001). Ivanitskaya, Clark, Montgomery and Primeau (2002, p. 95) suggest that through interdisciplinary learning, learners develop a "more advanced epistemological beliefs, enhanced critical thinking ability and metacognitive skills, and an understanding of the relations among perspectives derived from different disciplines". For example, in geography, a hydrology module could include an element of using GIS to map potential flood risk, or to model river flow in a certain location. This would allow students to see the definition of the problem, see how GIS can be applied to it, through experiencing the entire research cycle: developing the solution in GIS and then evaluating and discussing how effective the solution is. This is a primary theme running through the Boyer Report (Boyer Commission, 1998) whose mission it was to suggest a model of higher education that would fundamentally transform undergraduate education. More than just focusing on inquiry, investigation and discovery as part of the research mission of research universities, it clearly shows that such an approach must be integrated into the undergraduate experience. The expected outcome from such an approach is a generation of graduates who understand the coherent body of knowledge of their discipline, and comprehend the interconnectedness of that body of knowledge with others. They should be capable of thinking logically and be able to explain the results of that logical thinking coherently – skills currently lacking in large proportions of university graduates.

As mentioned earlier, unfortunately GIS is often taught in a skills-based specific module, therefore lacking the information about the setting, and the interconnectedness discussed above. There are a number of good reasons for why modules are set up like this, including:

- Technical difficulty of GIS requiring specific teaching.
- Limited staff time and skills to integrate GIS into their existing modules.
- Students require a certain level of IT skills to make most effective use of GIS.
- Application of GIS will need supervised time in a computer lab, which is difficult to integrate into the timetable (although basic GIS work could be done outside of the computer lab, in the student's own time or on their own laptop in a lecture setting, but there can be a much higher risk of technical issues, depending on the software involved).
- Making significant changes to an existing module can involve a certain level of institutional resistance.
- Resistance to change and innovation from the teaching staff, largely due to their academic training.

In spite of this, more could be done in this setting to develop problem-based learning approaches to GIS. There could be more focus on the background of the case study, and how GIS is applied to it. For example, using the paint factory example from above, this could be developed to include more justification for and explanation of the planning requirements, i.e. which laws and regulations state that the paint factory needs to be more than 600 m from a river, etc. Depending on the student's subject, they could be asked to research this element before the GIS practical and so provide the criteria for the GIS analysis themselves.

In a number of institutions, GIS is already taught within an integrated module, although this is often within a skills-based module rather than a subject-based module. There are a number of subject-based modules, such as *Managing Rivers and Coasts* and a 3rd year *Physical Geography* module at UWE that integrates GIS, but in our experience, these are few and far between. More common are GIS modules, covering a range of different types of GIS skills and applications, but often these lack the additional subject setting, and therefore the "asking geographic questions" and "acting on geographic knowledge" stages which embed critical spatial thinking in real-world settings.

GIS can be used as a tool to look at spatial relationships and help educate geographers about why the relationship between many spatial objects is important (Bednarz, 2004). GIS can achieve this through its emphasis on "... visual expression, collaboration, exploration, and intuition, and the uniqueness of place ..." (Wright, Goodchild, & Proctor, 1997, p. 358). Geographers are not simply those studying geography; the lessons and techniques can be applied to any students, and GIS is a valuable tool to be able to use (as is critical spatial thinking) for any graduate (Dunn et al., 1997; Whyatt et al., 2011). There is opportunity to develop the existing GIS curriculum to include more of the "first" and "last" elements of the geographic thinking process (i.e. asking geographic questions and acting on geographic knowledge) by including more context-specific information. The element of discussing the GIS output would also include the process of evaluating what the GIS "answer" was, and including the fact that the GIS answer is not necessarily correct all the time. This will allow the users (or students in this case) to be critical of the answer the GIS provides, and not just accept it at face value. This element can be included in a wider teaching element of critically analysing maps to help students really think about what is represented on a map, and then apply that same critical approach when creating their own maps, developing key critical spatial thinking skills (Committee on Geography, 2000).

If the students attending a GIS module have also completed some human geography, then they could discuss how maps are just representations of a particular, subjective reality. It is also relevant to all students to discuss how spatial data are just one possible representation of reality, and so developing the students' understanding of spatial data and data in general in this direction. Building on this, all students can discuss the concept of uncertainty within the conceptualization of spatial data, as well as how information is stored and represented within spatial data, and how uncertainty can propagate through analysis. Through teaching and students' understanding, these concepts increase the likelihood that they will be able to apply the acquired knowledge to many different scenarios (Bednarz, 2004).

Conclusions

Critical spatial thinking has been discussed extensively in this article, identified as one of the theoretical aspects of applied GIS, i.e. understanding how objects in the world relate geographically to one another, how they are represented in the GIS and how a GIS can be used to analyse their relationships. This skill-set is separate from (but related to) the technical skills to use different GISs to perform analysis, and a full understanding of the former is required to (in our view) be able to implement the latter effectively.

The current methods of teaching GIS have been considered, and the fact that the inclusion of GIS within specific skills modules often limits the ability of the material to include the initial project requirements. These initial project requirements are important because they lead to the decision to use GIS, and subsequently influence the application of the results from the GIS analysis to the original project. One approach that addresses this is to embed GIS within subject-specific modules, for example, looking at population flows within a migration module. However, this is quite challenging to achieve, with the limited time and resources available in a typical university teaching setting, in addition to the potential of resistance to change in universities. An alternative approach we discuss is to develop the problem itself within a GIS module, for example, in a case study setting. We discussed this proposal in reference to a number of our own GIS teaching modules, and explored the feasibility of this suggestion.

This skill of critical spatial thinking, that is for students to be able to understand the spatial relationships that different objects have, and to know how we can analyse these relationships, is something that is inherent in the interdisciplinary nature of geography. This skill is no doubt known by a variety of names in different areas, and it is something that is fundamental to GIS. Unfortunately, it can get displaced in a pressured GIS curriculum, ultimately leading to a poorer understanding of GIS and a lower level of employability in the course content. This paper has discussed different approaches of coping with this problem, both from a GIS skills-based module and an integrated geography subject module.

This topic can be developed in two different, but complementary, ways in the future. Firstly, the issue can be considered from a pedagogical point of view, looking at how the technical side of GIS could be most effectively integrated with the case studies. For example, a comparative analysis of highly computer literate students vs. less computer literate students exposed to identical GIS analysis. One major avenue of research involves both cognitive psychology and neurophysiology. Gersmehl and Gersmehl's (2007) seminal work regarding spatial thinking in young children deconstructs some of the very critical thinking skills of which we speak here and that much spatial learning might result from a continuous process

from early childhood to adulthood. Future research of this nature will not only have to account for computer skills but also previous exposure to spatial learning. One approach would be to administer a pretest which would indicate a baseline of spatial skills, prior to the teaching course and final testing.

Secondly, a research agenda can be constructed, outlining some of the ideas already discussed and developing them to create a definition of a “spatial citizen”, linking to existing research developing this subject. This would particularly link to some of the literature in the general pedagogical area, as well as specifically in terms of GIS teaching methods and approaches. Outputs from this research agenda would be beneficial to both members of the geography community who teach the skills associated with critical spatial thinking, as well as those outside geography who are also interested in these skills. This would also support the development of teaching-only staff within geography departments, helping with their professional development (Bearman, Dyer, Walkington, & Wyse, 2015). This approach could be achieved by considering GIS to be a generic literacy skill (like literacy, numeracy and IT literacy), and then GIS would need to be integrated into the curriculum across many different modules.

GIS has reached a new phase in its technological development, and we are now able to move on from the purely technical point of view (of being limited by what GIS software can do) and continue to develop the critical spatial thinking aspect of geography within the framework that GIS provides us with. This allows spatial issues to be taught from a problem-based learning point of view, rather than a technical GIS point of view, which allows the consideration of the whole geographic inquiry process. However, there are limitations with this approach, mainly stemming from the wide range of technical skills and competences that undergraduate students have, which often require intervention to develop their technical skills before they can get the most from their critical spatial thinking skills and from the GIS software.

Notes

1. ESRI ArcGIS, <http://www.esri.com/software/arcgis>.
2. QGIS, <http://www.qgis.org>.

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