

How does the use of a geographic information system (GIS) engender spatial thinking in Year 8 geography students?

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A Research & Development Project Submitted for the  
MSc Learning & Teaching 2018

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**How does the use of a geographic information system (GIS) engender spatial thinking in Year 8 geography students?**

## Abstract

This research investigates the impact of using a geographic information system (GIS) on students' spatial thinking. This was done through the design and implementation of two GIS-based schemes of work. Collaboration took place through the planning and teaching of both interventions to Year 8 geography students.

This small-scale evaluation used qualitative methods to investigate students' and collaborators' views. Student work was also analyzed using a framework developed for the assessment of spatial thinking skills. The findings suggest that the use of a GIS does enhance, and in most cases improves students' spatial thinking skills, but, that spatial thinking as a skill is hard to quantify and difficult to measure progress in. Another benefit that using a GIS affords the reflective practitioner is the creation of engaging, contemporary and interactive lessons, using real data, from which Year 8 students derive a lot of geographical value.

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## Introduction and rationale

The inclusion of geographic information system (GIS) technology into classroom teaching has been at the forefront of my current school's departmental improvement plan for some time now. It is omnipresent in school geography curricula, both nationally and globally, and researchers and practitioners advocate that it is an essential skill for students to master in the 21<sup>st</sup> century for both business and education (Bearman *et al.*, 2016; Collier, 2007; West, 2003; Selwyn 1997). Moreover, geography educationalists advocate that GIS can improve spatial literacy, and help develop critical spatial thinking (Zwartjes *et al.*, 2017; Kerski, 2008a; Bednarz *et al.*, 1994). The rationale for this project came from the desire for the geography department in my current school to develop the teaching of GIS in Key Stage 3. My Part 2 assignment for the MSc in Learning and Teaching (MLT) stimulated my interest in geography educational issues, but it was the department's desire to develop the use of GIS in the geography curriculum that confirmed it as the focus for this piece of research.

Having reviewed the department's schemes of work for evidence of teaching with GIS, I identified a complete absence of GIS within the Year 8 scheme of work, despite this being encouraged in the National Curriculum (Fargher, 2018; DfE, 2014a, 2014b, 2013). There was some evidence of it in the Year 7 scheme of work but none in the Year 9 curriculum. Due to Year 9 feeding into GCSE geography, it was decided not to develop the use of GIS with this year group as there was too much pressure already to cover the syllabus. There was no reference to spatial thinking at all in any schemes

of work, therefore, having also conducted a brief review of the literature on GIS to refine my research interests for Part 3; I decided to focus on the role of GIS in developing students' spatial thinking skills, as the practical benefits of this has received comparatively little attention in the published literature compared to the theoretical benefits (Bednarz, 2017; Liu *et al.*, 2010; Milson and Curtis, 2009; Bednarz, 2007).

## Aim

The aim of this study is to collaboratively implement a successful series of GIS-based lessons into two current Year 8 schemes of work, and to then assess the perceived benefits of doing so on students' spatial thinking. This was done through a series of two interventions so that progress over time could be measured. This research is a small-scale project with significance for me as a teacher, and, one that aims to help other teachers through collaboration. It also aims to develop my own teaching practice, as a reflective practitioner, through learning about and teaching with GIS technology.

I consequently decided on the following questions to explore whilst reviewing the research literature:

1. What is spatial thinking and how can it be measured?
2. How can secondary school geography students' spatial thinking be improved using a GIS?

## Literature review

This section aims to review the current research literature on GIS and spatial thinking, and further develop my initial questions into research questions.

### Geography and space

Geography has always been concerned with the 'where' of things and their relationships in space (the significance of this aspect of geography can be seen in Figure 1). Space is an important, if not underpinning aspect of geography:

*Geographical space comprises location, or where we are on the Earth's surface in relation to geographical coordinates; distances measured in a variety of ways; and directions that complete the interrelationships of different locations on the Earth's surface. A key corollary of the focus on geographical space has been the ways in which the Earth's surface is depicted. Maps, cartography, and, most recently, satellite images, qualified by scale and forms of representation, are the working tools for much geographical analysis (Matthews and Herbert, 2008).*

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**Fig. 1** The matrix of geographic perspectives. Geography's ways of looking at the world—through its focus on place and scale (horizontal axis) —cuts across its three domains of synthesis: human-societal dynamics, environmental dynamics, and environmental-societal dynamics (vertical axis). Spatial representation, the third dimension of the matrix, underpins and sometimes drives research in other branches of geography (National Research Council, 1997, p. 12).

The National Research Council (1997) argue that geographic approaches to spatial representation are closely linked to a set of core spatial concepts (including location, region, distribution, spatial interaction, scale, and change) that implicitly constrain and shape how geographers represent what they observe. In effect, these concepts become a priori assumptions underlying geographic perspectives and shaping decisions by geographers about how to represent their data and what they choose to represent.

While we may have long agreed that geography is about this central relationship between space and place, *how* we have chosen to study it has been the subject of much more variation and debate (Little, 2014). Space is indeed a convoluted yet ever-developing aspect of the geographic discipline. According to Thrift (2009) all kinds of new spaces of differentiation are being constructed (Holt-Jensen, 2018; Murdoch, 2006; Amin, 2002; Whatmore, 1999; Massey, 1994).

### Spatial thinking

Whilst the concept of space in geography is developing, so too is how we think about space, not just in geography; but also more broadly through spatial thinking. There are many forms of thinking; verbal, logical, metaphorical, hypothetical, mathematical, statistical etc. which can be distinguished in terms of their representational system (e.g. verbal – using linguistic symbols; mathematical – using mathematical symbols), or their reasoning system (e.g. logic, metaphor) (National Research Council, 2006). It can be argued, therefore, that spatial thinking is a collection of cognitive skills. According to the seminal report produced by the National Research Council (2006) these skills consist of:

*Declarative and perceptual forms of knowledge and some cognitive operations that can be used to transform, combine, or otherwise operate this knowledge. The key to spatial thinking is a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning. It is the concept of space that makes spatial thinking a distinctive form of thinking. By understanding the meanings of space, we can use its properties (e.g. dimensionality, continuity, proximity, separation) as a vehicle for structuring problems, finding answers, and expressing and communicating solutions.*

Whilst no clear definition of spatial thinking exists (Metoyer and Bednarz, 2017; Wakabayashi and Ishikawa, 2011), researchers in the geosciences have attempted to

define what it means in relation to the subject and geographic information science's pedagogical aims. According to the National Research Council (2006), spatial thinking is:

*Thinking that finds meaning in the shape, size, orientation, location, direction or trajectory, of objects, processes or phenomena, or the relative positions in space of multiple objects, processes or phenomena. Spatial thinking uses the properties of space as a vehicle for structuring problems, for finding answers, and for expressing solutions.*

Kerski (2017) provides a more succinct working definition of spatial thinking in the geosciences as identifying, analysing and understanding the location, scale, patterns and trends of the geographic and temporal relationships among data, phenomena, and issues.

An early example of the use of spatial thinking to solve a problem in epidemiology is Dr John Snow's 1855 map of the cholera outbreak in south London (see Snow, 1855). As shown in Figure 2, Snow was able to link cholera deaths and water pumps, represent them graphically, and instrument the removal of a central water pump handle – with dramatic results. It is perhaps the earliest example of a map being used to plot data and to analyse the patterns (Biddulph *et al.*, 2015). Spatial analysis using a GIS would have made this task much easier.

The figure originally presented here cannot be made freely available via ORA because of copyright. The figure was sourced at Biddulph, M., Lambert, D. and Balderstone, D. (2015) *Learning to Teach Geography in the Secondary School: A Companion to School Experience*. Oxford: Routledge.

**Fig. 2** Dr John Snow's 1855 map of the Soho cholera outbreak (Biddulph *et al.*, 2015 p. 144 ).

Geoscience demands extensive spatial thinking from learners and practitioners (National Research Council, 2006; Kastens and Ishikawa, 2006). A few examples are outlined by the Science Education Resource Centre at Carleton College (2016) - geoscientists describe and classify, and look for casual meaning in the shape of myriad objects in nature, inferring strain history from the shape of a mineral, temperature of an ancient ocean from the shape of a marine microfossil, and atmospheric conditions from the shape of a cloud.

## Spatial thinking in the curriculum

Spatial thinking is an important aspect of many subjects, including, but not necessarily limited to mathematics (Small, 2017; Ginsburg *et al.*, 2008; Clements, 1998; Campbell, 1993; Clements and Battista, 1992), science (Kozhevnikov *et al.*, 2005; Wu and Shah, 2004; Kozhevnikov *et al.*, 2002; Kozhevnikov *et al.*, 1999; Kareiva, 1997), history (Kastens and Ishikawa, 2006; Matthewson, 1999; Gauvain, 1991), ICT (Johnson *et al.*, 2011; Wegerif and Dawes, 2004; Tomaszewski, 2004; Linn, 1994) and religious studies (Knott, 2014; Knott, 2005; Park, 1994).

Whilst other subjects have received a comparatively large amount of attention with regard to developing spatial thinking to improve attainment, geography educationists and researchers (Bearman *et al.*, 2016; Kim and Bednarz, 2013; Matthews and Parker, 2013; Goodchild and Janelle, 2010; Bednarz, 2004; Hall-Wallace and McAuliffe, 2002) have identified a dearth of literature surrounding spatial thinking. However, all researchers agree that spatial intelligence has not received the same level of interest in education as reading, written communication, and computational reasoning. There is therefore a real need to develop spatial thinking skills within the secondary school geography curriculum. Jarvis (2011) suggests this may be because spatial literacy is so integral to geography it is being neglected.

Biddulph *et al.* (2015) argue that perhaps too often in schools, the 'spatial' element of geographical understanding gets reduced to a map skills unit at the beginning of Year 7, and the occasional use of an atlas or Ordnance Survey (OS) map further up the school. Similarly, the National Research Council (2006) documented the lack of formal

attention spatial thinking receives in formal curricula, despite assertions that it is a primary form of intelligence (Bodzin, 2011; Newcombe and Frick, 2010; Mathewson, 1999; Eliot, 1987; Gardner, 1983). Indeed, findings show that individuals who are more spatially adept have greater success in higher-level problem solving (Smith, 1964; Kozhevnikov *et al.*, 1999, 2002, 2005; Goodchild and Janelle, 2010). This disregard for the development of spatial thinking skills is even more surprising given the affirmation that spatial intelligence is malleable and can be enhanced and improved through education and training (Metoyer and Bednarz, 2017; Science of Learning Institute, 2016; Richland and Simms, 2015; Newcombe, 2013; Newcombe, 2010; Lee and Bednarz, 2009; Wright *et al.*, 2008; Shin 2007; Newcombe and Huttenlocher 2006; Terlecki 2004).

What is clear, is that spatial thinking should be integrated and promoted in both the geography curriculum and the wider curriculum (Thatcher and Imaoka, 2018; Baker *et al.* 2015; Patterson, 2007). Profound accomplishments have emerged through applying spatial thinking to a large number of applications over the past few centuries (Goodchild and Janelle, 2010) – human settlement patterns, correlations between the physical environment and human health, and human migratory flows over time, to give three examples. In the classroom, spatial thinking is best understood when intentionally taught (Oldakowski and Johnson, 2018).

## Measuring spatial thinking skills in geography

Spatial understanding is an integral and distinctive part of learning geography. As a result, researchers (Manning, 2014; Gersmehl and Gersmehl, 2007; Gersmehl and Gersmehl, 2006) have sought to identify lists of spatial thinking skills specific to the subject. The Association of American Geographers (AAG) describe eight fundamental spatial thinking skills (see Table 1). These were later developed by Kim and Bednarz (2013) who identified five spatial habits of mind that derive from using a GIS (see Table 2).

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**Table 1** Spatial thinking skills (Biddulph et al., 2015, p. 145).

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**Table 2** Five spatial habits of mind (Kim and Bednarz, 2013).

However, Biddulph *et al.* (2015) contend that it is unclear to us what benefits accrue to geography teachers from knowing that different mental functions are performed in different parts of the brain. A better application of these skills is for students to use these terms fluently to express their geographical thinking when using and interpreting GIS images. Bloom's (1956) taxonomy could be more appropriate for this, although further research into the practicality of this is needed, and is nevertheless contested. The taxonomy (see Table 3) is primarily designed to generate higher-order questioning in geography lessons, as championed by Roberts (2013) and Anderson and Krathwohl (2001). In relation to spatial thinking, the categories could be seen as discrete spatial thinking skills, ranging from simple knowledge or comprehension of a map or chart to the synthesis or evaluation of that dataset.

The figure originally presented here cannot be made freely available via ORA because of copyright. The figure was sourced at Roberts, M. (2013) *Geography Through Enquiry: Approaches to Teaching and Learning in the Secondary School*. Sheffield: Geographical Association

**Table 3:** Framework of levels based on Bloom's taxonomy of cognitive objectives (Roberts, 2013, p. 100).

Much work has been done to answer *how* we measure these skills in geography in order to help improve students' spatial thinking. Whilst this is not easy the recent work by Zwartjes *et al.* (2017) provides an excellent summary of the literature to date and suggests a taxonomic framework for measuring spatial thinking skills. As discussed earlier, Bloom's (1956) taxonomy could be a useful starting point for developing such a taxonomy. However, Jo and Bednarz (2009), contend that Bloom's (1956) taxonomy does not address the major components of spatial thinking; specifically concepts of space and tools of representation, in the knowledge and cognitive domains. Their framework uses the three concepts of spatial thinking; namely space, tools of representation, and reasoning as primary categories to develop spatial thinking questions. This was later simplified by Scholz *et al.* (2014) in order to evaluate spatial thinking materials in textbooks (see Figure 3).

The figure originally presented here cannot be made freely available via ORA because of copyright. The figure was sourced at Scholz, M. A., Huynh, N. T., Brysch, C. P. and Scholz, R. W. (2014) An evaluation of university world geography textbook questions for components of spatial thinking. *Journal of Geography*, 113 (5), 208-219

**Fig. 3** Three components of spatial thinking in questions (Scholz *et al.*, 2014).

A more suitable method for assessing spatial thinking skills as a whole is based on Lindner-Fally and Zwartjes (2012)'s idea of a learning line. They define a learning line as an educational term for the construction of knowledge and skills throughout the whole curriculum. A good example of this is the Flemish curriculum for secondary geography (see Table 4).

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Available at: <http://www.gilearner.ugent.be/wp-content/uploads/GI-Learner-SpatialThinkingReview-3.pdf> [Accessed 23 May 2018]

**Table 4** A learning line from the Flemish curriculum (Zwartjes *et al.*, 2017).

This idea was further developed by Perdue and Lobben (2013) who proposed that certain spatial thinking skills are higher order than others and build upon the previous, less complex skills. Therefore, this is a useful method of assessment as learning lines imply a conceptual process of learner progression (Zwartjes *et al.*, 2017). Young (2010), however, suggests these skills cannot be developed through generic curriculum approaches and they must involve a curriculum that is driven by content as the carrier of concepts, rather than relying on one based around skills and concepts.

## GIS in the secondary school

Although there is no single universally agreed-on definition of a GIS (much like spatial thinking), GIS professionals do agree on several general principles. Firstly, a GIS requires a combination of computer hardware and software tools. Second, a GIS requires data, and this data must possess a spatial or location component. Third, a GIS requires knowledgeable individuals to develop the database and carry out the data processing. Although GIS software has become much easier to use since the introduction of graphical user interfaces, GIS programs and much of the underlying geographic theory require people to have a basic understanding of maps and map analysis. This is perhaps the single biggest drawback to using a GIS, especially to support spatial thinking. Lastly, and perhaps most importantly, a GIS is a system for analysis. That is, a GIS is useful for the examination, display, and output of information gleaned from the data that are stored and maintained in the system (Steinberg and Steinberg, 2006).

A GIS can loosely be defined as an integrated system of hardware, software and procedures designed to support the collection, management, manipulation, analysis, modeling and display of spatially referenced data about Earth's surface in order to solve complex planning and management problems (Bednarz et al., 1994). Yap *et al.* (2008) offer a simpler definition of a GIS, as a system of hardware and software used for storage, retrieval, mapping, and analysis of spatially referenced geographic data. There is a plethora of GIS software available. We have become increasingly familiar with 'digital Earth' through virtual globes such as Google Earth (Fargher, 2018). Conventional examples of GIS software include Esri's ArcGIS Online, QGIS and AEGIS

3 GIS. The field of cartography has shifted its focus from printed map communication to an emphasis on 'geovisualization' (MacEachren, 1995), which, has increasingly become central to scientific visualization and exploratory analysis (MacEachren and Kraak, 1997). This is because geovisualization allows spatial data to be collected, analyzed, synthesized and presented effectively (Kim *et al.*, 2017). There has also been a shift towards community-led innovation through collaboration. For example, access to Esri's applications was originally only available through through a paid subscription. In April 2017 Esri announced it would provide the ArcGIS Online platform to UK secondary schools for free. For the first time, this gives teachers access to a powerful, easy-to-use GIS environment complete with access to the Esri support team and help pages rich with information (West and Horswell, 2018). Recently produced, collaborative lessons that teachers and students can access include a project to map the British-Irish ice sheet (Clark *et al.*, 2018: see Figure 4 below), calculating landslide risk for communities affected by wildfires (Esri, 2018a), and estimating storage capacity using drone imagery in the Yucaipa Valley, California (Esri, 2018b).

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**Fig. 4** The maximum extent and pattern of retreat of the British-Irish ice sheet constructed by landform data using ArcGIS (Clark *et al.*, 2012).

Technical tools, when used appropriately as instructional supports, have the potential to enhance student learning and teacher instructional success (Bednarz, 2004; Dede, 1998; Cognition and Technology Group at Vanderbilt, 1996). GIS offers many benefits to the secondary school geography student: it explores real-world, global issues (Bednarz, 2004); develops geographical understanding (Bearman *et al.*, 2016); improves computer literacy (Collier, 2007) and develops the use of spatial data both through presenting it and analyzing it (Akinyemi, 2016). West (2003) supports the idea that GIS stimulates both higher-level thinking processes and increased intrinsic motivation - personal involvement in detailed geographical analyses of issues of personal significance and immediate relevance can also occur. A good example of this

is the analysis of crime near where a student studies or lives. Moreover, as a generic tool, information technologies are an integral component of students' lives (Selwyn 1997). As such, GIS increases the personal and societal significance of geographical study. Bednarz (1995) suggests there is a relationship between constructivist learning and the use of GIS. Indeed, it is argued that it is the inquiry-based nature of GIS' applications that offers real-world contexts in which students may develop geographical knowledge and skills (West, 1998; Turner and Beeson, 2003).

GIS and the analysis of spatial data has increasingly been included as a core element of the geography curriculum; according to Fargher (2018), the 2013 Geography National Curriculum highlights this use of GIS more prominently than ever. The Key Stage 3 geography curriculum (DfE, 2013) identifies GIS as a key technology that pupils can use to think spatially, as well as the ability to use maps and other geographical images to collect, present and analyze data. The revised GCSE and A-level curriculums put even more emphasis on developing spatial thinking skills using GIS. At GCSE, students are required to describe and interpret geo-spatial data presented in a GIS framework (DfE 2014a), whilst at A-level, pupils must demonstrate the following skills specific to quantitative data:

- understand what makes data geographical and the geospatial technologies (e.g. GIS) that are used to collect, analyze and present geographical data;
- demonstrate an ability to collect and to use digital, geo-located data, and to understand a range of approaches to the use and analysis of such data (DfE, 2014b).

There is much debate surrounding the role of GIS in the curriculum. In particular, the successful implementation of this technology to support meaningful outcomes. Bednarz (2004) suggests that many of the assumptions made by the 'respectable early adopters' of GIS (Longley *et al.*, 2001) are now being questioned, particularly given that after investigating geography in UK schools, Ofsted concluded that:

*Core knowledge for the majority of the students surveyed, but especially for those in weaker schools, was poor. All but the best students interviewed were spatially naïve. The mental images they held of the world were often confused and they were not able to locate countries, key mountain ranges or other features with any degree of confidence.... Their study of geography was isolated and not set within any context they could identify with (Ofsted, 2011 p. 22).*

It is important here to define what is meant by core and powerful geography knowledge. Core geography knowledge is the ability to recall facts and identify features such as locations of countries and places, as well as define key processes (Hirsh, 2011; Hirsh, 2007; Hirsch, 1987;). The importance of core geography knowledge is often overlooked, especially by new teachers who are often careless of the significance of locational context within a wider global narrative when teaching about place (Mitchell and Lambert, 2015). Similarly, Lambert (2011) states that the regional gazetteer approach gave geography a bad name and geography teachers (especially new ones, recruited into a rapidly expanding state system) were ready for the conceptual revolution and more 'scientific' approaches to both human and physical geography. Powerful geography knowledge is an idea introduced by Young (2009) and developed by others (Roberts, 2014; Morgan 2015; Morgan; 2011; Firth 2013; Firth, 2011a; Catling and Martin, 2011). It is part of a broader argument for the importance of subject knowledge in the school curriculum, in opposition to a focus on

generic skills and learning outcomes (Maude, 2016). Young (2010) further defines powerful knowledge as knowledge that students would not have access to at home or at work and knowledge that takes them beyond their experiences. Lambert (2011) argues for a synthesis between core and powerful knowledge in the geography classroom. The benefit of this is that it would provide the opportunity for teachers to grasp the purpose and place of core knowledge in the context of the broad and balanced curriculum they play a crucial part in making. (Maude (2016) argues that this literature has focused on questions of philosophy, epistemology and pedagogy without much discussion to identify types of geography knowledge that are powerful. Nevertheless, there is therefore a great research need in this area into GIS' place in the curriculum, and how it can nurture powerful knowledge that promotes higher-order geographically-relevant spatial thinking.

Fargher (2018) suggests that the government White Papers, *Educational Excellence Everywhere* (DfE, 2016) and *The Importance of Teaching* (DfE, 2010), offer us lenses with which we can look at the role of geographic information in geography education. Firth (2011b) argues that this implies that geography will have a presence within the school curriculum as one of the subject disciplines that will enable the curriculum to be rigorous and stretching and support high participation though its future is not confirmed. The White Paper, however, does not make clear what is meant by 'essential knowledge' and 'traditional subjects'. Lambert (2011) makes a strong case for the importance of GIS in developing this core and powerful geography subject knowledge. Fargher (2011) supports this idea but advocates the use of a GIS only if it constitutes part of a richer and broader geographical picture which enhances access

to more powerful geographical knowledge. Indeed, Roberts (2014), maintains that whatever knowledge is selected and justified, it is only potentially powerful. Students must remain motivated to learn. This is a view supported by others (Firth, 2011b; Cosgrove, 2008) who advocate a multiple-perspectives viewpoint that can be attained through engagement, i.e. using a GIS. More critical use of such technologies has much to offer in promoting geographical understanding (Fargher, 2018), and, geography educators argue that the critical use of GIS can develop young people's awareness of major contemporary issues of our time (Annoni *et al.*, 2011; Fargher, 2011). Moreover, it is the only ICT application that is specific to work in geography (Martin, 2006). Bednarz (2004) concludes that the use of GIS in school geography not only encourages intrinsic motivation by satisfying the conditions needed for optimal learning (West 1998), it better positions geography within the school curriculum (Naish *et al.*, 1987).

### Implementing GIS in the secondary school geography classroom

Since its inception, GIS has been integrated into a small number of school geography classrooms both globally and in England, predominantly through the efforts of a minority of committed geography teachers (Walshe, 2017b). However, Kerski *et al.* (2013) argue this increased use in a school context exists due to the perceived benefits it provides, an idea also supported by Bednarz (2004), who suggests that these individuals have worked under an assumption that GIS offers benefits for the geography student. Baker *et al.* (2015) propose there is therefore a specific research need to more confidently support these assertions.

Training teachers to use GIS is of fundamental importance to the successful implementation of GIS-based lessons that engender spatial thinking and develop spatial understanding and spatial literacy. How to best prepare teachers for teaching geography; whether teaching as a stand-alone subject or integrated into other disciplinary areas, has been an area of interest for some time, and this has been a global concern (Walshe, 2017a). Mitchell *et al.* (2018) further develop this assertion, stating that geography consists not just of content (e.g. place awareness, physical systems, social systems), but also skills related to spatial thinking and GIS.

One of the main reasons teachers avoid using GIS in their teaching is due to the perceived difficulty in using the software. Kerski *et al.* (2013) argue that teachers shy away from engaging with GIS in their classroom as it can be seen as being too complex, too difficult to integrate into an already busy curriculum, too time-consuming to produce resources for or simply impossible to do in departments with limited access to computers. This is an idea supported by Walshe (2017b) who looked into how Initial Teacher Education (ITE) courses support teachers in the use of GIS. She concluded that the knowledge culture in schools and teacher self-efficacy were significant barriers preventing the use of GIS in schools. Tondeur *et al.*, 2017 also support this assertion. Kerski (2003; 2000; 1999) found that other reasons why teachers are not using GIS is because of a lack of GIS training and the inaccessibility of the computer hardware. However, training can be costly, difficult to arrange and quickly become out-of-date (Mishra and Koehler, 2006). Demirci *et al.* (2013) surveyed three public high schools in Turkey and found that teacher-centered problems were the most important challenges in the implementation of GIS-based projects in schools. Most

teachers lacked knowledge, skills and experience using GIS in their lessons and did not receive adequate motivation or encouragement to develop their proficiency.

Bednarz and Van der Schee (2006) state that those geography teachers using GIS do so for three reasons: 1) GIS supports geography and teaching and learning; 2) GIS is a tool for investigating geographical problems at different scales; and 3) GIS is a necessary tool for the business world in the 21<sup>st</sup> century.

If we are to develop support for teachers using GIS further, consideration of a theoretical framework is likely to be only the beginning of the process (Fargher, 2018). However, Mishra and Koehler's *TPACK framework* is an important model which helps assess the barriers that need to be overcome in order to develop GIS in the geography classroom. Whilst expert teachers bring this framework into play every time they teach, it is useful for teachers wanting to introduce GIS into their teaching as it considers the complex set of challenges that may confront them in doing so (Mishra and Koehler, 2006). According to the model, there are seven areas that a teacher needs to consider before using a GIS in their teaching (see Figure 5).

The figure originally presented here cannot be made freely available via ORA because of copyright. The figure was sourced at Koehler, M. and Mishra, P. (2009) What is technological pedagogical content knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education*, 9 (1), 60–70.

**Fig. 5** TPACK framework and its knowledge components. This framework shows the challenges teachers face in order to develop the use of GIS in the geography classroom (Koehler and Mirsha, 2009, p. 63).

Technological Pedagogical Content Knowledge (TPACK) is the amalgam of all these elements (Fargher, 2018). Technological Content Knowledge (TCK), for example, is the knowledge needed to bring GIS into the geography classroom. This could be the teacher knowing how data is inputted into a GIS. Technological Pedagogical Knowledge (TPK) is an understanding of how teaching and learning can change when particular technologies are used in certain ways. This includes knowing the pedagogical affordances and constraints of a range of technological tools as they relate to disciplinarily and developmentally appropriate pedagogical designs and strategies. To build TPK, a deeper understanding of the constraints and affordances

of technologies and the disciplinary contexts within which they function is needed (Koehler and Mirsha, 2009).

There are limitations to this model. Bednarz and Van der Schee (2006) identify classroom management as being the most significant. Manageability and consistency are also important. If a GIS is not regularly used, or practice with a system is not built into regular schemes of work, then teachers are less likely to adopt GIS as a teaching tool. Still relevant today are the words written by Hassell (2000 p. 91), although 'ICT' could easily be replaced with 'GIS':

*It is easy to look at the use of ICT and say there are so many problems and issues that ICT just cannot be integrated successfully. This approach is not viable, since our students deserve to have a geographical education which reflects the world in which they live, where ICT is completely pervasive and more importantly changing the nature and processes involved in the subject.*

## The role of a GIS in spatial thinking

A GIS can answer five generic questions (see Figure 6).

The figure originally presented here cannot be made freely available via ORA because of copyright. The figure was sourced at Bednarz, S. W., Bettis, N.C., Boehm, R.G., DeSouza, A. R., Downs, R. M., Marran, J. F., Morrill, R. W. and Salter, C. L. (1994) *Geography for Life: National Geography Standards*. Washington, DC: National Geographic Society

**Fig. 6** Geographical questions that a GIS can answer (Bednarz *et al.*, 1994).

Therefore, a GIS is clearly a useful tool to use for spatial thinking. Fitzpatrick and Maguire (2001) argue that a very particular type of spatial thinking lies at the core of conventional GIS; one that can be used to solve geographical problems. An idea supported by Fargher (2018) as it allows quantitative techniques through the visualization of spatial data as well as providing a means of utilizing various data sources (Schuurman, 2004). Additionally, it presents geographers with ways to visualize spatial arrangements, and, in the process, restores intuition as a valid heuristic technique. Kerski (2008a) argues that the most important question that a spatial thinker can ask is *why*, not *where*. *Why* is a scaffold upon which can hang other geographical knowledge. *Where* by itself cuts short spatial thinking and subsequent spatial analysis. We should encourage students to think holistically and spatially about problems with which they are using GIS software and skills to answer. They should be encouraged to think beyond the software.

This inherently means that geography cannot simply be done by computers, because, every machine requires an operator; someone who decides what is to be done and why, but also someone who can question the answers (Bednarz *et al.*, 1994). The power of a GIS is that it allows us to ask questions of data and to perform spatial operations on spatial databases. To do this requires a fundamental competency in geography itself. Brown (2001) defines spatial analysis as the process of:

- looking at what is where and where things are in relation to others;
- integrating different types of data;
- asking specific questions about how events, patterns, or conditions in one place affect those in other places;
- using maps interactively, to display the data, generate new questions, to provide new views of the situation and thus to produce better understanding.

One could argue this could be done using maps, as the cartographic tradition led to the nurturing of another geographical skill, which had been labelled 'graphicacy' (Matthews and Herbert, 2008). Nevertheless, whilst maps do allow the brain to develop patterns, especially given that around 30% of the brain's neurons are used for visual intelligence (Grady, 1993); spatial analysis is differentiated from 'mapping' or 'graphicacy' because it generates more information than can be gathered from a map alone. According to Schuurman (2004) it is a synergistic means of extracting information from spatial data. Using a GIS therefore fits into the three dimensions of learning (Illeris, 2007), especially within the interaction and incentive dimensions (see Figure 7).

The figure originally presented here cannot be made freely available via ORA because of copyright. The figure was sourced at Illeris, K. (2007) *How We Learn: Learning and non-learning in schools and beyond*. Oxford: Routledge

**Fig. 7** The three dimensions of learning (Illeris, 2007, p. 26). Content and incentive are part of the individual acquisition process, and the social and societal dimension, to do with the interaction process between the individual and the environment. The circle indicated that learning always takes place within the frames of an outer societal context.

The powerful analysis functions afforded by a GIS are crucial to answering spatial problems. However, according to Schuurman (2004) analysis has been treated like a 'black box', that is; the processes are hidden and therefore not transparent to users, who, by implication must trust the results. Cloud and Clark (1999) use the expression of a 'shutter box' to refer to the process of obtaining glimpses into the algorithms and models that provide intelligence for GIS analysis. For the purposes of this research, pupils are not required to understand the complex algorithms and formulas that help them derive results, but, it is worth noting for users who want to perform more complex spatial analysis, particularly at degree level and beyond. It is however

preferable for students to have some technical understanding of how a GIS operates to gain access to the 'shutter box'.

It should be noted that the use of GIS is just one way to develop students' spatial thinking skills. Newcombe (2013) advocates methods such as sketching, interpreting diagrams and understanding the space-time continuum to improve students' spatial literacy. Spatial thinking is a necessary skill for tomorrow's thinkers, practitioners and innovators to develop; especially in an increasingly inter-disciplinary world, both in education and industry. Goodchild and Janelle (2010) suggest that the development of spatial thinking in learning and teaching in curricula will require a combination of conventional course-based curriculum, intensive peer-to-peer interaction, project-based learning, and engagement with activities across the education spectrum.

#### [Developing spatial thinking using GIS: a summary of findings and scope for further research](#)

Metoyer and Bednarz (2017) reason there is a correlation between thinking spatially and thinking geographically. Therefore, this section aims to review the findings of projects that have attempted to use GIS to enhance students' spatial thinking skills and therefore identify the rationale for this project. However, it must be acknowledged that empirical research that explicitly examines the role of GIS in promoting spatial thinking is lacking (Hall-Wallace and McAuliffe, 2002).

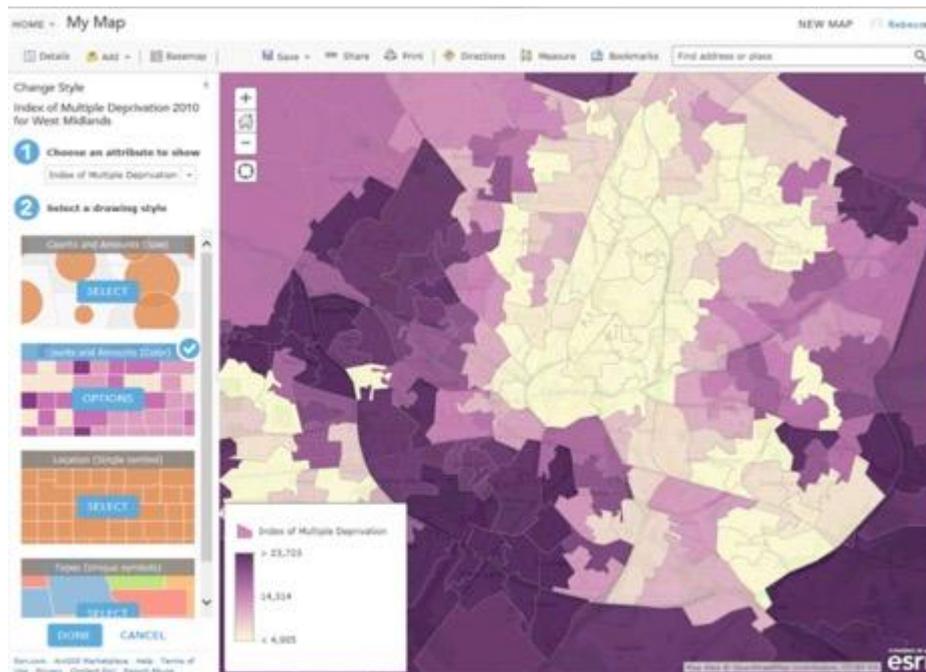
Sinton and Bednarz (2007) investigated the use of GIS to study Hurricane Katrina. They examined how spatial data helped people understand the event, its causes and

responses to the hazard, and how framing this knowledge through a GIS helped to build a 'cognitive geographical context':

*Our ability to interact with and manipulate GIS-based maps of the Hurricane Katrina region increased our awareness of the region's geography. When students assume control over the scale, display, and organization of the data, they are empowered to gain deeper knowledge. The potential for students to learn varies quantitatively and qualitatively along a continuum, anchored at one end by educational experiences such as viewing static maps, and at the other by working hands-on with GIS software to create maps (Sinton and Bednarz, 2007).*

It is this *empowerment* that is key to improving students' spatial thinking using a GIS:

Liu *et al.* (2010) found that problem-based learning with GIS developed students' analytical and evaluation skills. By giving students control over what they are doing they are able to develop higher-order thinking skills by questioning and interpreting what they see in front of them. That is provided they have the skills and knowledge to use the GIS, and that their learning takes place within a geographical context. Fargher (2018) argues that framing the geographical learning is key part of using GIS when teaching. Milson and Curtis (2009) reported that using a GIS was an effective way to enhance students' critical spatial thinking. Their task was to locate a new business using a GIS. Students had to determine criteria on which to base their decision, find data to support the criteria, and finally defend their thinking processes. In the UK, Priest (2017) is using GIS to support her teaching and develop students' spatial thinking skills. For example, at GCSE level students create a choropleth map using the Index of Multiple Deprivation 2010 for the West Midlands and describe the pattern, suggesting reasons for it (see Figure 8).



**Fig. 8** Index of Multiple Deprivation 2010 for the West Midlands ready for interpretation and analysis by GCSE students using ArcGIS Online (Priest, 2017).

However, on the whole, few geography teachers have committed to using GIS in their teaching and this reluctance for geography teachers to integrate GIS into their teaching is an international problem. Demirci (2008) undertook some research into the effectiveness of GIS in Turkish schools and found that GIS helped students to develop spatial thinking skills by exposing them to spatial analysis. However, having conducted his research in an environment where the IT provision was lacking, this lack of infrastructure severely impaired the results and further research is required. Yap *et al.* (2008) used two sets of questionnaires, as well as focus groups, to interview heads of department and geography teachers in 106 of the secondary schools in Singapore. Out of the 89 heads of department surveyed, 56.2% did not have access to any GIS software. Lack of funds was cited as the main reason for not acquiring any GIS

software. Interestingly, despite the Ministry of Education offering every school a subsidy of \$2000 to purchase GIS software in 2002, not all schools took advantage of this offer. Despite these setbacks, 90.3% of the 323 teachers surveyed perceived GIS as appropriate and relevant to the teaching and learning of geography. Olsen (2002) surveyed around 400 New Zealand secondary schools and found that fewer than 8% had access to GIS software. This reluctance in uptake of GIS in schools is also evident in the USA. Donaldson (1997) surveyed 750 high schools in Ohio and found a lack of GIS awareness. Moreover, only 3% of teachers surveyed used GIS in their teaching. Kerski (2003) conducted a 33-item nationwide survey in 1520 high schools. Of those surveyed only 5% owned a GIS package.

## Research questions

According to West and Horswell (2018), the ArcGIS Online platform now offered freely to secondary schools in the UK has the potential to transform the teaching of GIS in UK secondary schools. It provides a data-rich, interactive, and fun learning experience for students. For this reason, and having reviewed the literature on GIS and spatial thinking in UK secondary schools, this research aims to answer the following questions:

1. To what extent does a GIS help students to think spatially and what are the perceived benefits for the reflective practitioner?
2. How is collaboration effective at implementing GIS in the Year 8 geography curriculum?
3. In what ways does the design and implementation of GIS-based schemes of work contribute to a teacher's developing practice?

## Methods

### Research design

In order to investigate the impact of using a GIS on students' spatial thinking skills, two interventions were planned to take place over the course of a series of lessons – one analyzing deforestation rates in the rainforest and the other looking at crime in the local area. The first intervention took place in February 2018 (six lessons) and the second in June and July 2018 (eight lessons).

The first set of lessons involved using Global Forest Watch<sup>1</sup>, a free open-source web application that monitors global forest loss and gain in near real-time. Students can select an area of forest anywhere in the world and analyze it to determine loss and gain (see Figure 9). Explanations are provided, which students can make links to justify their findings, in the form of 'stories' – case study material that is geo-referenced into the online platform. The rationale for starting with this application was that it was more intuitive for students to use and less knowledge of GIS and how a GIS works was required beforehand.

The second set of lessons involved using ArcGIS Online<sup>2</sup> – a free cloud-based online mapping and analysis solution (see Figure 10). The rationale for using this program was that it is widely used since it was made free for use by UK secondary schools in April 2017. This suite of lessons was conducted over a longer time period following Johanssen's (2006) assumption that it is necessary to revert to the teaching of GIS

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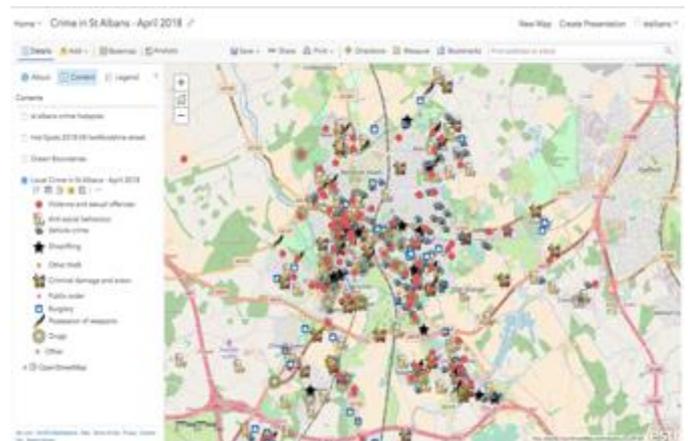
<sup>1</sup> <https://www.globalforestwatch.org/>

<sup>2</sup> <https://www.arcgis.com/home/index.html>

before using it in the classroom. This second set of lessons investigated crime in the local area and finished with a student-led project in which they mapped their perceptions of crime hotspots in school. Similar to the first intervention, pupils conducted several tasks using the maps they produced in order to develop and apply their spatial thinking using a GIS.



**Fig. 9** Analyzing deforestation in Brazil using a free online GIS application.



**Fig. 10** Interpreting spatial patterns of crime in the local area.

Each intervention used pre-prepared material that is freely available online. I had to adapt these schemes of work accordingly, with the input of collaboration, to tailor them to the students we teach. Another reason for doing this was because, as a department, we had not taught with GIS technology in Year 8 at all and were therefore using it with students for the first time in that scheme of work, but, not the cohort as students had briefly been introduced to it in Year 7. Shin (2007) advocates keeping the GIS simple, as often; over-complication with GIS lessons leads to frustration.

## Research approach

This research will use a small-scale evaluative approach within the theoretical framework that by using a GIS, students' spatial thinking will be improved; an assertion that has been made in much of the literature. A small-scale evaluative approach was deemed most suitable because this project is primarily practitioner research and I am investigating my own classroom practice through a series of two interventions. Robson (2000) and Punch (2009) support this as a suitable approach, as, small-scale evaluations are likely to:

- *be local – rather than regional or national;*
- *involve a single evaluator – or possibly a small team of two or three;*
- *occupy a short timescale – perhaps to be done in between one and six months;*
- *have to be run on limited resources;*
- *take place at a single site – or possibly a small number of related sites.*

An overall evaluative approach is best suited for this research as evaluations aim to provide personalized information on the dynamics of a program and on participants' perceptions of their outcomes and impact (Fink, 1993). Evaluation has traditionally been an important part of enabling improvement to be made in educational curricula (Talebear *et al.*, 1971; Scriven, 1967; Cronbach, 1963), but evaluation in the late 1970s and early 1980s developed as something from which to learn and make changes (Simons, 1987). However, this only partly covers what is really being measured in that evaluation of outcomes can only assess how far a project or intervention meets its goals. Process evaluation is concerned with answering a 'how', or 'what is going on'

question (Robson and McCartan, 2016). This involves observing and measuring what is going on in the project. It complements outcome evaluation as it provides explanations as to how the outcome may have happened. However, it is also important for evaluations to consider the mechanisms that give rise to these processes as these may be derived from the personal experiences of the participant or teacher within a project. As Robson (2004, p. 74) states:

*It is not the program activities themselves which constitute the mechanisms, but the response they generate in those involved. These activities are, of course, important. Program developers not only have theories (ideas, hunches) about possible mechanisms, they also assume that the various program activities lead to the operation of these mechanisms.*

There are disadvantages to using a small-scale evaluative approach. One is the limited amount of time and resources available which therefore has an impact on measuring all aspects of the project (outcomes, processes and mechanisms). However, Robson (2004) argues that it is better to complete a simple do-able design than to only get part way through a methodologically complex evaluation. Another is that, due the collaborative aspect of this project; I do not have control over every aspect of the design process. Nevertheless, and for good reasons such as the increased effectiveness of the evaluation, other collaborators should have a voice (Robson, 2004).

With regard to this research, this involves assessing students' spatial thinking skills before and after using both GIS platforms to determine whether their spatial thinking has improved i.e. assessing the outcome. It is therefore important to think *how* students' spatial thinking skills could be assessed. As discussed in the literature

review, merely knowing spatial thinking competencies is not a sufficient method with which to measure spatial thinking skills. Therefore, the taxonomic learning line shown in Table 5 will be used to assess students' spatial thinking skills throughout the lessons with differentiated outcomes planned around these skill levels.

The figure originally presented here cannot be made freely available via ORA because of copyright. The figure was sourced at Zwartjes, L., de Lazaro, M.L., Donert, K., Sanchez, I.B., De Miguel Bonzalez, R. and Woloxzynska-Wisniewska, E. (2017) Literature Review on Spatial Thinking [Online]

**Table 5** The framework used for assessing students' spatial thinking skills (adapted from Zwartjes *et al.* (2017)).

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<sup>3</sup> A note for referencing these levels: Level 1 should be reached in primary education; level 2 can already be reached in primary – depending of the class group - but must be reached in lower secondary education. Level 3 can be reached in lower secondary – again depending of the class group, but must be reached together with level 4 in upper secondary education Zwartjes *et al.* (2017).

## Participants

The school that this research project was carried out in is an independently selective school for boys with 805 students on roll. The school is co-educational in the Sixth Form. This research was carried out with Year 8 students only; 72 in total. There are no Special Educational Need and Disability (SEND) students within the year group but there are 36 Gifted and Talented (G&T) students (students with a VRT score above 130). Within Year 8 there are three classes; two consisting of 25 boys and one of 22. I am responsible for teaching two of the three classes (8A and 8C, both with 25 boys in) with the collaborating teacher responsible for the third (8B, with 22 boys in). Pupils in Year 8 have two timetabled 50-minute geography lessons per week.

## Collaborators

As an evaluator it is virtually impossible to do a good job by relying solely on your own resources (Robson, 2004). Collaborators must therefore play an active role in the evaluation and in the case of this research; help design and implement new schemes of work within the Year 8 curriculum. Schon (1987; 1983) suggests that this is beneficial for the collaborating practitioner as they may develop new perspectives, develop professionally or reawaken interest in their role. The collaborative aspect of this research project is the design and implementation of two GIS schemes of work. The other collaborator, John, is another teacher in the geography department in my school, who is also a teacher in the computing department, and already had an interest in GIS from planning the Year 7 scheme of work in previous years. Collaboration took place in the form of planning meetings which informed both sequences of lessons. However, it is acknowledged that the collaborative aspect of

any evaluation can affect the stress, morale, job satisfaction and workload of any collaborator and the meetings were, in reality, limited to a couple of planning sessions before each scheme of work was to be taught and two follow-up meetings after each project had run.

### Ethical issues

The following ethical issues were identified before undertaking any research:

- gaining consent from pupils and collaborators to be part of the research project;
- the unequal power relationship between myself as a teacher (adult) and a student (child);
- issues arising from interviews e.g. a student's view on a staff member;
- storage of data and anonymity of information;
- conflict of interest with the computing department through collaboration;
- my own ability to take on the study.

BERA guidelines (2011) state that all educational research should be conducted with an ethic of respect. Therefore, my responsibilities to participants include:

- the duty to inform participants of the nature and purpose of the research and to obtain their voluntary consent as participants;
- the duty to avoid any form of deception;
- a responsibility to ensure the anonymity of information;

- the duty to treat participants with respect, including respect for their privacy and also their right to withdraw from the study.

In order to conduct my research ethically, informed consent was sought from all participants by making them aware of my research and explaining that they could opt-out of the project at any time. Informed consent is preferable for low risk studies as there is evidence to suggest that samples may be skewed by the use of opting-in procedures (Jungians *et al.*, 2005).

Thomas (2009) supports the idea that there is an unequal power relationship between any adult and any child. My position as a researcher therefore heightens the perception of authority held by any child involved in this research and I therefore decided to send a letter detailing my research intentions to my school's headteacher (see Appendix 1). I also informed all parents/guardians of Year 8 students of my research intentions and stated that all participant responses would be anonymous and confidential (see Appendix 2), and, reinforcing that participants could opt-out at any time. Any names mentioned in this study are pseudonyms. I outlined that any data stored would only be kept for as long as it was deemed to have academic value, and that it would be stored securely on password-protected devices or on the school's encrypted computer system. In order to prevent a conflict of interest with the computing department, I outlined to my collaborator that all information and opinions they expressed would be treated confidentially and all data made anonymous and stored securely.

As part of the university's policy on ethical research, I had to gain ethical approval of my research project from the Central University Research Ethics Committee (CUREC). Savin-Baden and Major (2013) state that one of the primary responsibilities of an ethics review board is to ensure that the potential for harm to participants is outweighed by the potential good of the study.

A further consideration I took into account is that researchers should possess the skills and abilities to undertake a study. Lacking such ability could make the research unethical. Hammick (1996) states that the researcher should have or develop the necessary abilities or therefore not take on the study. Moreover, Hammick (1996) further argues that research should have a sound scientific basis and that researchers should be able to provide a strong rationale for the methods chosen. These are ideas supported by Whiting and Vickers (2010) who also state that ethical research should contribute to the development of knowledge. I therefore decided to conduct a thorough literature review and consideration of methods before conducting any research. My Part 2 involvement on the MLT course (see the Introduction for context) also helped assuage any doubts of researcher competence, and this project's contribution to the development of knowledge, by affording me the opportunities to discuss my intentions with other colleagues and my supervisor.

## Sampling

The choice of sampling strategy is arguably more important to the qualitative researcher than the quantitative analyst as qualitative researchers have various goals

driving the choice of sampling methods (Thomas, 2009). This is an idea supported by Maxwell (1996) who states that often, qualitative researchers are inherently interested in the nontypical cases as much as the typical. In order to get a representative sample, and to keep my data manageable due to the time constraints of the project, I used stratified random sampling to build my sample of students. According to Robson and McCartan (2016), stratified random sampling is appropriate where members of a group share a particular characteristic; in this case their class. Moreover, stratified random sampling can be more efficient than random sampling as the means of stratified samples are likely to be closer to the population mean (Robson and McCartan, 2016). Each student in the three Year 8 classes was given a number and a random number generator was used to select four students from each class to form a sample of 12 students. These students would then be interviewed, and their work used for analysis.

### Research instruments and triangulation

Qualitative methods were deemed the most appropriate in light of this research. This is because they capture the complex and fluid stream of events taking place even within a seemingly simple program (Robson, 2004). Moreover, as Merriam and Tisdell (2016) suggest; the overall purpose of qualitative research is to achieve an understanding of how people make sense of things. As this research is interested in how students think spatially, which is a personal construct, and also how teachers can implement successful GIS lessons that enhance spatial thinking; qualitative methods will help interpret what students and teachers are thinking. This research will

therefore take a post-modern view on qualitative research, following the ideas of Savin-Baden and Major (2013), in that there is no unified reality, but individual realities.

Cohen *et al.* (2011) define triangulation as the use of two or more data collection methods. Triangulation allows results to be viewed from more than one standpoint and is therefore a powerful way of demonstrating concurrent validity (Campbell and Fiske, 1959). Relying on one data collection method may bias the results as research methods act as filters through which the environment is selectively experienced (Smith, 1975). In order to increase the validity I will use a variety of data collection methods (methodological triangulation) thus enabling me to be more confident in my results.

For this research, a number of methods were used to collect data: semi-structured and un-structured interviews with my collaborator and the student sample respectively, although group interviews were used when questioning students. The final method used was the analysis of students' work produced in the two interventions. Structured interviews were avoided as this research is primarily exploratory, and I did not want to be constrained by pre-planned questions. Instead, I desired to get behind the meaning of pupil and teacher constructs of spatial thinking and GIS. The amount of structure was therefore crucial in determining how fruitful my results would be. Merriam and Tisdell (2016) support this assertion stating that the most common way to decide which interview to use is to determine that amount of structure desired.

#### Semi-structured interviews - collaborator

Semi-structured interviews were used to interview my collaborator. This method was chosen as I wanted to ascertain the success of each scheme of work whilst also recording the collaborator's evaluative views. Pre-determined questions helped structure this as I could decide on the topics to be covered beforehand, having been influenced by my own teaching of that particular intervention. Moreover, Savin-Baden and Major (2013) claim this is a useful method to use when time is limited. Moreover, it aims to keep the interaction focused given the limited time I have to conduct interviews.

#### Un-structured group interviews - students

Un-structured interviews were selected to avoid any a priori categorization which may limit the field of enquiry when interviewing pupils (Punch, 2009). Indeed, Thomas (2009) states that the interviewee should inform the researcher what the issues are – the desire of interpretive research. This method is therefore a powerful way to produce rich and valuable data as it is so flexible (Douglas, 1985), and the interviewee is leading the conversation. Furthermore, a successful in-depth interview has many of the characteristics of a long and intimate conversation exploring the issue at large (Punch, 2009).

A group interview was decided as the best approach to interview students principally to make them feel more comfortable with what can be a very formal and often daunting process. The overall aim for the student interviews was to collect meaningful data which could then be analyzed to ascertain the impact of GIS on students' spatial

thinking skills. Therefore, a group interview lent itself to more of a discussion which placed the importance on the students' views, rather than them 'second-guessing' the answer or saying what they perhaps thought I might want them to say; ideas both supported by Yin (2009). Punch (2009) argues that group interviews are a suitable tool for this as the role of the researcher in a group interview changes to that of a moderator or facilitator.

All interviews were recorded using ALON Dictaphone software on my iPhone and subsequently transcribed. This was to ensure that I could be actively listening to the responses but I did take concise notes, particularly of ideas I thought were important for further analysis or follow-up.

#### Student work analysis

The maps the student sample produced during the two interventions, as well as the follow-up work was also used as a data source for analysis. Any written work, like drawings reflects a student's knowledge and understanding of the world (Menter *et al.*, 2011). The work pupils produced could be assessed against the spatial thinking framework outlined earlier (see Table 5) in order to see which tasks benefitted student's spatial thinking skills. Moore *et al.* (2008) and Elliot *et al.* (2008) both support this idea in that such analysis can help access participants' views. Student work was also used as a prompt in the semi-structured and un-structured interviews. Bailey *et al.* (2009) state that such methods can serve as a springboard for discussion. This is an idea also supported by Bryman (2004).

## Question design

In order to determine what questions I would ask during the interviews, I used the six types of question that an interviewer can ask proposed by Patton (2015) as a starting point (see Table 6).

The figure originally presented here cannot be made freely available via ORA because of copyright. The figure was sourced at Patton, M.Q. (1980) *Qualitative Evaluation and Research Methods*. Thousand Oaks, CA; Sage

**Table 6** Six types of interview question to stimulate responses from an interviewee (Patton, 2015).

Experience and behavior questions were used to gauge the success of each intervention – both for my developing practice with regard to collaboration and to find out what the students thought they had got out of each scheme of work to assess their spatial thinking skills. Opinion and values questions were also used to find out what the students and collaborators thought about each intervention. These were particularly useful questions to use when interviewing John as they helped evaluate each intervention. Menter *et al.* (2011) suggest that tensions can arise when interviewing colleagues, particularly face-to-face. Therefore, it was important to structure the questions accordingly to keep the interview on track. Finally, knowledge questions were used to elicit what outcomes students had from each intervention. ‘Why’ questions were avoided as they tend to lead to speculation about casual relationships (Patton, 2015).

Probes were used in the semi-structured interviews in order to follow-up on what was asked. Glesne and Peshkin (1992) point out that probes may take many forms ranging from a single word to silence. Similarly, Seidman (2013) defines this as exploration and therefore Merriam and Tisdell (2016) argue that it is virtually impossible to specify probes ahead of time. Consequently, some basic ideas were included in my interview design but I made a point of being flexible with these during the interview process to ensure I could fully explore interviewee's responses.

#### Methodological limitations: validity, reliability and generalizability

It must be acknowledged that triangulation on its own does not necessarily mean the results will be valid – this is sought by using appropriate methods designs. Patton (1980) supports this in that triangulation using multiple methods does not ensure consistency or replication. Further, Fielding and Fielding (1986) suggest that methodological triangulation does not necessarily increase validity or reduce bias.

The obvious limitations of using qualitative methods for this research are the biases and shortcomings of using the human instrument (Merriam and Tisdell, 2016) as the main method of data collection. Peshkin (1988) dismissed these restraints instead arguing that these 'subjectivities' can help shed light on these personal constructs. Lather and St. Pierre (2013) support this idea as, in a postmodernist approach to qualitative research, both the researcher's and participants' views are made visible. Another disadvantage of qualitative methods is that they can be time-consuming and resource-intensive (Savin-Baden and Major, 2013), therefore potentially affecting validity.

Whilst it can be argued that the suitability of the term reliability in qualitative research could be contested (Golfashini, 2003 and Stenbacka, 2001), reliability can be regarded as a fit between what researchers record and what actually occurs (Bogdan and Biklen, 1992). Therefore, a potential problem with my sampling technique is that probability sampling allows the investigator to generalize the results of the study from the sample to the population from which it was drawn. Merriam and Tisdell (2016) reason that this could be an inappropriate method. However, Robson (2004) argues that in a small-scale evaluation, the researcher is more interested in a representative rather than a biased sample due to the constraints aforementioned with this method. Moreover, Thomas (2009) maintains that using non-probability sampling where it is not appropriate may lead inexperienced researchers to inappropriate research designs.

Fontana and Frey (1994) outline the problems associated with group interviews which could affect the reliability of the results – group culture and dynamics, and achieving balance in the group interaction. A weakness of semi-structured interviews is that they often do not provide scope for the interviewee to express their own opinion (Savin-Baden and Major, 2013). Moreover, they are dependent on the honesty of the participant and the quality of the questions. Whilst the former cannot be designed out, to avoid the latter; I made sure to design the interview framework with enough open-ended questions from which to lead further discussions. At the end of the interview, I asked the students and John what they thought and if they would like to add anything else to the interview that I had perhaps missed in my questions. This

proved useful in prompting meaningful discussion and also gaining their opinions on matters.

Another aspect that may affect the reliability of the results is that the interviews had to be conducted at break, lunch or free periods as John and the students were either in lessons, or, I was teaching. This limited the amount of time that I could spend conducting the interviews. However, Robson (2004) argues that these parameters concentrate the mind wonderfully and help to keep the project on task.

Leung (2015) states that most qualitative research studies are meant to study a specific issue or phenomenon in a certain population or ethnic group, of a focused locality in a particular context, hence generalisability of qualitative research findings is usually not an expected attribute. However, Finfgeld-Connet (2010) suggests that a pragmatic approach to assessing generalizability for qualitative studies is to adopt same criteria for validity which I have tried to achieve through systematic random sampling, triangulation and the proper documentation of my findings.

### Methods of data analysis

Transcripts were created in order to undertake qualitative analysis through coding. The group interviews in particular generated a large amount of information. Relevant sections within the transcripts were therefore highlighted in order to identify themes. Rabiee (2004) identifies this as a suitable method when dealing with lengthy

transcripts as it helps the researcher to make sense of the data. Analytic coding was used to interpret what each student said in order to assess their level of spatial thinking used when completing the two interventions, and, to determine how their thinking had changed over time. The same process was used when coding John's interviews. This method was chosen due to its suitability for investigating the theme of spatial thinking (Gibbs, 2007). Similarly, Miles and Huberman (1994) argue that codes should enable the researcher to catch the complexity and comprehensiveness of the data. Therefore, as a starting point, codes were devised from the spatial thinking skills level descriptors outlined by Zwartjes *et al.* (2017) – perception, analysis, structure and application (see Table 5) in order to assess how students' spatial thinking skills had changed over time.

The three summative pieces of work produced by each student from the two interventions (one in the first and two in the second) were analyzed using a similar process based on the framework proposed by Zwartjes *et al.* (2017). Although a seemingly novel method, it was a useful tool to measure improvement in spatial thinking between the two interventions. This is based on the work of Flick (2014), who describes this process of data analysis as the classification of visual material in order to make statements about implicit and explicit dimensions within it.

## Findings and discussion

In this section, I will present the findings of this research and critically evaluate them in light of the published literature, with reference to my three research questions.

Research question 1: To what extent does a GIS help students to think spatially and what are the perceived benefits for the reflective practitioner?

### Finding 1: Using GIS helped improve students' spatial thinking

Overall, through the course of the two interventions, students' spatial thinking skills were improved. In line with the framework proposed by Zwartjes *et al.* (2017), nearly all of the students before the first intervention identified their spatial thinking skills to be level 1, or at most level 2. After the second intervention all of the students in the sample felt that overall, they had improved their spatial thinking skills and competence in using GIS technologies (see Table 6).

However, not all of the students felt confident with every aspect of using a GIS and the idea of spatial thinking. The areas that some of the sample still found difficult, even after completing the two interventions, were the concepts of time (three students) and scale (six students), as well as difficulties with presenting data with a GIS (six students). Reassuringly, only one student in the sample felt that an aspect of their GIS skills had decreased - student six still did not understand how to accurately present geospatial data after the two interventions. Although, this is an anomaly as all the other students had improved their GIS skills to some degree. Two students also

struggled with detailed analysis, but most could use the analysis tools within a GIS to perform calculations.

Student	Using a GIS		Analysing data with a GIS		Time	Scale	Presenting data with a GIS
	<i>I can add/remove data layers using a GIS</i>	<i>I can explore data using a GIS</i>	<i>I can calculate forest loss/gain of a country using analysis tools within a GIS</i>	<i>I can analyse a specific area of a map using shape</i>	<i>I can map changes over time using a GIS</i>	<i>I can identify patterns over a range of different scales using a GIS</i>	<i>I can produce accurate maps using a GIS</i>
1 before	Green	Red	Red	Green	Red	Red	Red
1 after	Green	Green	Green	Green	Yellow	Yellow	Green
2 before	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
2 after	Green	Green	Green	Yellow	Green	Green	Green
3 before	Red	Yellow	Red	Red	Yellow	Yellow	Green
3 after	Green	Green	Green	Green	Yellow	Yellow	Yellow
4 before	Red	Green	Yellow	Yellow	Yellow	Green	Red
4 after	Green	Green	Green	Green	Green	Yellow	Green
5 before	Red	Yellow	Yellow	Green	Red	Red	Red
5 after	Yellow	Green	Green	Green	Green	Yellow	Yellow
6 before	Red	Red	Red	Red	Red	Red	Red
6 after	Green	Green	Green	Green	Green	Green	Red
7 before	Red	Yellow	Red	Red	Red	Red	Red
7 after	Green	Green	Green	Green	Green	Green	Green
8 before	Red	Red	Red	Red	Red	Red	Red
8 after	Green	Green	Green	Green	Green	Green	Green
9 before	Red	Red	Red	Red	Red	Red	Red
9 after	Green	Green	Green	Green	Yellow	Yellow	Yellow
10 before	Red	Red	Red	Yellow	Red	Red	Red
10 after	Green	Green	Green	Yellow	Green	Yellow	Yellow
11 before	Red	Green	Red	Red	Red	Red	Red
11 after	Green	Green	Green	Green	Green	Green	Yellow
12 before	Red	Green	Red	Red	Red	Red	Red
12 after	Green	Green	Green	Green	Green	Green	Yellow

**Table 7** Student perceptions of their own GIS and spatial thinking skills before and after the two interventions (see Appendix 3 for original data).

These findings were echoed in the interviews. After the first intervention, it was clear that students were demonstrating level 2 skills of analysis. As one student commented:

*It's interesting because you can go back in time and look at the world back in time, and see what has changed in that area, and see the effect what that's had. And it makes it very clearly, the effect.*

This was also clearly evident in the student work produced, as the two examples below demonstrate. In Figure 11 the pupil is analysing the data by critically evaluating it: *Some roads are also present on the island, but I do not think this is the cause of the tree cover loss.* In the second example (see Figure 12) the student is interpreting content: *Only 102 hectares of tree cover gain have occurred.* This student is also critically analysing the results by making links to human activities and the need for development in the area.



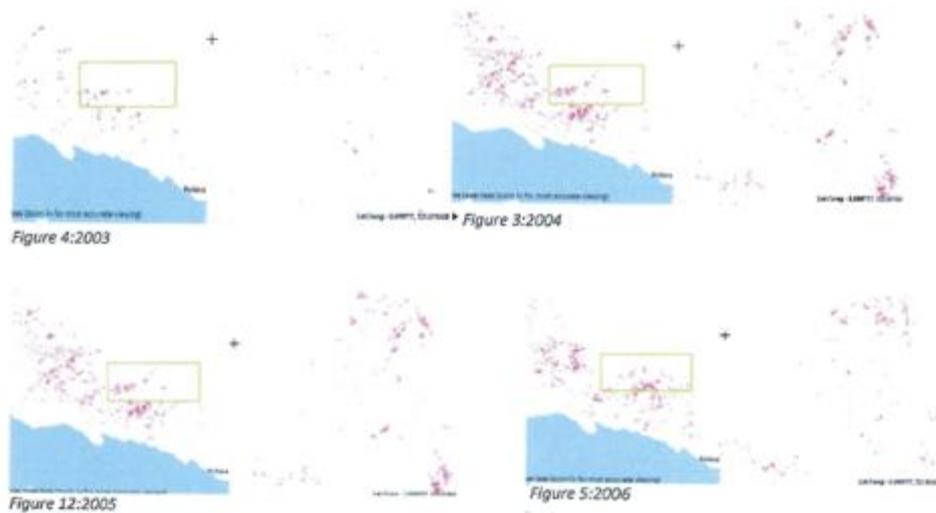
### Tree cover loss

As a whole, the two islands have had a loss of 390 hectares worth of trees, from 2001 to 2016. (with >30% canopy density). This converts to 8.73% of the total tree cover area. However, it has also had a tree cover gain of 225 hectares, converting to 5.04% of the total tree cover area. The tree cover gain is only from 2001 to 2012. As a result, the tree cover gain may be higher as it has missed a period of 4 years' worth of checking. Some roads are also present on the island, but I do not think this is the cause of the tree cover loss.

### Conclusion

In conclusion, I have analysed my area and found out that it suffered a loss of 390 hectares of trees from 2001 to 2016, but also a gain of 225 hectares from 2001 to 2012. I was not able to find out what the cause of the loss is due to the lack of information. Nothing has been done on the island, but other islands and countries have seen some activity. Nonetheless, deforestation still remains a threat to the world's rainforests and if it is not stopped or managed properly, the total area of rainforests and their trees could decrease and bring disadvantages to the natural landscape and perhaps us as well.

**Fig. 11** Excerpts taken from a student's work produced during the deforestation GIS project.



Only 102 hectares of tree cover gain have occurred, while around 3,500 hectares of tree cover loss has occurred from 2001 to 2016. The percentage of tree cover loss is over 50% of the total area. Tree cover loss occurred from 2001 to 2016 in that area, but however mainly occurred between the years 2014-2016. I believe that tree cover loss has occurred due to citizens of that area needing more land, so they began cutting down trees nearer to the mainland of Indonesia. I know this, because between 2001-2016, the tree cover loss rates increased every year, moving further and further East, towards the middle of the country.

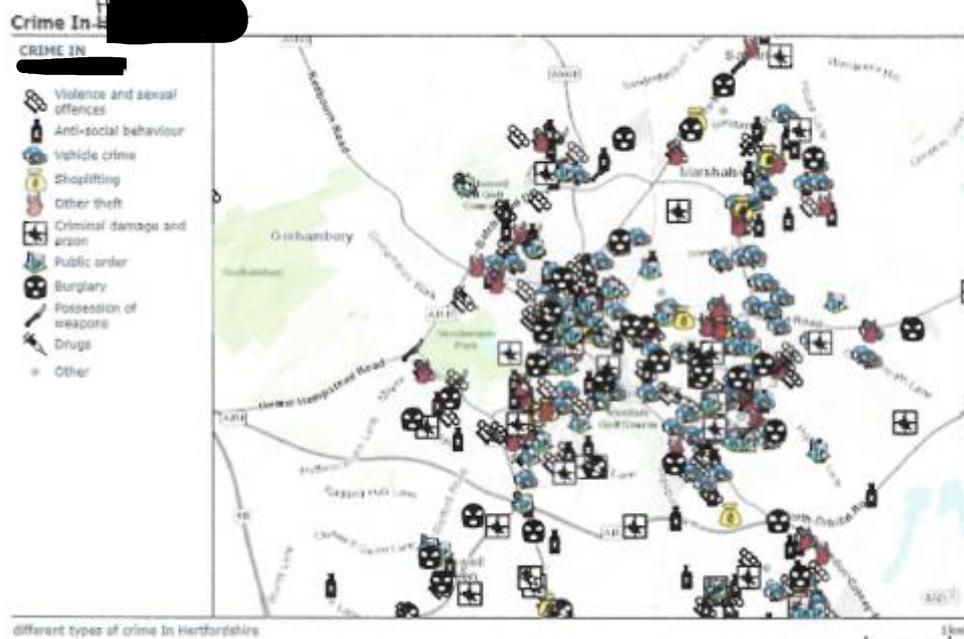
**Fig. 12** Excerpts taken from a student's work produced during the deforestation GIS project.

By the end of the second intervention, most students in the sample were demonstrating level 4 application skills. This was particularly evident when interviewing students after the crime GIS work using ArcGIS Online:

*It's a lot easier to pinpoint where the most crime happens, and which crime is where and, especially in this one here [referring to their work], exactly where the hotspots are for individual crimes.*

In Figure 13, it is evident that the student is aware where the most shoplifting takes place (the high street, according to the data) and is able to apply their knowledge to solve the problem: *Police could also patrol down the high street to make people aware of their presence.*

Similarly, there was much evidence of level 3 structuring - looking for complex connections and relationships within the maps they had produced. It was evident they were able to make links between the maps and the geography of the local area. As one student wrote: *On the high street where clubs and bars and stuff, there's more antisocial behaviour and say for instance, down a dark alleyway, there's possession of weapons and violence and stuff because it's in a dark alleyway it's easier to commit and not many people can see it so geographically more people would commit crimes in certain areas.*

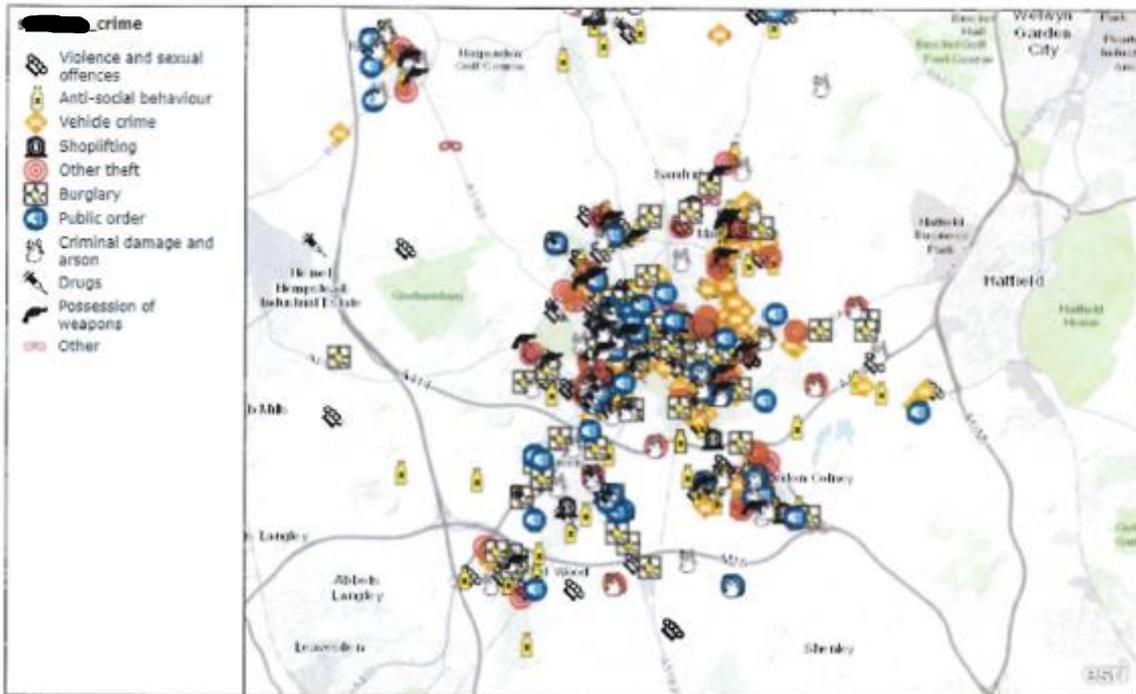


-What could be done by the Police to reduce the number of crimes in S [redacted]

-Police could put CCTV in the areas of crime that are dark and leave people vulnerable. Police could track cars better to reduce car theft. Police could insure that people have working and the correct alarms to reduce burglaries. CCTV could also be put into shops to stop shoplifting. Police could also patrol down the high street to make people aware of their presence, this would make people be scared of them are they are less likely to commit a crime.

**Fig. 13** Excerpts taken from a student’s work produced during the crime GIS project.

Similarly, in Figure 14, the student has identified patterns and relationships within the data: *Most of the crimes are directed around the centre of X with other large hotspots dotted around the outside.* However, the student has identified an anomaly in that they would have expected more crimes to have taken place in less busy areas.



- The most common crime in S██████████ April 2018 was violence and sexual offences with a total of 239 crimes.
- Most of the crimes are directed at the centre of ██████████ with other large hotspots dotted around the outside.
- It surprises me that most of the crimes were directed near the centre where it would be most busy. I would think that they would be spread out in less busy areas as to not get caught.

**Fig. 14** Excerpts taken from a student’s work produced during the crime GIS project.

Students were also able to apply their results to real-life problems. When asked to suggest what the police could do to reduce crime in the local area, students were able to suggest feasible improvements in local policing:

*If you’re like, for example, a police force and you see muggings in a specific area you could maybe put CCTV cameras or something to prevent this happening in areas to reduce the crime rate.*

One student, in one of the group interviews, suggested that these maps could be used to inform first time buyers which locations were safest to live in:

*If you were, I don't know, buying houses maybe, for example, you could look at maybe the best areas to do it using something like this if you compared maybe two towns or areas within a town.*

These findings align with much of the published literature relating to GIS and spatial thinking (Bednarz, 2017; Bearman *et al.*, 2016; Liu *et al.*, 2010; Collier, 2007). Demirci *et al.* (2013) concluded that GIS-based projects helped students in their understanding of space, and in answering spatial questions by working on real and local problems. Moreover, Priest (2017) found that students working with real data were more able to develop higher-order spatial thinking skills using GIS. From my experience of the two interventions, this research concluded that students were far more interested in the crime in the local area scheme of work as it used local and real data that was relevant to them.

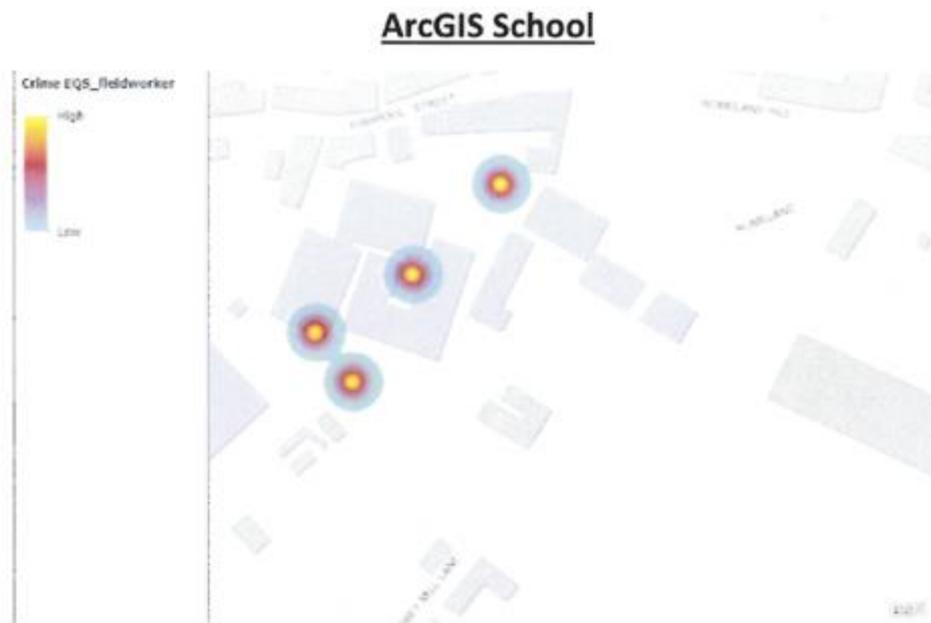
Overall, it is clear that students' spatial thinking benefitted from the two planned interventions. However, as posed by Lee and Bednarz (2009), a more pertinent question is what is the source of this improvement? This is certainly an area for further research and one beyond the scope of this project.

## Finding 2: Task design affected the outcome from which to assess spatial thinking skills

Not all students had improved their spatial thinking as they struggled to master the technology. With regard to the first project, one student commented:

*I think the hardest bit was actually trying to... I don't know how to say it, more plot the area that you wanted to grow trees from.*

Moreover, in the second project, students encountered great difficulty collecting their own data around the school site. This consequently affected their analysis of their findings as the example below shows (see Figure 15). Here, students were trying to identify areas around school where bags were most likely to get stolen. One of the tasks was to incorporate a second piece of data into the map in order to provide reasons for why the area was a crime hotspot (a level four skill). The students were clearly unable to do this within ArcGIS Online so ended up guessing that there may be a link between bags being stolen and the amount of litter.



-What does your map show? Why did you choose to present this data?

Our map shows the amount of litter and how likely is it like to get your bag stolen. We used a heat map to present this data.

**Fig. 15** Excerpts taken from a student's work produced during the crime GIS project.

Likewise, John raised this when I interviewed him after both interventions had taken place:

*When collecting data around school, there were a couple of reluctant users of the app. One had a broken phone which didn't therefore work.*

Similar problems were encountered with John's group when analysing this data:

*Once [the data] had loaded up it wasn't brilliant. The students couldn't pool the data they had collected so most just ended up with a map consisting of a few meaningless points with which they were unable to perform any analysis on. But they went out for 20 minutes or so. I'm not convinced, again the same particular characters gained anything from the experience other than no being in the classroom for 20 minutes.*

It was therefore clear, that, following the second intervention, the task itself, aided by the complexity of the software, had hindered the outcome. The difficulty was that because neither John or I had done anything like this before, we were essentially piloting the lessons with the hope that it would help students develop their spatial thinking and GIS skills. This is similar to the findings of Biebrach (2007) who identified the complexity of GIS software as a barrier to engagement. Although, in this case, it was more applicable to the complexity level of the task when designing it as a teacher, rather than a barrier to student engagement.

**Finding 3: Measuring the extent to which students' spatial thinking had improved was difficult using qualitative methods**

Overall, students found it quite hard to verbalize the impact that the two interventions had on their spatial thinking ability. John also struggled to quantify to what extent students' spatial thinking skills had developed over the course of the two interventions. When interviewed before undertaking any GIS work, students could only guess at the benefits of using a GIS on their spatial thinking skills:

*A GIS is probably easier to use than a map, so it would be easier to get more from a GIS.*

Similarly, after completing the first intervention, students could only describe what they had done rather than explain what had helped them do a particular task:

*And you can see how much deforestation there is in real terms and how much deforestation over time, so it's more real terms than just figures.*

Comments on students' evaluation sheets were equally as fruitless; when asked to comment on how they thought their spatial thinking had developed, one student wrote: *I think my spatial thinking got better as I have now understood more about the location and problems in Indonesia* (see Appendix 3).

Overall, the students' work proved more useful when actually assessing their level of spatial thinking skills with me as an interpreter. This was because their work could be referenced to the four spatial thinking skills identified by Zwartjes *et al.* (2017) in their proposed learning line. Most research into spatial thinking has used quantitative tests to ascertain a benchmark of students' spatial thinking before an intervention takes place (Collins, 2018; Johnson *et al.*, 2011; Lee and Bednarz, 2009). Qualitative researchers (Scholz *et al.*, 2014; Perdue and Lobben, 2013; Jarvis, 2011; Young, 2010; Jo and Bednardz, 2009) have used a similar method to evaluate the level and type of spatial thinking found in the curriculum, lesson plans and textbooks, but more research into the efficacy of such methods is needed.

Research question 2: How is collaboration effective at implementing GIS in the Year 8 geography curriculum?

Finding 4: Collaboration was not an effective way to implement GIS-based lessons and the school environment severely limited collaborative opportunities

Due to time constraints, I had to plan the first intervention with no collaborative input. John and I simply could not find the time to meet-up. This is something that John identified in our interview after the first intervention had been taught. However, he acknowledged that going forward this would be beneficial, so we arranged a time to meet-up and collaboratively plan. Kerski (2008b) argues that GIS projects are an excellent opportunity for teachers to collaborate, but, this was the only time we were able to discuss ideas in the whole project. In the interview, John identified the difficulties with collaboration in the school:

*In our environment, there is no time. Because everyone's doing ridiculous amounts of things, we don't have the time to sit down for two hours to plan and work through together to collectively write, or draw things up, or decide things and so on.*

The school environment seemed to be a barrier to collaboration. Teachers simply did not do this in the school. As John identified:

*I don't think it's particularly useful. I think more probably, even when you send stuff out, people don't look at it, and it's a shame, and I know it's the same all round.*

Therefore, the reality of collaboration in the two interventions, with regard to GIS, was that it was very difficult to organize, and, due to the nature of the software used,

was a time-consuming process as many of the ideas planned were simply too hard to execute in reality.

An example of this is when planning the second intervention, John suggested using QR codes to give the students more information about each crime hotspot around the school. The reality of this was that we did not have the time to learn how to use the extra piece of software and write all the information needed. As a result of this, John ended up simply following my lesson plans with no proper understanding of how to use either GIS program fully. I spent a lot of time learning how to use each program, and, as the designer of both interventions, knew what I needed to teach in order to help students achieve the desired learning objective each lesson. John agreed this had been challenging:

*If you don't use it [GIS] often... I couldn't go back to the rainforest thing and say, oh now you do this and that... I haven't got the time to spend effectively teaching a lesson to myself before I teach a lesson. And it's not my interest and it's not my role.*

This had an impact on students' learning, particularly in John's group, and, although to a lesser extent; on their spatial thinking skills. When comparing what students had learned in the two interventions, students in John's group had encountered more difficulties, especially with the student-led data collection around the school:

*That was the bit we were meant to do for homework, but the link didn't work.*

Another student added:

*I didn't do the crime around school work.*

Similarly, when asked about their experience using ArcGIS Online overall, one student explained:

*I don't think we've come across it.*

These findings are echoed in the literature. Ramsey (2008) found collaboration using GIS an 'agonizing' task. Alibrandi and Palmer-Moloney (2001) in their study of training teachers to use GIS effectively, found that developing distributed collaborative learning environments means acting as teachers and learners, and therefore, they argue; requires infrastructural support. Moreover, the learning curve is steep for everyone. However, Solem *et al.* (2003) stresses that *student* collaboration is a positive element of doing GIS tasks. In all our lessons, John and I noted that students were more successful when working together to help each other complete the activities.

Despite the shortcoming of the collaborative aspect of this research, it seems this may be particular to this project but perturbingly inimitable to GIS education. Bednarz and Van der Schee (2006), despite advocating a community of learners approach to help integrate GIS into geography curricula, identified that reality shows that certainly in secondary education this is not always working (Zwartjes *et al.*, 2017). Much research indicates that collaboration between teachers is an excellent way to improve student outcomes (Musanti and Pence, 2010; Goddard *et al.*, 2007; Kelchtermans, 2006), although there are exceptions (Johnson, 2003). Briscoe and Peters (1997) argue that collaboration facilitates change because it provides opportunities for teachers to learn both content and pedagogical knowledge from one another, encourages

teachers to be risk takers in implementing new ideas, and supports and sustains the processes of individual change in teaching. Moreover, successful evidence of collaboration is found in the IT literature (Miranda and Jaffe-Walter, 2018; Spillane and Shirrell, 2018; Flanagan and Jacobsen, 2003). Further research is therefore required into teacher-led initiatives to collaborate with GIS.

[Research question 3: In what ways does the design and implementation of GIS-based schemes of work contribute to a teacher's developing practice?](#)

**Finding 5: The school's technology infrastructure hindered the development and teaching of GIS-based schemes of work**

One of the main factors that inhibited students from completing their final investigation into crime around school, plotting their own data in ArcGIS Online, was the technology infrastructure of the school. The school has a limited number of computer rooms, all of which are bookable by any teacher. Despite booking the computer rooms in advance, some of the rooms had limited computing facilities with low processing speeds. This meant that students spent much of the lesson waiting to log-on or for the browser to load a new webpage. John had similar difficulties and, despite being timetabled for one out of the two geography lessons he taught each week with his Year 8 class in a computer room, could not always book a computer room in advance for the second lesson, which he identified as a major issue for

continuity within the scheme of work. This meant it was especially hard for students to simply pick up from where they left off two or three lessons ago.

Another factor was the difficulty in setting-up accounts for students. This was handled by IT, and support was offered by Esri, but they all encountered numerous difficulties in doing so which slowed down the development of the schemes of work, as myself and John had to learn how to use the software before teaching with it.

Students also mentioned these problems during the interviews, identifying it as a school-wide problem. One student in an interview commented:

*'Cos some of the times when we're doing languages, the computer's using a buffer or really slow.*

Similarly, in the crime scheme of work; the school's WiFi prevented many of them from downloading the app needed to collect geo-referenced data points. John explained that parental control over phones had prevented some students from doing this, and therefore, they were unable to collect any data. Likewise, he found that during the initial attempt to make a crime map of the local area:

*The data wasn't accessible. The file provided was too big when you tried to load it. GIS said it needed a subscription model rather than the model we've got, in order to cope with the size of the data.*

Much of the literature sites teachers feeling constrained by the lack of GIS-based resources available (Yap *et al.*, 2008). Shepherd (1999) raises the issue of how instructional technology can best be tailored for learning. He argues that technology must be carefully matched to a particular learning task, thereby ensuring that the

most educationally appropriate technology is chosen. Goodchild (2011) states that ‘the GIS user interface remains complex, hard to learn and use, and lacking any consistent conceptual or theoretical framework’. However, this research concluded that this was not the case. I found both the Global Forest Watch and ArcGIS Online interfaces intuitive to use, after a little familiarisation. John, however, struggled because he did not have the time available for basic familiarisation with each interface. This would have only taken a few hours, but, teachers are more often than not, and, as in this case; time poor (Peske, and Haycock 2006; Villegas and Lucas, 2002; Abel and Sewell, 1999). Technological difficulties coupled with a lack of infrastructure support and an absence of resources are commonplace within the literature (Collins, 2018; Johnson *et al.*, 2011; Demirci, 2008; Yap *et al.*, 2008).

#### Finding 6: After using GIS, students and teachers were far more aware of its applications and function

Because GIS is so much a part of the curriculum (Fargher, 2018; DfE, 2014a; DfE, 2014b; Firth, 2011b; Lambert, 2011) simply using a GIS helped students explore a GIS’ functions, despite the setbacks outlined in the previous section. Prior to the interventions, pupils had only been able to guess at the benefits of using GIS, often making tenuous assertions, based on limited exposure to such technologies:

*If you know the general place you can type it in it takes you straight there.*

*It’s constantly updating itself. Maps are just always the same and you’ve got to get new ones somewhere.*

The same could be applied to myself and John who had only really touched upon GIS beforehand. Even with limited a priori understanding, we soon realized the benefits for students and ourselves as learners *and* teachers. Kerski (2003; 2000) states that integrating GIS into classroom practice is a complex process. Nevertheless, after the two interventions, pupils were using the ‘five senses of GIS’, as outlined by Van Leeuwen and Scholten (2009), when tackling geospatial problems, and benefitting from:

- a sense of reality – pupils were using real data from their own environment – this helped make abstract spatial theories real;
- a sense of urgency – the data really got students interested in what they were doing. This kept them engaged in the interventions;
- a sense of their experience having influence – pupils were afforded the opportunity to visualize the impact of their suggestions for reducing deforestation and reducing crime in the local area;
- a sense of fun – both GIS programs were easy to use and intuitive. This kept students engaged, and interesting data made the case studies exciting;
- a sense of location – the fieldwork in the second intervention, where pupils explored crime around the school gave an extra dimension. Location became an exciting thing to explore.

Moreover, much research shows that the most successful GIS is the easiest to integrate, especially where students are participating in enquiry-led projects

(Zwartjes *et al.*, 2017). Overall, it is clear that using GIS hugely benefits students' spatial thinking skills. However, the challenge still lies in institutionalizing GIS into curricula. As observed by Bednarz (2001), teachers in the USA that had most successfully integrated GIS had done so by a total reorganization of their curriculum and a general shift to problem-based learning. Much research outlines this is the key to successful teaching with GIS and developing students' spatial thinking skills (Zwartjes *et al.*, 2017; Liu and Zhu, 2008; National Research Council, 2006; Bednarz, 2001). This aligns with the findings of others (Favier, 2013; Koutsopoulos, 2011; Tschirner and O'Brien, 2006) who argue that to achieve an overall integration of GIS, students first need to learn about GIS (theory and practice), and then apply this knowledge to learn *with* GIS (Zwartjes *et al.*, 2017). However, using GIS in this way requires both the teacher and student to undergo a paradigm shift in their goals and expectations (Yap *et al.*, 2008; Kerski, 2003; 2000). Despite these limitations, and those outlined earlier; the two interventions clearly helped develop two useful GIS-based schemes of work that enhanced students' experiences of geography, and enabled them to think develop their spatial thinking.

## Conclusions, evaluation and implications: taking GIS and spatial thinking further within my teaching, the school and the wider educational community

This project aimed to answer three research questions through the implementation of two GIS-based schemes of work, planned collaboratively, into the Year 8 geography curriculum:

1. To what extent does a GIS help students to think spatially and what are the perceived benefits for the reflective practitioner?
2. How is collaboration effective at implementing GIS in the Year 8 geography curriculum?
3. In what ways does the design and implementation of GIS-based schemes of work contribute to a teacher's developing practice?

In conclusion, it is clear that GIS has many pedagogic advantages for students and teachers in secondary schools – an idea purported by Demirci (2008). Through the course of the two interventions, using a GIS improved students' spatial thinking. Most, if not all of the pupils in the sample demonstrated evidence of using higher-order spatial thinking skills by the end of the second project (level 4 application according to the framework proposed by Zwartjes *et al.* (2017)). However, this project also determined that task design is of fundamental importance for determining the level of spatial thinking students can apply to a project. Students benefitted far more from

using real data. This increased the intrinsic motivation of the students and meant they felt more involved when analysing the results.

GIS technology has come a long way in the last decade. However, geography teachers are still reluctant to incorporate such technology into their teaching due to the many barriers created by utilising such technology (Yap *et al.*, 2008; Liu and Zhu, 2008). Despite not encountering significant difficulties, this project highlights that teaching with GIS is not easy, but, once the initial and seemingly daunting barriers are overcome, it is an excellent teaching tool that benefits students of geography. It brings course content to life and gives students the freedom and confidence to explore real, global issues themselves. It puts them in control of the investigating and, through enquiry, gives them a curiosity about the world around them that is not necessarily generated through other spatial teaching methods.

Furthermore, this research has highlighted the need for GIS and spatial thinking to be more integrated into geography curricula across the UK, as well as globally. This may however become realised since the advent of the A-level investigations (DfE, 2014a; DfE, 2014b) in which students have to use GIS for analysis of spatial phenomena. A wider range of resources would also make GIS teaching easier, as well as further research into the benefits of GIS on students' spatial thinking abilities. Collaboration using GIS was difficult, although, my school's environment did not help this aspect of the research. Still, there is certainly scope for further research into the efficacy of such methods, and a fundamental need for teachers to work collaboratively on a national or global level; if GIS technology is to be incorporated into regular teaching to improve

spatial thinking. Conducting similar projects on larger samples may also lead to an improved understanding about spatial thinking, as this project was limited to being a small-scale evaluation due to the time constraints aforementioned.

The collaborative aspect of this project has improved my relationships with colleagues who share a passion for teaching with technology. It has certainly been challenging implementing GIS into the Year 8 geography curriculum, but then nothing that is worth doing is ever easy. The department has benefitted from this research as the Year 8 curriculum now includes two GIS schemes of work, and my current school has benefitted as this research has fostered an interest in teacher-led research amongst other staff and myself, which, will hopefully lead to a publication, or at the very least the dissemination of the key findings from this research project. It has given me motivation to network with other teachers interested in GIS to learn from them and see if there is a possibility of inter-school collaboration in order to help develop the pedagogy of teaching with GIS. I hope now to take the skills I have learned with me into roles of responsibility. As one of my desires is to be a Head of Geography; a knowledge of GIS, the benefits it affords learners and teachers, and a working knowledge of how to implement successful GIS-based schemes of work, will help with developing a successful and innovative geography department.

I feel that by undertaking this research I have been able to develop as a geography teacher. I am now a more reflective practitioner and my teaching practice has benefitted as I feel more comfortable teaching with GIS, having seen first-hand the benefits it affords students, particularly with the development of their spatial

thinking. I have also realized the importance of spatial thinking within geography and wish to develop this as a core skill for students to develop within other schemes of work, and with other year groups in the school.

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## Appendices

### UNIVERSITY OF OXFORD DEPARTMENT OF EDUCATION

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Director Professor Jo-Anne Baird



[REDACTED]

08/02/2018

Dear [REDACTED]

I am writing to enquire about conducting research in school this academic year. As you know, I am studying for the Master's in Learning and Teaching at Oxford University, supervised by Dr Roger Firth. In my final research project; "How does the use of a geographic information system (GIS) engender spatial thinking in Year 8 geography students?", I will explore the effectiveness of GIS to promote students' spatial thinking through the development of a series of GIS-based lessons. These lessons will be taught by myself and other teachers involved with the year group. Therefore, the research will take place with the three Second Form geography sets, for which I am responsible.

By participating in the research, the school will be contributing to a project that will deepen our understanding of spatial thinking for geography students, and so contribute towards developing ways of improving attainment for similar students in the school in the future. It will also contribute to geography education more widely. I hope to conduct this research between March 2018 and August 2018. I plan to interview/audio-record students engaged in focus groups, as well as other class teachers of the GIS-based schemes of work.

Oxford University has strict ethical procedures on conducting ethical research, consistent with current British Educational Research Association guidelines. The University also recognises, however, that my study is a piece of practitioner research, and that schools already operate with the highest ethical standards. Therefore, only your formal consent as headmaster is necessary, and not that of individual parents or staff. However, throughout the research, students and teachers will be able to refuse to participate in any research activities at any time.

All participants, including students, teachers and the school, will be made anonymous in all research reports. The data collected will be kept strictly confidential, available only to my supervisor, Dr Roger Firth ([roger.firth@education.ox.ac.uk](mailto:roger.firth@education.ox.ac.uk)), and me, and only used for academic purposes. It will be kept for as long as it has academic value.

If you are happy for me to proceed with this study, please confirm this using the attached reply form. If you have any concerns or need more information about what is involved, please contact me or my supervisor. Furthermore, if you have any questions about this ethics process at any time, please contact the chair of the department's research ethics committee, though: [research.office@education.ox.ac.uk](mailto:research.office@education.ox.ac.uk).

I look forward to hearing from you.

Yours sincerely,

[REDACTED]

### Appendix 1 Letter to my school's headteacher outlining my research project.

27/02/2018

Dear Parent/Guardian,

### **MSc Research in Second Form**

I am undertaking some research as part of an MSc in Learning and Teaching with the University of Oxford. It is designed to complement the two topics that we are already covering in the latter part of this academic year; tropical rainforests and conflict, where we have integrated the use of geographic information systems (GIS) into the Second Form curriculum. This is because manipulation and analysis of geographical data is becoming a key skill within the field of Geography.

Normal lessons will not be affected by my research. However, as part of my studies, I would like to interview a random sample of students in order to ascertain their understanding of spatial thinking and (GIS) both before and after each project. The research will involve pupils 'opting-in' to questionnaires and I will then invite a number of students to be interviewed further.

By taking part in this research, please be assured that all responses will be anonymous and not attributable to your son. I am interested solely in his opinions on GIS and spatial thinking, and the responses to my questions will only be used as part of this research. The data will, of course, be stored securely.

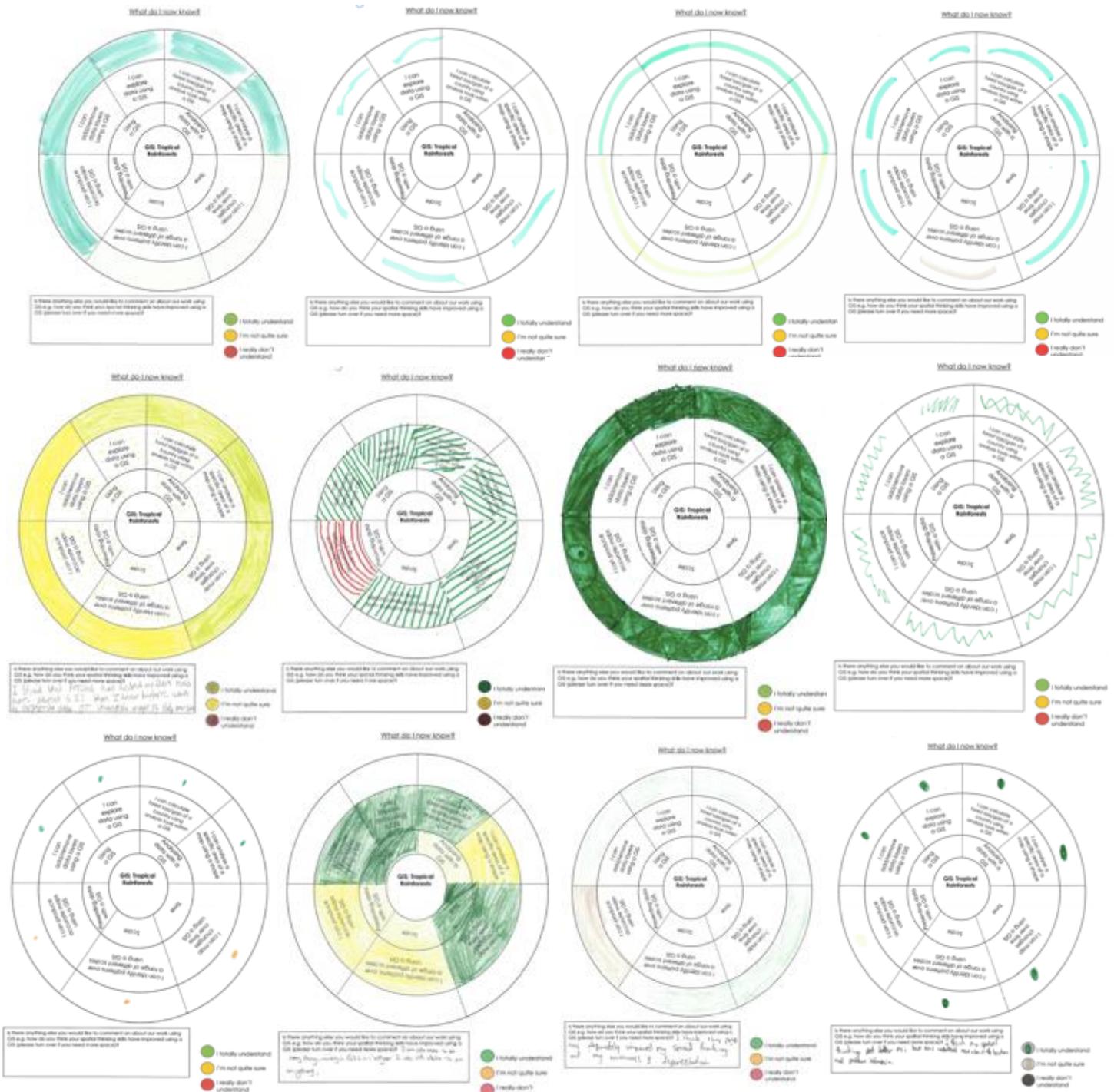
If you are happy for your son to take part in the questionnaires and interviews then you do not need to respond to this letter. However, please do let me know if you do not wish your son to take part. My e-mail address can be found at the top of this letter.

Yours sincerely,

  
Teacher of Geography

**Appendix 2** Letter informing parents about my research intentions.





**Appendix 3** Student responses to surveys before and after the two GIS interventions. Each student's response is in the respective location relevant to the corresponding table i.e. numbered from top left (student 1) to bottom right (student 12).