Developing and assessing students' spatial thinking skills when using GIS

James Hickman, St Albans School, UK

Unsplash image by Ben Lundquist

Originally published in Teaching Geography, Vol 46, Autumn 2021. Reprinted with permission.

In this article James describes some of the benefits of using GIS to improve students' spatial thinking skills and considers a simple framework for measuring these competencies.

Spatial thinking and GIS

Spatial thinking is the ability to identify, analyse and understand the location, scale, patterns and trends of the geographic and temporal relationships among data, phenomena, and issues (Kerski, 2017). This should be inherent in the learning and teaching of geography, but spatial thinking has received little direct attention in the geography curriculum. When students think spatially benefits include problem-solving, pattern recognition, and other skills.

A GIS is a framework designed to gather, manage, present, and analyse spatial data. Examples of intuitive web-based GIS programmes include ArcGIS Online; Google Earth; Digimap for Schools and MAGIC. GIS is an established part of the UK national curriculum for geography. It is integrated into the geography curriculum from key stage 2, and by key stage 3, students are expected to

- use Geographical Information Systems (GIS) to view, analyse and interpret places and data (DfE, 2013, p. 3)

while at A level, students should

- understand what makes data geographical and the geospatial technologies (e.g. GIS) that are used to collect, analyse and present geographical data (DfE, 2014, p. 13).

This is especially important for students undertaking their independent investigation where the use and presentation of geospatial data is expected.

There is much evidence to suggest that a GIS is a useful tool for students to develop spatial thinking skills (Fargher, 2018), as well as powerful geographical knowledge (Healy and Walshe, 2019). Considerable work has documented the successful use of GIS in the classroom (see Bailey, 2018; Clark ***et al***., 2018; Walshe, 2016).

Putting it into practice

I decided to undertake a small-scale evaluation in order to assess students' spatial thinking skills using a GIS. This involved the creation of two new GIS-based suites of lessons that were structured to develop students' spatial thinking skills, based on tasks that increased in complexity as the lessons progressed. Tasks were structured around the skills that I wanted students to develop, based on the learning line proposed by Zwartjes ***et al***. (2017) from the GI Learner project (Figure 1) that suggests a hierarchy for less complex (e.g., interpreting data and collecting data from the field to present in a GIS) and more complex spatial thinking skills (e.g., creating maps and problem solving). This framework was selected as it facilitated a constructivist approach to learning that would need to take place in the lessons. This was important as many of the students had never used GIS before so needed to start with learning the basics of using the software.

Learning line level	Level descriptor	Learning outcomes
Level 1 – perception	Being able to work with digital maps and virtual globes	1. Open digital maps and virtual globes on a computer 2. Indicate the different parts of digital maps/virtual globes (navigation bar, menu, scale, map window) 3. Interpret symbols on digital maps 4. Understand the construction of digital maps as a representation of the real world (topology, layers, database)
Level 2 – analysis	Selection of the relevant geographic information	1. Work with digital maps and virtual globes: find locations, pan, zoom, orientate, make measurements 2. Access information efficiently and effectively, evaluate information critically and competently 3. Be able to gather and evaluate information from data resources or through fieldwork activities 4. Interpret content
Level 3 – structure	Look for complex connections and relationships	1. Use digital maps and virtual globes for a variety of different purposes 2. Identify and ask significant questions that clarify various points of view and lead to sustainable solutions 3. Manipulate maps by creating own maps 4. Communicate cartographic information
Level 4 – application	Thinking problem solving	1. Be aware of generalisation levels applied in different zoom levels (e.g. road density) 2. Understand the basic purpose and application of digital earth to real world problems 3. Use advanced digital earth tools for learning (starting with web-based GIS, GIS viewers to GIS software) 4. Frame, analyse and synthesize information in order to solve problems and answer questions

Increasing complexity

*Figure 1: The framework used for assessing students' spatial thinking skills (adapted from Zwartjes **et al** (2017)).*

Empowerment is key to improving students' spatial thinking using a GIS (Sinton and Bednarz, 2007), and meaningful learning can have lasting impacts on students.
I decided on the topics of deforestation and crime, as they already fitted in with the year 8 curriculum at the school. There were datasets and lesson plans already freely available on the internet for these topics that could be easily adapted to develop higher-order spatial thinking skills. As this was the first time using GIS at key stage 3, I tried to keep lessons as simple as possible and focus on the outcome. Early activities simply introduced GIS (following advice from Trafford, 2017) but by the final lessons, students were interpreting and analysing the maps that they had created.

The first intervention involved using Global Forest Watch to map deforestation in Indonesia, write a follow-up report on areas most at risk and suggest action that could be taken to reduce deforestation. The second intervention used ArcGIS Online to create local crime maps using freely available police crime data, subsequently suggesting improvements to local policing (Figure 2). An example of the type of task involved for the report can be seen in Figure 3.

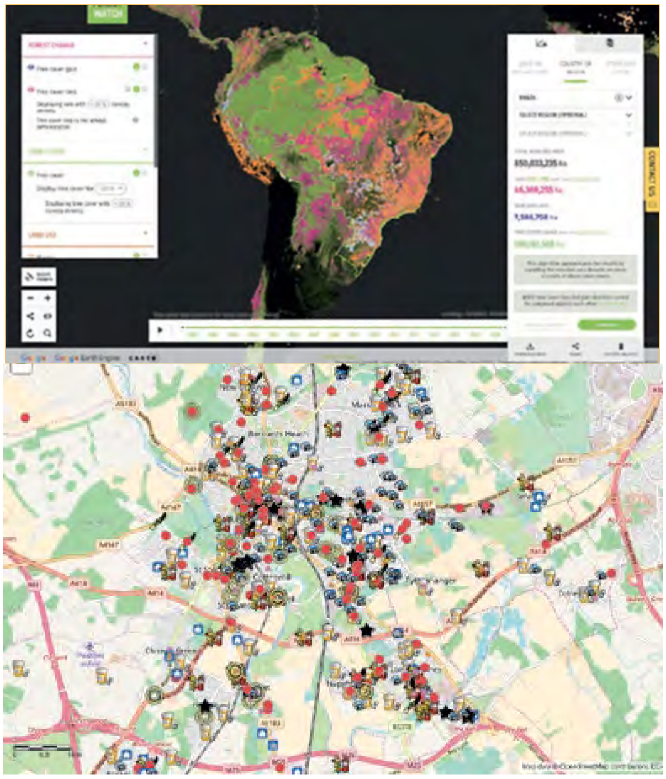

Figure 2: Examples of maps created by students using two web-based GIS programmes. The map on the left uses Global Forest Watch to show deforestation rates. The map on the right shows local crime data for April 2018 and was constructed using freely available Police data in ArcGIS online.

Introduction

Set the scene for your report. Explain what you are going to do. For example, you might like to start by saying '*In this report, I am going to investigate deforestation in [area]*'. Use a range of scales in your description (global, regional and local). Give some general reasons for deforestation but avoid giving detailed explanations in this section.

The location and size of the area

In this paragraph, you will need to use data to support our points. This is self-explanatory but ensure that you keep your units consistent.

Tree cover loss

Again, you will need to generate data using the analysis tool. Focus on the loss of trees in your area. You should suggest reasons why this is happening. Look out for patterns and clues, e.g. roads or urbanisation.

After the tree cover loss

Here you should explain what has happened after the tree cover loss, i.e. what has the response been? How have people acted? Have they done anything to complain against future deforestation?

Protected sites and conservation

In this section, you should describe and explain if anything is being done to conserve the area you have selected. Give examples to support your point of view, e.g. the names of companies or protected areas.

Conclusion

Summarise the finding of your report and avoid presenting any new ideas or data. You could start your opening sentence with '*In conclusion, I found that [area] suffered [amount of forest loss] between [year] and [year]*' Briefly explain why (reasons) and summarise what is being done (management).

Figure 3: A template for the report students had to write after mapping deforestation in Indonesia using Global Forest Watch. The objective is to elicit more complex spatial thinking.

Trial and error

While planning the interventions it was important to consider the knowledge components that engender the effective use of GIS. Koehler and Mishra (2009) distil the seven components needed to use GIS in the classroom into a technological pedagogical content knowledge (TPACK) framework (Figure 4). If any of these knowledge components are missing, teachers will struggle to use GIS effectively. Similarly, if GIS is not regularly used, then teachers are less likely to adopt it as a teaching tool (Trafford, 2017). Much recent work has been done by ITE providers, schools, and the wider GIS community to address the divide in technological competence and willingness to engage with GIS that still exists between practitioners, resulting in isolated pockets of GIS excellence (Walshe, 2016), and often prevents teachers from using GIS (Healy and Walshe, 2020; Walshe, 2017).

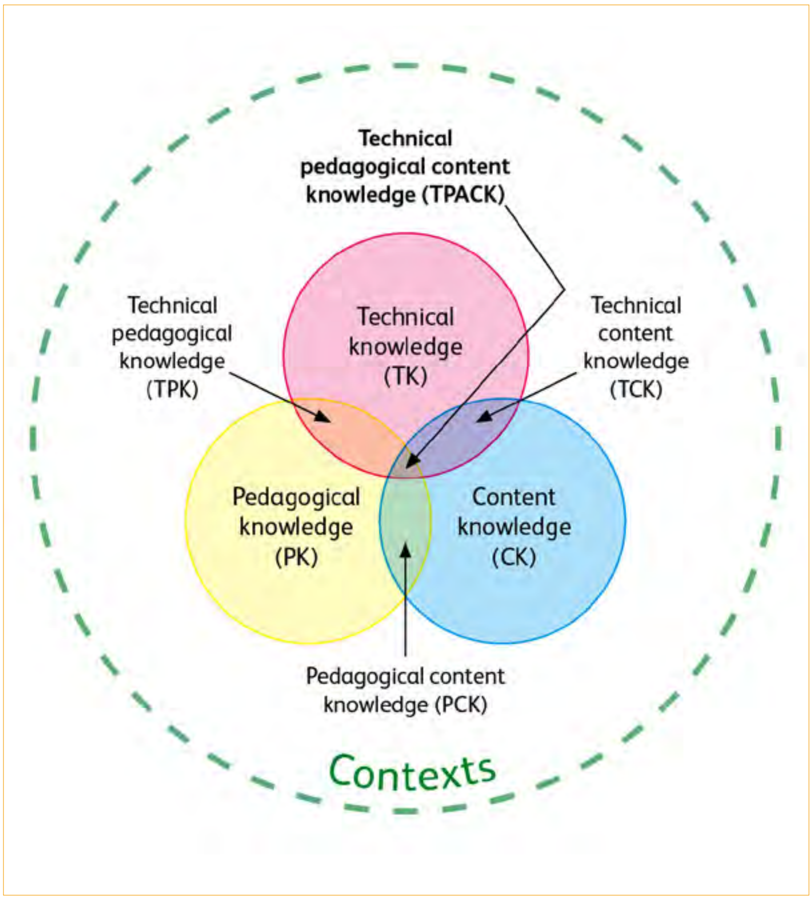

Figure 4: The TPACK framework and its knowledge components. This framework shows the challenges teachers face in order to develop the use of GIS in the geography classroom (Koehler and Mishra, 2009).

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 deficit). 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 four 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 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 was the cause of the loss 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.

Figure 5: Snippets from student work displaying level 2 spatial thinking skills after the first suite of GIS-based lessons.

Outcomes: developing spatial thinking skills

After conducting group interviews and a year group survey, the evidence was clear that, over the course of the academic year, in the two suites of lessons most students (92%) were confident that they had improved their spatial thinking skills through the use of GIS when measured against the competencies outlined in the framework proposed by Zwartjes et al. (2017). This can be seen in the work they produced. For example, as the student work in Figure 5 shows, the student is demonstrating level 2 skills of analysis and is critically evaluating the results by making links to human activities and the need for development in the area.

By the end of the second intervention, most students in the sample were demonstrating level 4 application skills. In the example below (Figure 6), it is quite clear that the student is aware where 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.

However, not all students had improved their spatial thinking, as they struggled to master the technology and some encountered difficulty when collecting data. Therefore, good task design is paramount if students are to apply their spatial thinking skills. Similarly, much preparation had to be done before each intervention to ensure our practitioner 'TPACK framework' was complete, such as creating resources, and ensuring that teacher knowledge was up-to-date. This meant that, once the task had been explained to students, the teacher could act more as a GIS assistant.

What could be done by the police to reduce the number of crimes in St Albans?

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 Ensure 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 [sic] they are less likely to commit a crime.

Figure 6: An example of student work displaying level 4 spatial thinking skills after the second suite of GIS-based lessons.

Conclusion

GIS is a powerful tool that can be used to develop students' spatial thinking skills, but care needs to be taken with task design so that students can develop level 4 application skills, according to the framework proposed by Zwartjes ***et al***. (2017). Students not only developed their spatial thinking skills through undertaking work using GIS, but they were better able to think geographically when reflecting on their own learning. Students demonstrated that they could make connections between ideas as well as ask geographical questions at a variety of scales using real world data, and this has benefited students in their wider geography education. Our next steps as a department are to further research how higher-order spatial thinking skills can be developed and measured, and to further integrate the use of GIS into our curriculum.

References

All websites last accessed 26/07/2021.

Bailey, D. (2018) 'Digimap for Schools – what is it and what can you do with it?', *Teaching Geography*, 43, 2, pp. 73–5.

Clark, C. D., Ely, J.C. and Doole, J. (2018) 'Glacial landforms: a teaching resource in maps and GIS', *Teaching Geography*, 43, 2, pp. 76–9.

DfE (2013) *National curriculum in England: geography programme of study – key stage 3*. London: DfE. Available at https:// assets.publishing.service.gov.uk/ government/uploads/system/uploads/attachment_data/file/239087/SECONDARY_national_curriculum_-_Geography.pdf

DfE (2014) *Geography: GCE AS and A Level subject content*. London: DfE. Available at https://assets.publishing.service.gov.uk/ government/uploads/system/uploads/attachment_data/file/388857/GCE_AS_and_A_level_subject_content_for_geography.pdf

Fargher, M. (2018) 'Using Geographic Information (GI)'. In Jones, M. J. and Lambert, D. (ed) *Debates in Geography Education* (pp. 197–210), 2nd ed, Oxford: Routledge.

Healy, G. and Walshe, N. (2019) 'Real-world geographers and GIS: relevance, inspiration and developing geographical knowledge', *Teaching Geography*, 44, 2, pp. 52–5.

Healy, G. and Walshe, N. (2020) 'Real-world geographers and geography students using GIS: relevance, everyday applications and the development of geographical knowledge', *International Research in Geographical and Environmental Education*, 29, 2, pp. 178–96.

Kerski, J.J. (2017) *A Working Definition of Spatial Thinking*. Available at https://community.esri.com/ community/education/ blog/2013/05/24/a-working-definition-of-spatial-thinking/

Koehler, M. and Mishra, P. (2009) 'What is technological pedagogical content knowledge (TPACK)?', *Contemporary Issues in Technology and Teacher Education*, 9, 1, pp. 60–70.

Sinton, D.S. and Bednarz, S.W. (2007) 'About the G in GIS', in Sinton, D.S. and Lund, J. (eds) *Understanding Place GIS and Mapping across the Curriculum*. Redlands, CA: ESRI Press. pp. 19–34.

Trafford, R. (2017) 'How to … integrate GIS effectively into the curriculum', *Teaching Geography*, 42, 3, pp. 106–7.

Walshe, N. (2016) 'Using ArcGIS Online story maps', *Teaching Geography*, 41, 3, pp. 115–7.

Walshe, N. (2017) 'Developing trainee teacher practice with geographical information systems (GIS)', *Journal of Geography in Higher Education*, 41, 4, pp. 608–28.

Zwartjes, L., de Lázaro, M.L., Donert, K., Sánchez, I.B., De Miguel González, R. and Wołoszy ska-Wi niewska, E. (2017) *Literature Review on Spatial Thinking*. Available at http://www.gilearner.ugent.be/wp-content/uploads/GI-Learner-SpatialThinkingReview-3.pdf

Online resources

To access the appendices to this article please go to www.geography.org.uk/ Journals/Teaching-Geography and select Autumn 2021.

Appendix

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