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GI-Pedagogy: Innovative Pedagogies for Teaching with Geoinformation

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INTELLECTUAL OUTPUT 1

An Innovative Pedagogical Model for Teaching with GIS

Elaborated by EUROGEO
www.eurogeography.eu

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Contributed to by all project partners

Keywords:
pedagogies, GIS, digital competences, teaching and learning, teacher training

Abstract:

This output consists of a review, analysis and evaluation of existing, prevailing teaching practices that incorporate GIS in schools and an exploration of evidence related to alternative, innovative, pedagogical approaches to teaching with GIS.

As a result of the review and analysis of findings, a series of recommendations are provided to inform the development of the teacher professional development course and toolkit of innovative pedagogical approaches to teaching with GIS and connect to the case studies of outcomes.

This project has been funded with support from the European Commission. This document reflects the views of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein

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1. The GI Pedagogy Project

GI-Pedagogy (2019-2022) is a school education project funded under the KA2 cooperation for innovation action of the Erasmus Plus programme (European Commission, 2019), that seeks to consolidate in a coherent concept, structure, and set of outputs, the following three major elements, considered key for integrating the use of GIS and spatial learning at a pan-European scale:

1) Theme: The project focuses directly on innovative pedagogy specifically applied to national curricula. It responds to the need to train teachers how to integrate innovative GI Science pedagogy into their lessons. It seeks to do this by developing essential teacher training resources. The project intends to transform existing available knowledge, materials, concepts, and ideas into real training of young teachers, with the further possibility for the professional development of existing teachers. To do this, GI-Pedagogy builds on previous innovative work and also incorporates the latest web-based tools and technologies.

2) Tools, Data, and Resources: GI-Pedagogy proposes to take advantage of the exciting and innovative world of open data and open science, thus offering easy access to sources for schools and connecting the school world with the real world (using official data and scientific results) and raising the pupils' awareness of citizenship and data issues. The project will take advantage of the growing number of easy to use web-based technologies becoming available online. GI-Pedagogy will use the innovative technologies made available through the European Commission Digital Skills and Jobs Coalition initiative (https://www.esri.com/en-us/school-program-europe/overview) and the pledge made by the leading GIS software company ESRI to support schools across Europe (Esri, 2016).

3) Geographic Focus and Previous Initiatives: Some material has already been produced to help teach GIS in schools; however, it has not been directed at initial teacher training, nor has it focused on new teachers, with European relevance. Additionally, the GI-Pedagogy project will build resources with a European focus and related to the Digital Skills and Jobs pledge. It builds on what has already been achieved by various European projects:

- the Herodot Thematic Network for Geography (2000-2009) brought GI and spatial thinking to the attention of many (Attard, 2010; Donert and. Charzyński, 2005). As a result of this project many other initiatives were taken, one of them leading to the iGuess project, coordinated in Flanders.
- The iGuess project (2007-2010) trained teachers in the use of GIS (Zwartjes, 2009), and in developing their own didactical materials using GIS. Although very successful (there are ongoing dissemination activities) the partners involved noticed that for many teachers the lack of curriculum guidance, including materials on GIScience, makes it difficult to fully integrate GIS in education.
- The digital-earth.eu network (2009-2013) focused on the development of a community of geomedia learners (Donert, 2013; Lindner-Fally and Zwartjes, 2012; De Miguel and Donert, 2014), but this only reached a specific group of teachers, educators, and those responsible for education.
- the GI-Learner project (2015-2018) created a spatial thinking competence model (Donert et al., 2016) and a learning line with ready-to-use lessons (Zwartjes and Lazaro y Torres, 2019) for secondary schools.
- the MYGEO project (2018-2021) aims at fostering the employability of students in higher education through promoting the acquisition of key skills related to the use of Geographic Information Systems (GIS) tools.

4) Educational Methods: If we want to bridge the chasm between the early adopters of GIS and the whole educational community, the only effective strategy is to explore and encourage innovative approaches

and furthermore to embed them in the process of initial teacher training. Promoting stronger coherence in the curricula using GIS is one of the stepping stones that will allow more pupils to obtain jobs in the growing geospatial industry, which has been expanding at more than 12% per annum over the past decade and forecasts even stronger growth in the years to come (GeoBuiz, 2018) such that education and training cannot keep pace with demand, leading to skills shortages and unfilled jobs.

The development of the GI-Pedagogy project was derived from: a) the results of the School on the Cloud - Connecting Education to the Cloud for Digital Citizenship network project, which explored how education should respond to Cloud Computing developments and how Cloud-based services can be used to improve the quality of education and transform learning and teaching in schools (Koutsopoulos and Papoutsis, 2016); and b) the GI-Learner project, which established a competence model and framework (Zwartjes, 2018). These projects also demonstrated that leadership for change is needed as described by Camburn et al. (2013), as the main issue today is no longer getting access to technology, but the capability to establish meaningful web-based learning and teaching approaches.

The GI-Pedagogy project aims to explore learning and teaching by developing training and resources for geography teachers. The highest-priority target group for the resources are those still in initial teacher training, Newly Qualified Teachers, and those in their first full year of teaching, who according to Christensen and Knezek (2017) are in the process of transitioning between educational environments - a critical stage for technology integration.

2. Introduction

Geographic Information Systems (GIS) are an innovative technology that uses Cloud Computing to deliver a wide variety of different IT services related to geospatial information, data, and even multimedia (Lu et al., 2019). The Cloud has become a ubiquitous tool enabling digital administrative and operational systems which can be established and used in real-time. The use of web-based applications on mobile devices is expanding, and includes services such as email, information storage, file sharing, collaborative tools, digital communication, and other services. Based on recently published guidance (Education Endowment Foundation, 2019), the question has shifted from whether or not technology has a place in the classroom to how technology can be integrated into the curriculum and especially into teacher training (Curtis, 2019; Hohnle et al., 2016) and ensure that those trained to teach pupils recognise the importance of web-based services in the wider world and in economic and social activities.

Technological advances have resulted in new paradigms and increasingly powerful tools for exploring spatial relationships, but much less attention has been directed at methods and strategies used to teach.

> *"the process of acquiring knowledge and skills within learning processes should not produce passive knowledge and isolated skills and abilities, but should instead result in applicable knowledge and integrated skills and abilities in a real-world context"* (Hartig and Klieme, 2007, p. 13).

Petras et al. (2015) describe the use of free and open source software, which has been considered a high priority (and often stated as mandatory by funding agencies), as it is fully transparent and more accessible for institutions, individual students and scientists. Open software, open data, open standards and open education are the key components of the open GIS framework. They suggest the application of geospatial concepts should be emphasized in education much more than software-specific tasks. If teachers understand not only the implementation, but also the underlying science and technology, then they will be able to develop better and more flexible learning solutions.

Web-based GIS is a very practical, active, and relevant way of including digital technology in school education and teacher training (Hong and Stonier 2015), however as technology advances it makes decisions about when and how to do this increasingly harder. Previous European geotechnology education projects had demonstrated that the most challenging period for technology integration is getting teachers to recognise the value of the tools so they are prepared to address the classroom issues. It has been shown that training is critical (Zwartjes and Lazaro y Torres, 2019) so that teachers are able to develop basic skills and competencies in GIS and a sound framework for involving technology use in their classrooms and with pupils. Mathews and Wikle (2019) deal with teaching about GIS technology and its applications in higher education.

The European Commission acknowledges that Europe must become much more "Cloud active" to stay competitive in the global economy, and has tackled major barriers surrounding legal issues, data security and copyright. School learner expectations are also changing. Learners require ready access to relevant online tools and content, as well as secure, reliable networks which can offer the ability to create and share content on any number of devices. Applied computer systems like Web-based GIS provide a quick, reliable, 24/7 service, which conforms to this new and different service model (De Miguel González and De Lázaro Torres, 2020).

The adoption of GIS in school education remains fragmented (Jackson and Kibetu, 2019) because while Cloud Computing offers many advantages, teachers are largely unaware of the great needs of the industry and the potential benefits for learning and teaching. Improved training and enhanced support systems /

pedagogical tools are needed to help new teachers integrate the rapidly evolving Cloud Computing GIS environment into the classroom (Mitchell et al., 2018). Innovative pedagogical change is needed in teacher education, otherwise educators will continue the paradox of using old teaching methods but with new tools.

Little research has been undertaken demonstrating the integration of GIS and geospatial applications into the school curriculum. Roosaare and Liiber (2013) introduced a model of how to nationally integrate geo-media and GIS into general secondary school education, where geoinformatics was developed as an elective course for pupils at secondary school level in Estonia. This course has been used as an opportunity to apply the use of geo-media tools, emphasize ICT skills and students' geospatial thinking skills.

Baker et al. (2015) comment that research in GIS education seems to have had limited impact. It has largely focused on the educational and technical challenges that have affected its implementation in formal and informal learning environments. Bednarz (2004) suggests this has by and large related to computer speed and capacity; software use and complexity; shortages of resources and lessons, links to curriculum and standards; administrative and technical support; and time required to implement GIS-based methods.

Rickles, Ellul and Hacklay (2017) focus on the results of a survey on resources and platforms used in the interdisciplinary teaching of GIS and then exploring possible constructivist learning theories. They proposed a framework to act as the education-based structure for which GIS concepts can focus on and define interdisciplinarity as "between disciplines", suggesting the basic elements of at least two collaborators, at least two disciplines, and a commitment to work together in some fashion in some domain are necessary. However, the introduction of technology into curriculum is further complicated by speed of change, variety and diversity of contexts. According to Stringer et al. (2019), integrating technology into the classroom to improve learning requires addressing both pedagogy and implementation.

3. Digital competences

In teacher education, professional competences depend on subject-specific knowledge and skills in specific pedagogical domains. The competences serve as a basis for the implementation of an educational approach to the practice of teaching and learning and according to Schultz et al. (2012) relates strongly to curriculum development.

Digital competences are a key transversal competence, that citizens increasingly need to acquire. They are considered to be a necessity to achieving a degree of literacy suited to present-day society's needs. DigiComp is the European Commission framework designed to support an understanding of digital competence. It includes issues such as information storage, digital identity, developing digital content and behaviour online, in everyday life such as working, shopping and participating in society. Kluzer et al. (2018) provide a user guide with a broad range of examples from those who use the DigComp framework.

A DigCompEdu Framework has been developed to support the teaching profession in all sectors of education. It implies being able to use digital technologies in a critical, collaborative and creative way. DIgiCompEdu concerns the use and transmission of educator-specific digital competences for use in school and the classroom (Rubio et al., 2019). DigiCompEdu proposes 22 elementary competences organised in 6 areas (Figure 1). Area 1 is concerned with the use of digital technologies in professional interactions. Area 2 looks at the competences needed to effectively and responsibly use, create and share digital resources for learning. Area 3 is dedicated to managing and orchestrating the use of digital technologies in teaching and learning. Area 4 addresses the use of digital strategies to enhance assessment. Area 5 focuses on the potential of digital technologies for learner-centred strategies and Area 6 details the specific pedagogic competences required to facilitate students' digital competences.

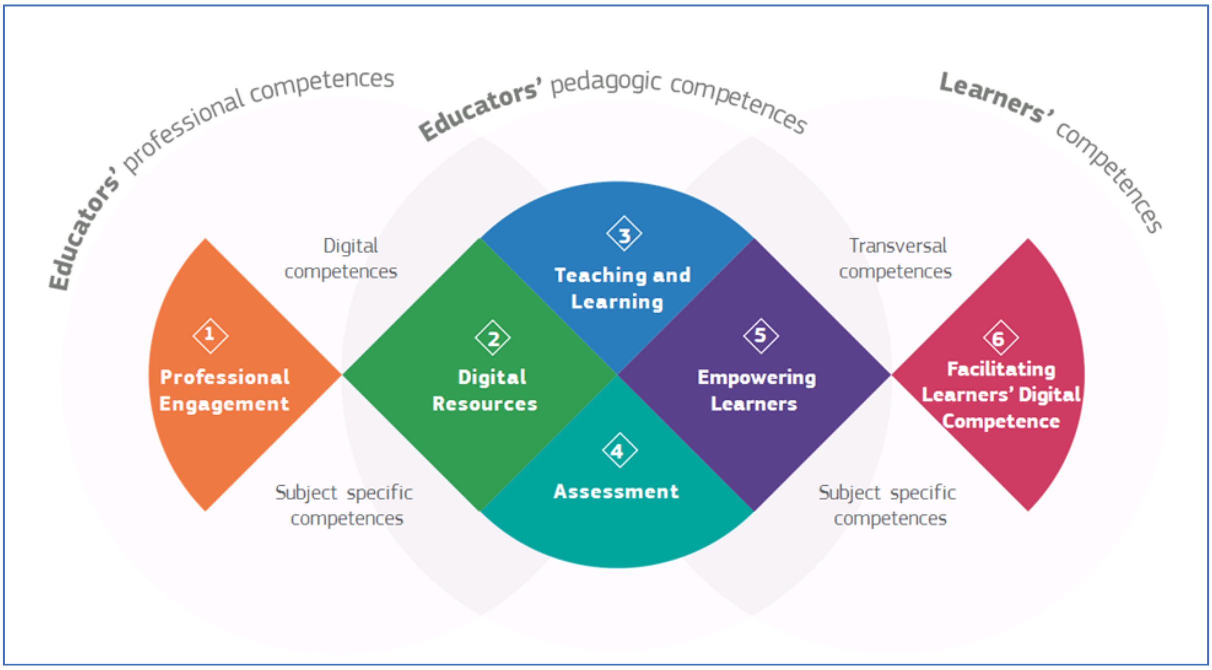

Figure 1: The European DigiCompEdu framework for teachers (Vuorikari et al, 2017)

The Framework outlines six different stages through which an educator's digital competence typically develops, so as to help educators identify and decide on the specific steps to take to boost their competence at the stage they are. In the highest stages, called 'Leader' and 'Pioneer', the teachers are able to pass on their knowledge, critique existing practice and develop their own new practices.

Schultz et al. (2013) comment on three core competences foundational to working with GIS: GIS-related knowledge and skills, spatial thinking, and problem-solving skills" (Schultz et al., 2013). Jakab et al. (2016) described how the strong cross-disciplinary character of GIS requires the application of wide range of key competences that help teachers shape and develop their professional identity. Bearman et al. (2016) noted how much training tends to be based on developing GIS skills, rather than on spatial problems, or understanding the usefulness of data, or the needs of the learners. As a result of this focus on the technology, courses attract teachers who are more technologically able and digitally literate than those who are not. This related to technical competences rather than critical spatial thinking.

As part of the GI-Learner Project, Donert et al. (2016) proposed a set of spatial thinking competences for pupils based on spatial thinking, where spatial thinking is a distinct form of thinking, which helps people to visualize relationships between and among spatial phenomena (Stoltman and De Chano, 2003), these were described as to:

1. Critically read and interpret cartographic and other visualizations in different media
2. Be aware of geographic information and its representation through GI and GIS
3. Visually communicate geographic information
4. Describe and use examples of GI applications in daily life and in society
5. Use (freely available) GI interfaces
6. Carry out own (primary) data capture
7. Be able to identify and evaluate (secondary) data
8. Examine inter-relationships
9. Synthesise meaning from analysis
10. Reflect, and act on the basis of knowledge.

They have been used to create learning progression objectives that teachers would translate into learning objectives, teaching and learning materials for the whole curriculum (K7 to K12) thus increasing spatial thinking education activities for high school pupils (Zwartjes, 2018).

4. Teaching with GIS

Donert et al. (2016) define and describe Teaching with GIS as a complex context of geospatial thinking and geospatial learning, exploring the integration of spatial literacy, spatial thinking and GIScience into schools as an outcome proposed in the KA2 Erasmus Plus GI-Learner project. Roosaare and Liiber (2013) suggest there is considerable diversity in understanding with regard to what, when and how to teach with GIS in geography education.

According to Favier and van der Schee (2014), it is not the technology itself that produces learning, but the complex whole of clear and appropriate learning goals, solid educational technologies, well-designed tasks, and high-quality instruction, coaching, and reflection provided by the teacher.

Kerski et al (2013) analyse the status of GIS in schools in thirty-three countries and proposes recommendations for advancing the implementation and effectiveness of GIS in secondary education. Their study revealed that use of GIS in secondary education remained small; however they suggest the convergence of citizen science, an emphasis on spatial thinking, mobile devices, open data, and Web-based map services could cause a significant increase in the numbers of schools, educators, and students teaching and learning with GIS. Despite hardware and software challenges repeatedly mentioned by educators, societal issues appear to cast the greatest constraint on GIS becoming an embedded, required tool throughout education. Of major importance seemed to be the lack of awareness of spatial thinking and analysis and their importance in education and society.

Favier (2013) presents a schematic view of 5 ways to deal with geoinformation technology (Figure 2). Teaching and learning about GIS focuses more on the theoretical aspects of GIS (knowledge of GIS, structure of the technology), whereas the other ways use the technology to develop and use spatial thinking skills. He suggests geography educators have predominantly focused on using geoinformation technology to learn subject knowledge and domain-specific skills, rather than focusing on learning to use the software. However, if geo-information technology is applied in lessons in which students sit behind the computer and are actively involved with the technology, you cannot avoid teaching them first about the characteristics of digital geoinformation and how the technology works. He suggests it therefore makes sense to start by using web-based GIS and virtual globes lessons, followed by lessons with desktop GIS, and finally apply GIS in small practical assignments. This would be a nice elaboration for a learning track for (geography) education with geo-information technology.

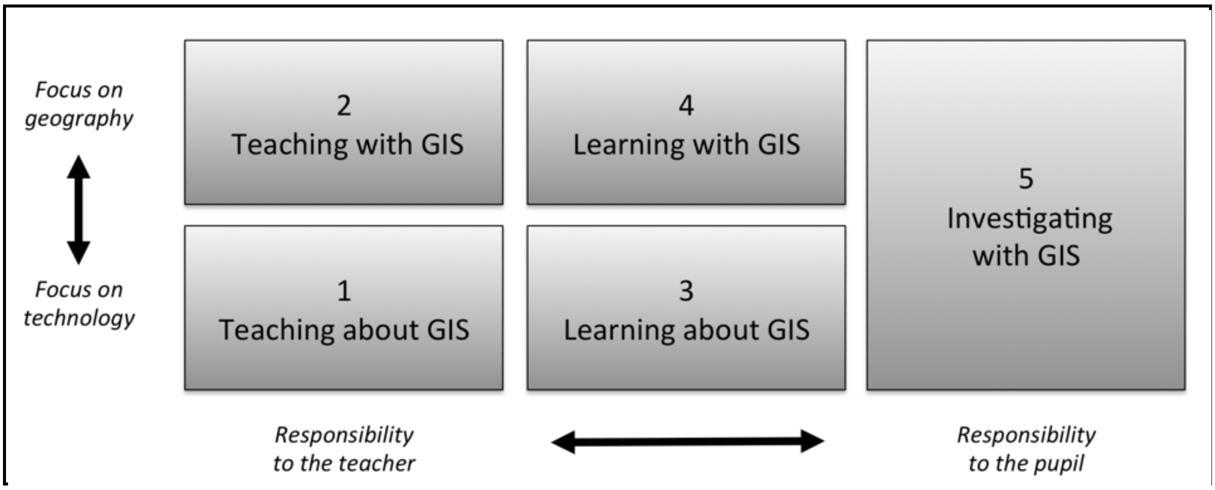

Figure 2: Five ways of integrating GIS in geography education (Favier, 2013)

4.1 Instructional Technology

Instructional technology, often used interchangeably with the term educational technology, is a specific technology field that deals with creating resources to support learning (Caldwell, 2019). Colvin and Tomayko (2015) suggest teachers today need to master instructional technology to prepare learners for a high-tech and increasingly interdependent world where professional tools are integrated into the classroom.

Stringer et al. (2019) considered how technology can improve teaching and learning, through a 4-stage implementation progress process (Figure 3) summarising how implementation of technology in learning and teaching can be described as a series of stages relating to thinking about, preparing for, delivering, and then sustaining change. Considering the impact to consider whether it can supplement, enhance or replace existing teaching.

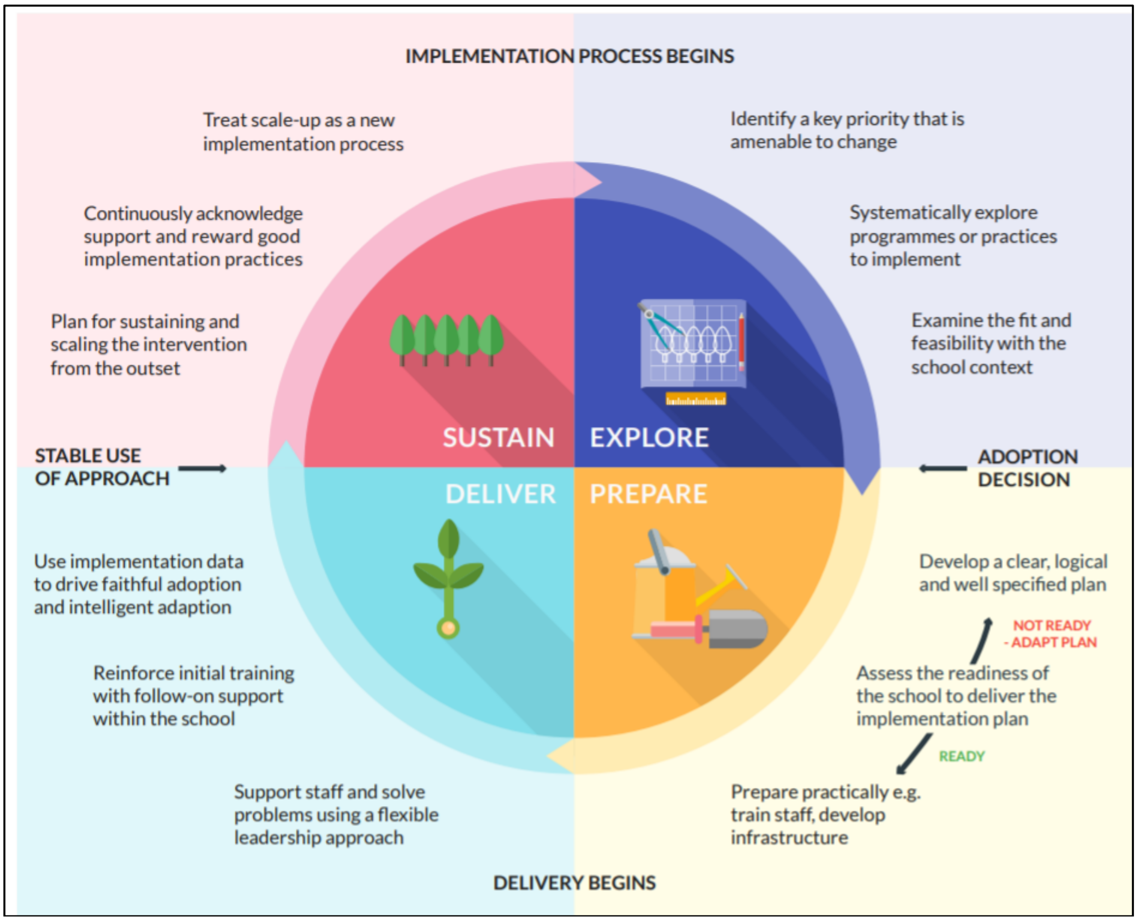

Figure 3: The Implementation Progress Process

Recent research by Mayer (2019) looked at the potential of multimedia instruction to improve learning in the classroom, where research evidence shows that people learn more when images are added to text as they work together to present an instructional message which leads to a deeper understanding, than words on their own, whether it is presented in a book or on a computer. The use of pictures can include static photos, charts, graphics and illustrations or dynamic videos and animations, and words can be either spoken or printed. According to Mayer, this cognitive theory is based on 3 key ideas from cognitive science, the dual-channel principle where verbal and pictorial information processing is separate (Baddeley, 1992), the limited capacity principle: which means only a few items can be processed at a time (ibid) and the active processing principle: which means that meaningful learning needs to be coherently organised and integrated with prior knowledge, so that relevant words and images can be selected from the working memory, to guide the learner's cognitive processing. (Mayer 2009)

Mayer (2019) proposes that in multimedia instruction, the working memory mentally organises the words into a verbal model and the images into a pictorial model, which combine with prior knowledge, making sure working memory does not become overloaded.

A set of 11 evidence-based principles for multimedia design are presented that increase student learning (Table 1).

Table 1: Design for multimedia instruction

Extraneous processing – cognitive processing that does not support instructional goals – i.e. unnecessary
- Coherence – keep instructional message simple, avoid unnecessary detail
- Signalling – highlight essential material
- Spatial continuity – integrate text with relevant part of graphics
- Temporal continuity – present spoken word simultaneously as graphics, drawing or animations
- Redundancy – do not duplicate narrated graphics with printed text as well.

Manage essential processing
- Segmenting – break down learning into parts
- Pretraining – teach an overview of key elements and words before introducing the diagram details
- Modality – spoken word supports more learning than if the words are printed

Encourage generative processing
- Personalisation – using informal conversation to present information
- Voice – using a human sounding voice rather than a machine
- Embodiment – include human like gestures on the screen

Alibrandi and Palmer-Moloney (2001) confirmed that as a technology, GIS offers new ways of viewing, representing and analysing information for transformative learning and teaching, however its use means stepping into the unknown, taking risks, creating pathways and experimenting. Baker (2005) noted the emergence of GIS as an instructional technology for supporting contextually rich student learning in the K12 curriculum. Fagin and Wikle (2011) commented that teachers using GIS befitted from significant advances in instructional technology.

4.2 e-learning, fieldwork and mobile GIS

E-learning is a set of models, technologies and processes for the acquisition and use of knowledge through the use of information and computer technologies. It has predominantly been used for teaching with GIS by incorporating a number of geospatial tools and techniques. In their paper Karolčík et al. (2019) analyse an e-learning environment for Geography in order to implement personalized active learning in Geography teaching and learning. The requirements of an adaptive tool for Geography teaching and learning are discussed and a theoretical framework for personalized e-learning environment is proposed. ICT can be used as a research tool to help students apprehend notions and analyse information. This allows a series of questions such as: where? what? and organizational aspects such as why? how? and relationships to take place. The challenge of a didactic process is to organize and support students' questions. Thus, according to Zwartjes et al. (2015) there is a need to model the processing of information in an educational context in 4 steps, the problem, data research, building an argument and producing results and .

Bearman et al. (2016) suggest the presence of an e-learning environment is important because it helps students to be able to access and make sense of (geo)information. They suggest GIS has been held back because of an emphasis on the technology rather than the spatial data highlighting the focus on IT skills rather than spatial literacy. As a result, students will not be taught the skills they need to be able to critically interpret maps and data. They also consider that practical technical sessions dominated in GIS curricula. In pedagogical terms, the student was often given a data-set and given instructions on how to use the GIS to process the data to get the final analysis output. This approach develops the student's ability to use the software in question, but it did not add much to their knowledge about the types of question that a GIS can answer. GIS analysis and GIS output were much easier to use than completing the whole problem-solving process.

Roosaare and Liiber (2013) report on the development of a web-based (Moodle) elective course opens the door for flexible and individualized teaching/learning solutions. The authors also report on the lessons learned from the Geo-Olympiad where, since 2005, computer-based exercises and GIS have been included in the written tasks for secondary schools. Students have to find, interpret and analyse some geographical information from Internet portals and problem-solve real life problems.

According to Feddern et al. (2018) learning software has been developed to support independent learning, based on techniques of retrieval, interleaving, spacing and visual cues, which they tested as randomised control trial with school pupils. Their independent learning platform was capable of being used with a variety of content yet not needing much staff training. The modules which introduce material or test students are short, and use an algorithm to interleave and space learning using a mixture of text, images and different types of questions, which are designed to promote retrieval practice.

Grunwald et al. (2005) report on the construction of a virtual modular learning environment based on the concept of Reusable Learning Objects in order to evaluate the efficacy of different e-learning tools for on-campus (OC) and distance education (DE) students in context of learning outcomes. They concluded that a virtual GIS course has the potential to generate equal learning outcomes comparable to on-campus GIS courses provided students are self-motivated to study the course material and capable of managing their time appropriately/effectively.

Belgiu et al. (2015) evaluate open education initiatives in the geospatial domain and the MOOC movement. The article focuses on Web-based technologies, fostering online courses and programs. Open Educational Resources (OER) have become the norm as OER imply legally open content licensing under a Creative Commons (CC) license. The use of MOOCs (Massive Open Online Courses) have become a popular open education model for higher education.

Caeiro et al (2011) evaluated the effectiveness of the use of videos in the students learning outcomes in a GIS e-learning course. The higher education students were guided by a curricular unit plan, digital resources, formative activities and a continuous assessment. The videos effectiveness was assessed by analysing students written assignments (e-folios). Their research confirmed that videos have the potential to be used as an important tool in GIS-education in an e-learning system, as they are a visual medium with the potential to support learning in different ways than other technologies do, including the potential for demonstrations and through the use of screen-capture technology.

Michel and Hof (2013) were concerned with taking e-learning and GIS into the field. They explore the use of mobile and spatially-enabled devices in the field and the combination of adventure and media pedagogy with multimedia environmental education. They consider how learning resources and outdoor activities are combined to get original nature experiences with its varied spatial and temporal dimensions. The authors provide the conceptualization of a game-based approach called the eGeo-Riddle (Figure 4).

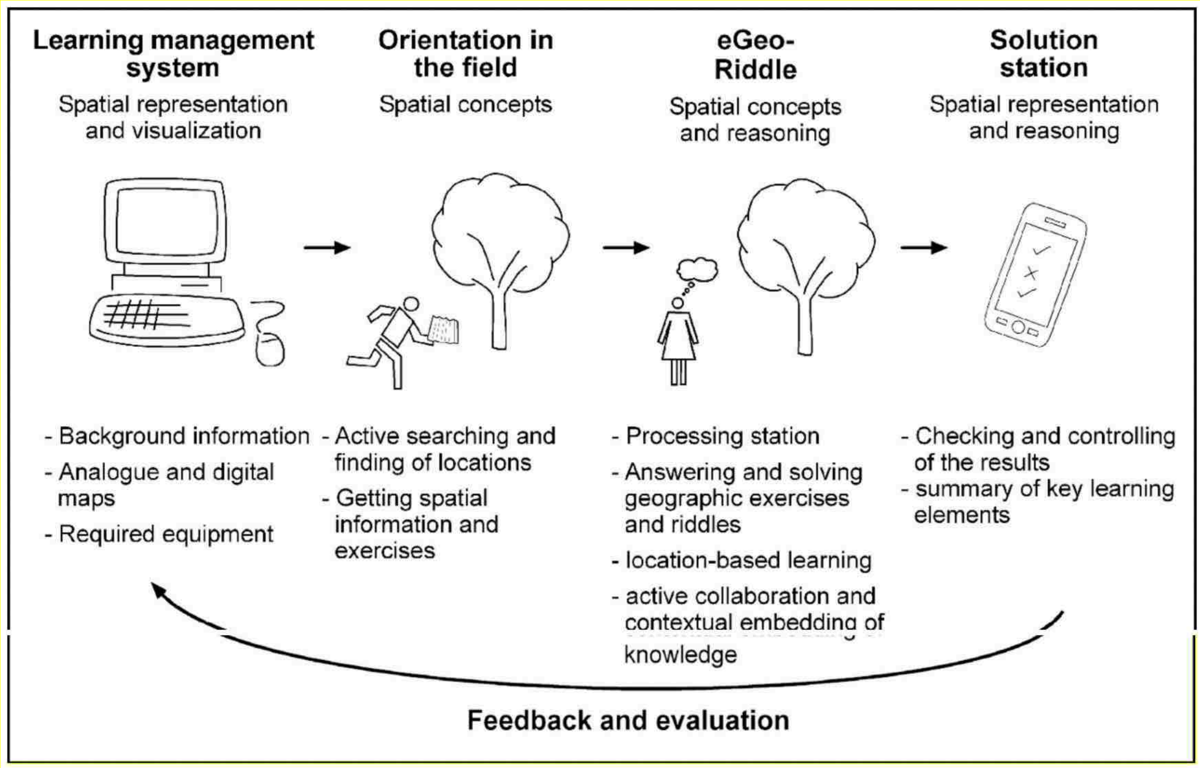

Figure 4: The eGeo Riddle approach

The mobile field trip was based on three learning units, a multimedia introduction with background information for knowledge transfer; the eGeo-Riddle with interactive exercises and riddles in the field; and the solution and evaluation station for post processing and knowledge consolidation. Within this framework, the field trip promotes spatial reasoning and interpretation, which invites students to detect and map different types and structures in an interactive map. But more importantly the students, by going outside, will make their own observations and collect samples, and are consequently practically and theoretically trained in thinking with and about space as well as acquiring a tangible imagination of spatial characteristics and differences.

Fieldwork is an integral part of education in disciplines with a strong spatial component. Kolvoord et al., (2019) say that the increasing importance of data and geospatial technologies supports education initiatives that teach GIS hands-on and applying it to local problems. GIS is therefore valuable for education since it can help students to identify and analyse spatial patterns. De Lázaro y Torres et al. (2016) suggested that outdoor learning in geography, using mobile devices and associated spatial thinking will serve students well for employment.

Pánek and Glass (2018) applied mobile GIS methods in fieldwork situations where students' work included the accumulation and evaluation of different types of data to construct a sense of the place they were studying. They suggested students needed to learn how to engage with a neighbourhood in ways to make meaning of the different layers of history of the research site. Lambrinos and Asiklari (2014) created a fieldtrip treasure hunt using a compass, GPS and GIS generated maps wit young pupils from the age of 10. They suggest that technology applications, like GIS and GPS, can be easier implemented through interdisciplinary subjects.

Brooks (2018) describes the processes and decisions made in the development of a mobile learning application. The intended users of this application were adult learners who want to learn about GIS concepts and skills. He suggests an active pedagogy should involve "kinaesthetic activities, the conscious analysis of spatial data, and reflection on learning". Building active learning into the curriculum can bring many benefits, including the claim that students learn more through the metacognition provided through active learning and that students learn more over traditional lecturing methods. The application described in this thesis essentially utilizes map mashups where students can interact with layers, features, attributes, analysis tools, and other GIS&T functions to learn the lesson concept. Incorporating these mashups as core components of the lessons and avoiding highly structured exercises, allows greater flexibility and personalization of content, which is one of the major advantages of map mashups.

Michel and Hof (2013) warn however, that in spite of the importance of location-based learning and the requirement of students for more practical examples, the quantity of days for field visits and practical fieldwork are being reduced. To tackle this several e-learning courses on the internet as well as a wide range of GPS-based learning and adventure opportunities have been established in recent years.

4.3 Web-based GIS

The internet is becoming more and more important for the provision, transfer and analysis of geodata. As a result, GIS features are being integrated and implemented in web-based information systems. These are Web-based geographic information systems or Web-based GIS. The enormous increase in the number of web-based applications that use techniques derived from geographic information systems (GIS) is based on the demand for the visualisation of geographic data on the Web.

In order to examine the potential associated with the use of web-based GIS in geography classes, Arslan (2015) analyses the usability and student learning outcomes of using desktop and Web-based GIS software with schools (Figure 5).

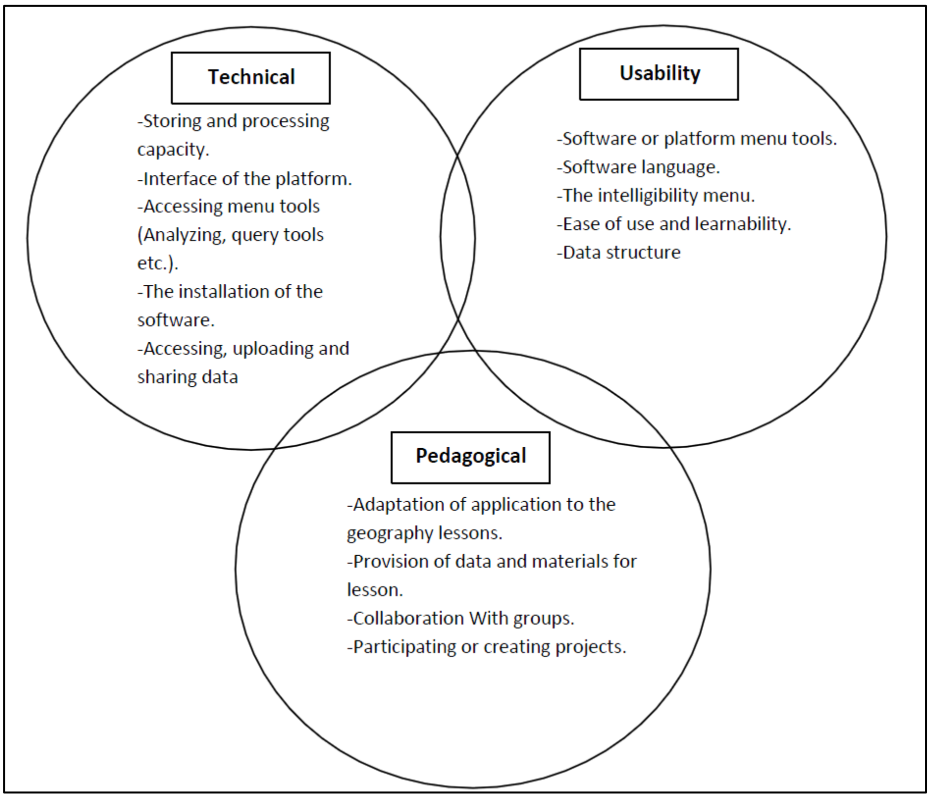

Figure 5: Criteria used to analyse Web-based GIS platforms (Arslan, 2015)

Web-based GIS, primarily, was seen to have a positive impact on student achievement. The real potential of web-based GIS for geography courses can be understood better when considering other benefits that web-based platform provided for students, course and teachers. The course was student-centered, there was evidence of many skills being developed, such as spatial analysis, spatial thinking, finding cause-effect relation, querying and creating questions. Web-based GIS was an effective teaching tool, easily used by teachers in their courses without technical issues. Students considered it to be an effective learning tool, help them to grasp ideas easily.

Milson and Earle (2008) explored the use of Internet-based GIS as a tool for integrating geospatial technologies in ninth-grade geography curriculum and instruction within an inductive learning environment. The study findings indicated that students were able to access and make use of geospatial data to construct their understanding of geography.

Kerski and Baker (2019) suggest that using a Web-based GIS system implies a change in how GIS are perceived and taught. Fargher (2018) argues that by drawing on a GeoCapabilities approach the teacher's use of WebGIS can be enhanced in deepening their students' abilities to think and reason with geographical knowledge and ideas. Fundamental to GeoCapabilities thinking is an emphasis on a progressive, subject-led approach to teaching school geography particularly through the development of powerful disciplinary knowledge (PDK), school subject knowledge can only be powerful when it enables young people to think in ways beyond their direct experience (Figure 6).

Type		Characteristic
1.	Knowledge that provides students with 'new ways of thinking about the world.'	Using 'big ideas' such as: • Place • Space • Environment • Interconnection These are meta-concepts that are distinguished from substantive concepts, like 'city' or 'climate'.
2.	Knowledge that provides students with powerful ways of analysing, explaining and understanding.	Using ideas to: • Analyse e.g., place; spatial distribution • Explain e.g., hierarchy; agglomeration • Generalise e.g., models (push-pull models of migration; demographic transition)
3.	Knowledge that gives students some power over their own knowledge.	To do this, students need to know something about the ways knowledge has been, and continues to be developed and tested in the discipline. This is about having an answer to the question: 'how do you know?' This is an underdeveloped area of geographical education, but is a crucial aspect of 'epistemic quality' (Hudson, 2016).
4.	Knowledge that enables young people to follow and participate in debates on significant local, national and global issues.	School geography has a good record in teaching this knowledge, partly because it combines the natural and social sciences, and the humanities. It also examines significant 'nexus' issues such as: food, water and energy security; climate change; development.
5.	Knowledge of the World	This takes students beyond their own experience—the world's diversity of environments, cultures societies and economies. In a sense, this knowledge is closest to how geography is perceived in the popular imagination. It contributes strongly to a student's 'general knowledge'.

Figure 6: A typology of Geography's powerful knowledge

GeoCapabilities adopts an approach underpinned by the belief that knowledge development in schools should be led by subject specialists who are best placed to provide young people with the highest quality geography education.

4.4 GeoMentoring

In the USA, the GeoMentor programme (http://www.geomentors.net), established by Esri and the American Association of Geographers, brings together people (experts) who are willing to help with the deployment of GIS into teaching. (DeMers, 2016) suggests professional GIS mentoring of educators rapidly improves the likelihood that GIS will reach the elementary and secondary teachers.

Healey et al. (2018) report on a programme to support teachers in introducing Web-based GIS in schools in the UK. To help the effective use of ArcGIS Online in classrooms, a dedicated educational team – including a former classroom teacher — and 300 professional GIS users registered as volunteer GeoMentors. These industry experts give their time to schools to support their use of GIS. They help teachers get familiar with the ArcGIS Online platform, create new resources in collaboration with staff, and inspire students to pursue their own careers in GIS by talking about their experiences. Healey and Walshe (2019) focus on how learning from real-world geographers including industry experts both from local contexts and from the GeoMentors network set up by Esri UK about the GIS they use in their everyday jobs can engage students.

Healey and Walshe (2020) explore the use of GIS in UK schools in the context of school and university crossover. The authors are particularly interested in the connection with curriculum thinking. They report a reluctance amongst teachers to engage with GIS, and explored the use of real-world experts to influence student perceptions of the relevance of GIS and real-world applications which then influences subsequent acquisition of student knowledge. A longitudinal study explores the UK GeoMentors scheme of ESRI/RGS-IBG which focuses on how tapping into the expertise of real-world, industry experts and the ways it can affect students' perceptions of the relevance of GIS to geography and support their acquisition of geographical knowledge. Their results suggest that engagement with industry experts increases students' understanding of what GIS is, allowing them to develop a more nuanced appreciation of its real-world applications; this then appears to play both a direct and indirect role in the subsequent development of students' geographical knowledge.

4.5 Personalised learning

As education is currently undergoing significant change brought about by emerging reform in pedagogy and technology, efforts have sought to close the gap between technologies as educational additive to effective integration as a means to promote and cultivate student centred, inquiry based and project-based learning.

GIS has become strongly personalised as location-aware services, personalised user interfaces and accessible mobile communication have evolved. Personalised GIS development has been reported in many diverse fields for instance in tourism (Poslad et al., 2001), community mapping (Ardissono et al, 2017), heritage information (Mac Aoidh et al., 2006), education (de Lázaro et al., 2017) and 3D navigation (Doulamis et al., 2013). In education, personalisation in GIS looks to integrate students in their environment and enhance their understanding.

Although there are differences in defining personalized learning, all definitions and research agrees on these principles:

- Personalized learning starts with the learner and the learner is in the centre
- The learner is active in designing their learning goals and processes
- The learner decides how to access and acquire information,
- The learner owns and takes responsibility of learning, thus more motivated and engaged in the learning process,
- The learner owns the capacity for critical monitoring of learning outcomes
- High quality teaching responsive to the different ways students achieve their best
- Creating an education path that takes account of learner's needs, interests and aspirations

- Making a strong contribution to equity and social justice (Zwartjes et al., 2015).

Personalised learning describes situations where learning was customised for the preferences and abilities of individual learners or groups of learners. It shifts the role of students from being simply a consumer of education to a co-producer and creator of their own learning pathway actively engages students in the process of learning (Bartle, 2015). From the teachers' perspective, is said to be a three-part process, which includes planning that promotes deeper student learning; understanding of each student's learning needs and interests; and provisioning of appropriate learning experiences that match each student's unique learning profile.

Personalised digital learning environments are usually Web-based systems and often utilise mobile devices offering a unique and personal platform for developing learner-centred educational experiences that to enhance students' learning engagement via personalised information and services (Masseleno et al., 2018). Personalised learning environments place the student into a more central and active role in their own learning, where learners can access relevant and contextual information based on their different tasks and needs. Learners can learn from the materials provided by learning systems based on their own learning pace and preference. This encourages learners' empowerment towards their own learning process and progress.

The Personalised Learning Environment concept places the focus on the appropriation of different tools and resources by the learner, whereby the learner is situated within a social context which influences the way in which they use media, participate in activities and engage in communities. The perspective is the basic theorem of the Activity Theory (Engeström 2001). The activity triangle model representing an activity system combines the various components into a unified whole. From this perspective, focusing on the three aspects – personal ('subject'), learning ('tools) and environment ('object') – means disregarding the so-called 'social basis' of the activity system (rules, community and division of labour) which situates human activities in a broader context. (Zwartjes et al,. 2015).

In the case of GIS, personalisation can lead to activities that combine authentic, contextualised, local situations and use location-based services. Zwartjes et a.l (ibid) describe the elements of a pedagogical approach for personalized education (Figure 7) and relate it to using geospatial technologies and ICT for landscape education (de Lázaro y Torres et al., 2017). They underline the importance of pedagogical methods to encourage individual guided learning at a distance, where students take their own decisions and are responsible for their learning in accordance with their interests and skills. In this context, the article underlines that the tole of the teacher is even more important than ever as they help customise the learning design of their students. However, Prain et al (2013) present a strong critique of personalised learning as it depends on both effective teacher differentiation of a set curriculum to address diversity of learner needs, and the development of independent learner capacities.

Karolčík et al. (2019) discuss the development of an e-learning environment for Geography, based on the personalization of the content and the student activities as well. They envisage personalised learning as tailoring education to meet different student needs, such as differences in knowledge levels, skills, ages and so on. Active learning should be encouraged in which the student participates or interacts with the learning process. In the future, according to Nikolov et al., (2016), it is likely that many of the advances in education will be brought about by further integration of personalised learning into smart learning environments.

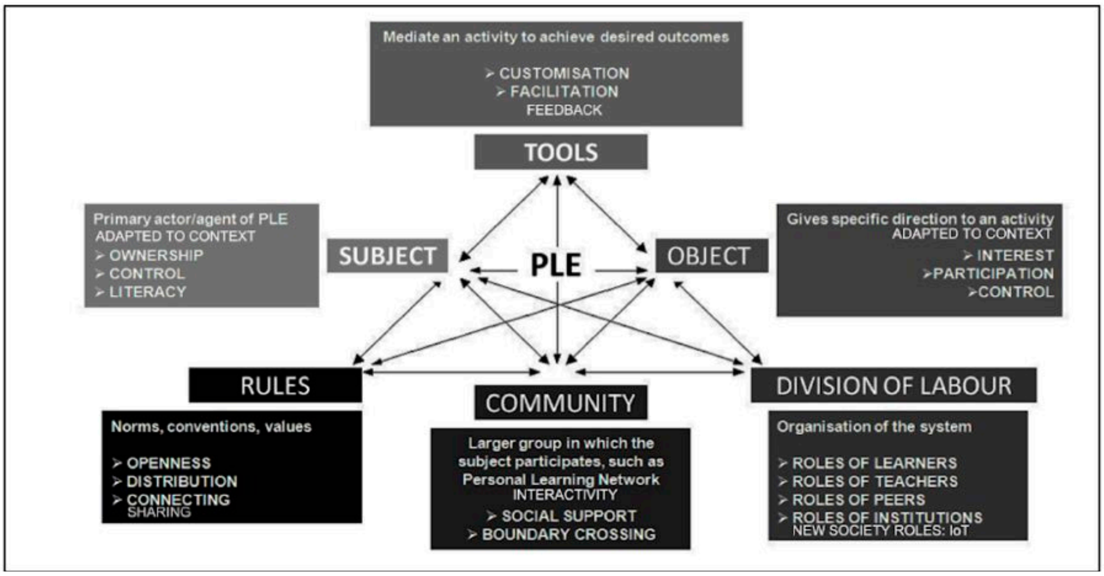

Figure 7: Elements of a personalised learning system

4.6 Rosenshine and effective instruction

Rosenshine (2012) developed ten principles of Instruction (Table 2) derived from research-based evidence from cognitive science and how brain acquires and uses information, classroom practice of expert teachers and cognitive instructional methods to help learn complex tasks. He recommends that experiential activities should always be used after the basic knowledge is learned.

Table 2: Rosenshine's Ten Principles of Instruction

1. **Daily Review** – of facts + skills to strengthen connections between the material learnt so recall becomes automatic, but takes lots of practice (5-8 mins). Can include marking homework, identifying difficulties + errors made, as well as anything else needing 'overlearning'.
2. **Use small steps to present new material** –guide students to practice recalling ideas learnt using strategies and modelling by 'thinking out loud'.
3. **Ask questions –** see how well material is learnt by getting students to explain processes and how they found answers.
4. **Provide models and worked examples** – using step-by -step instructions prompting who, where, why and how to develop questions.
5. **Guide student practice -** processing information by rephrasing, elaborating and summarising small amounts of material, making sure all students explain ideas and asking questions, give and receive feedback, to help develop understanding as well as transfer ideas to long term memory.
6. **Check student understanding** – frequent checking helps to increase connections made to previous learning.
7. **High success rate** – for optimal achievement, instruction and practice activities need an 80% success rate for all students both for oral responses as well as individual work.
8. **Provide scaffolds for difficult tasks** – provide temporary support which is gradually removed to allow 'novice learners' to observe 'expert thinking', students are helped through coaching to become more independent.
9. **Independent practice -** lots of practice (overlearning) takes place in order to become 'fluent and automatic in a skill', students start to work independently but with support on hand from both teachers and peers.
10. **Weekly and monthly review** –used to develop well-connected networks of ideas (schema) to free up space in the working memory as students build up patterns by 'utilization' or 'chunking' which improves their 'cognitive processing' capacity to review material learnt in the long-term memory.

Sherrington (2019) proposed grouping Rosenshine's principles into 4 strands that combine connected principles that can be ordered into a workflow of a lesson. These were sequencing concepts and modelling (presenting new material in steps, providing models and scaffolding), questioning (asking and checking understanding), reviewing material (daily, weekly and monthly) and stages of practice (guided and independent practice, obtaining high success rates). He suggests Rosenshine's Principles of Instruction provide clear guidance for teachers based on asking questions, practicing and sequencing concepts, as well as a useful reflection tool to weigh up how well this is being done.

5. Approaches to teaching with GIS

The approaches to teaching and learning are defined as the strategies that teachers adopt for their teaching practice. A student-centred approach is usually considered to be necessary for the successful integration of education technology in teaching and learning (Somekh, 2008; De Miguel, 2016). The following are examples of approaches developed in teaching with GIS.

5.1 Spatial thinking

In recent years, spatial thinking has attracted the attention of many researchers, dealing with the components of spatial thinking (Figure 8) and the skills and abilities of critical spatial thinkers (De Miguel, 2016).

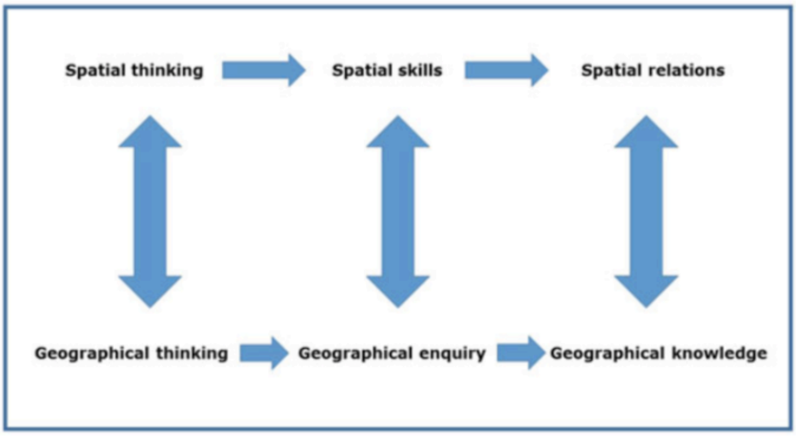

Figure 8. Spatial and geographical thinking sequence for teaching and learning with GIS (De Miguel, 2016)

Michel and Hof (2013) say spatial thinking describes not only the understanding of specialized spatial processes but it includes elements of spatial concepts, tools and methods for spatial representation, as well as the process of spatial reasoning (Figure 9).

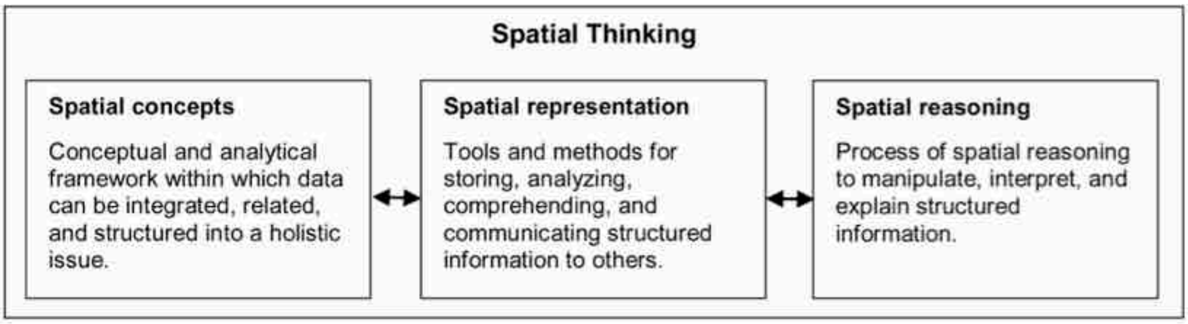

Figure 9: Elements of spatial thinking (Michel and Hof, 2013)

Goodchild et al. (2010) makes the case that critical spatial thinking should be a central theme in education for a world where information is increasingly seen through geographical filters. According to Bearman et al. (2016), critical spatial thinkers should be able to understand the effect of scale and critically evaluate the quality of spatial data being used and understand its implications. This implies that the processes of data manipulation, analysis and modelling will provoke and require critical thinking, Nguyen et al. (2019) focus on spatial thinking as an essential and basic function of a skills-oriented education program in schools, They emphasise the need to consider the three fundamental elements (concepts of space, tools of representation, and processes of reasoning), in creating Geography curriculum; and provide "examples of questions containing spatial thinking from low to very high level and questions of nonspatial-thinking in geography textbooks". They suggest the formulation of a cognitive processing taxonomy - Structure of Observed Learning Outcome (SOLO) should be developed to assess the process of reasoning.

De Lázaro y Torres et al. (2018) show how it is possible to take advantage of Cloud-based tools to enable spatial thinking and the development of digital competencies. They focused on explaining how, by using flipped teaching and collaborative work, student learning can be enhanced. The results of this flipped teaching learning activity were a collection of different story maps focused on specific topics demonstrating inquiry-based learning by collecting and using geodata and a web mapping application on WebGIS. Other proposed innovative aspects were how to integrate a web map with digital storytelling, using open geodata and collaborative student-centred learning about the topic.

5.2 Geographical questioning, enquiry and spatial reasoning

Several researchers have reported the effectiveness of using GIS in enquiry-based learning because of its capacity to promote students' higher-order thinking skills, connect the classroom with real-world issues, and construct meaning and knowledge through the enquiry process (Kerski, Demirci, and Milson 2013; Jadallah et al. 2017; Metoyer and Bednarz 2017).

Hong and Melville (2018) confirmed spatial thinking was fundamental to the geographic inquiry process. As a collection of cognitive skills comprised of knowing concepts of space, using tools of representation, and reasoning processes, GIS offers a disciplinary tool with great potential for enquiry-based learning. However, they confirm there is a lack of pedagogical resources for GIS for implementation in K–12 classrooms (Millsaps and Harrington 2017). They introduced an enquiry-based approach to designing effective professional development in GIS, which has the potential to empower teachers and students in enquiry-based learning with GIS technologies and ultimately increase student engagement and their understanding of a rapidly changing world.

Favier (2011) examines the processes and stages in geographical questioning (Figure 10), establishing the use of GIS within the wider issue and allowing students to see how GIS integrates as part of the wider cycle of problem – evaluation – solution loop. He defines six stages as asking geographic questions, acquiring geographic resources, visualizing geodata, cognitive processing of knowledge about the world around us, answering geographic questions and presenting the results of geographic inquiry. He concludes that critical spatial thinking requires the student to think about all of the steps in this process.

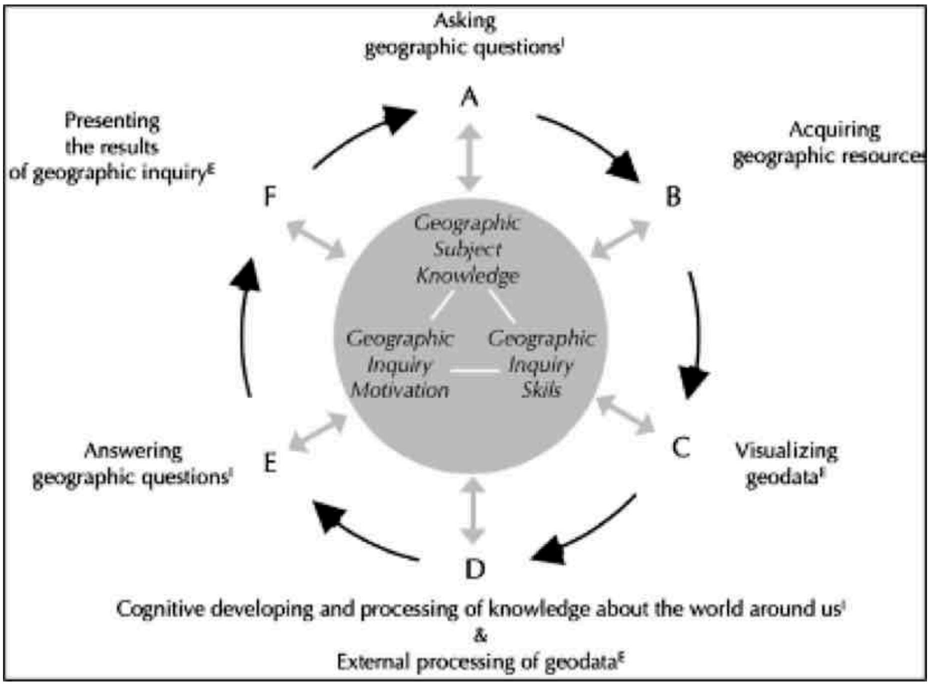

Figure 10: The processes adopted when answering geographic questions (Favier, 2011)

According to Favier (2013), while using GIS, we should not only focus on learning subject knowledge and domain-specific skills, but also about basic ideas about GIS. He explains this via a framework (Figure 11) for geographic enquiry using Geo-ICT research, where learning can be seen as a cyclical process.

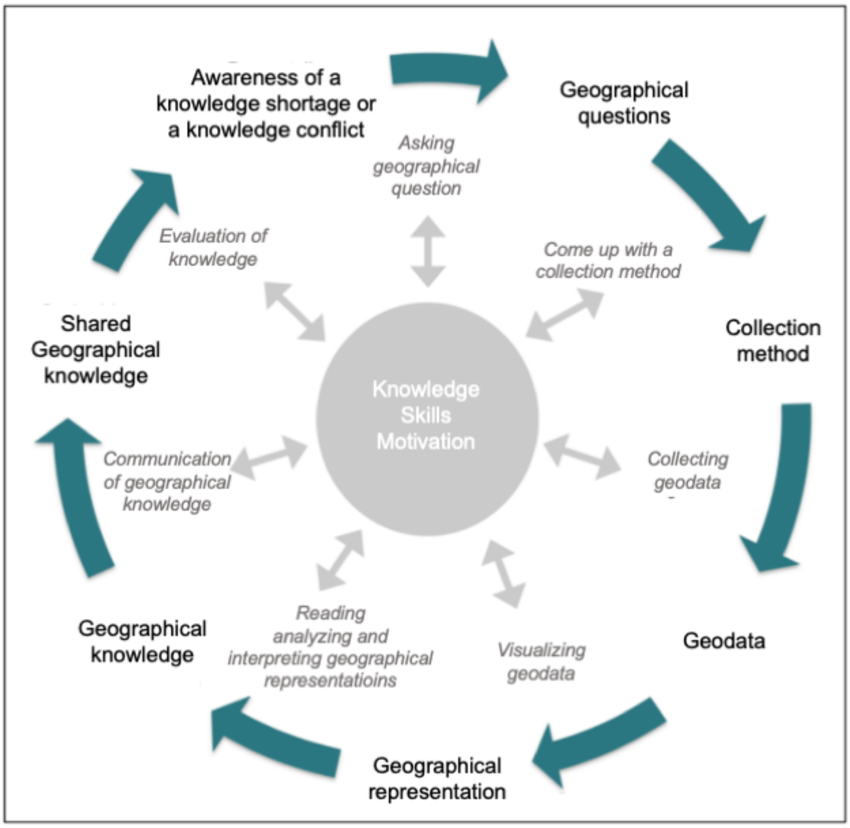

Figure 11: A framework for geographic enquiry using Geo-ICT (Favier, 2013)

Favier and van der Schee (2014) deal with the question whether geography lessons with geospatial technologies really contributed to the development of students' geospatial thinking, and in particular geospatial relational thinking. The use of geospatial technologies like GIS should enable teachers to develop instruction methods that aim to stimulate geospatial relational thinking skills that are often difficult to address.

Geospatial relational thinking connects to systems thinking, which is a holistic approach that focuses on spatial association and how the constituent parts of a system are related to each other, how such systems respond to changes, and how systems work within the context of larger systems. Their research sought to identify the effects on geospatial relational thinking of a series of lessons with geospatial technologies on high school students', when compared with a conventional lesson series. They found the use of geospatial technologies had positive effects on geospatial relational thinking, the students were also more positive about the effects on the learning outcomes and there was more attention on systematic geospatial relational thinking. However, students could only identify some of the relations and their knowledge was poorly structured in terms of geospatial systems as they could only take some of the relevant factors into account when they solutions for spatial challenges.

Hwang (2013) focuses on the role of GIS in furthering education about sustainability and emphasises GIS as a positivistic mode of observation, or a tool for quantitative enquiry and research. He proposes a hierarchy of five geospatial inquiries that students can make to explore sustainability issues using GIS (Figure 12). They are spatial distribution (SD) or where things are; spatial interactions (SI), how things interact between regions; spatial relationships (SRs), how things are related across domains; spatial comparisons (SCs), how things are different across regions and temporal relationships (TRs), how things change over time. He concludes these types of enquiries can help students to explore spatial patterns, relationships, and changes, and uncover place-specific processes.

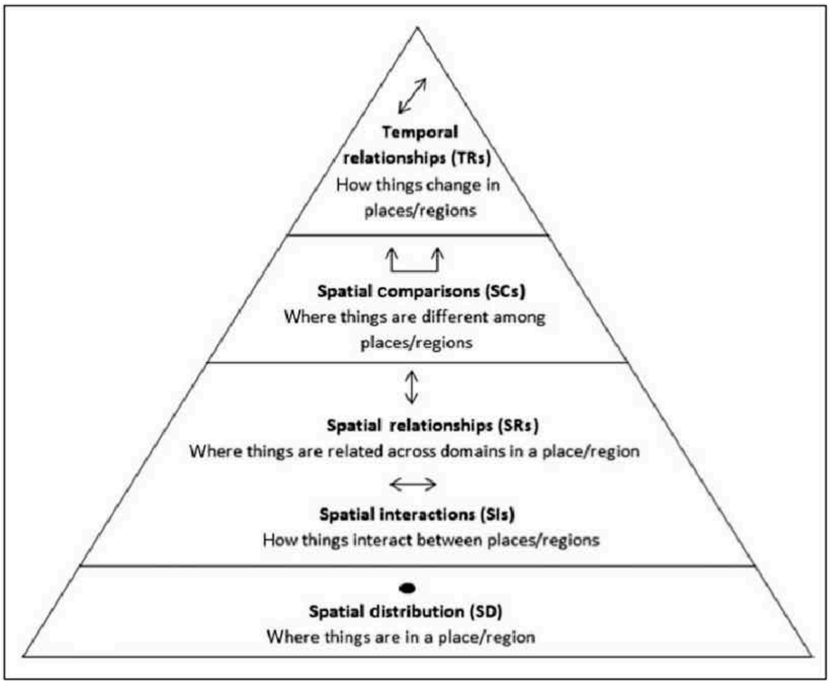

Figure 12: Definition of and hierarchy among five geospatial inquiries

Jant et al. (2020) explore spatial reasoning and the role of spatial thinking in STEM education and to extend the importance of spatial thinking in STEM education beyond what is typically measured by spatial ability tests and bring it in line with approaches that emphasise the practices of STEM thinking. Their results suggest that GIS-based instruction can be used to enhance students' use of spatial reasoning when solving STEM-relevant problems. They indicate that GIS training helps student to consider, understand, and implement spatial solutions and thus the authors recommend spatial thinking could, and should, be central to scientific reasoning, just as modelling and evidence-based argumentation are.

Perdue and Lobben (2013) propose a spatial thinking framework and hypothesized that certain spatial thinking skills are higher order than others and build upon previous, less complex skills (Figure 13). So, in the example shown, regional identification is conceptualized as a high level skill, achieved through the accumulation of proximity, boundary, clustering, and classification skills.

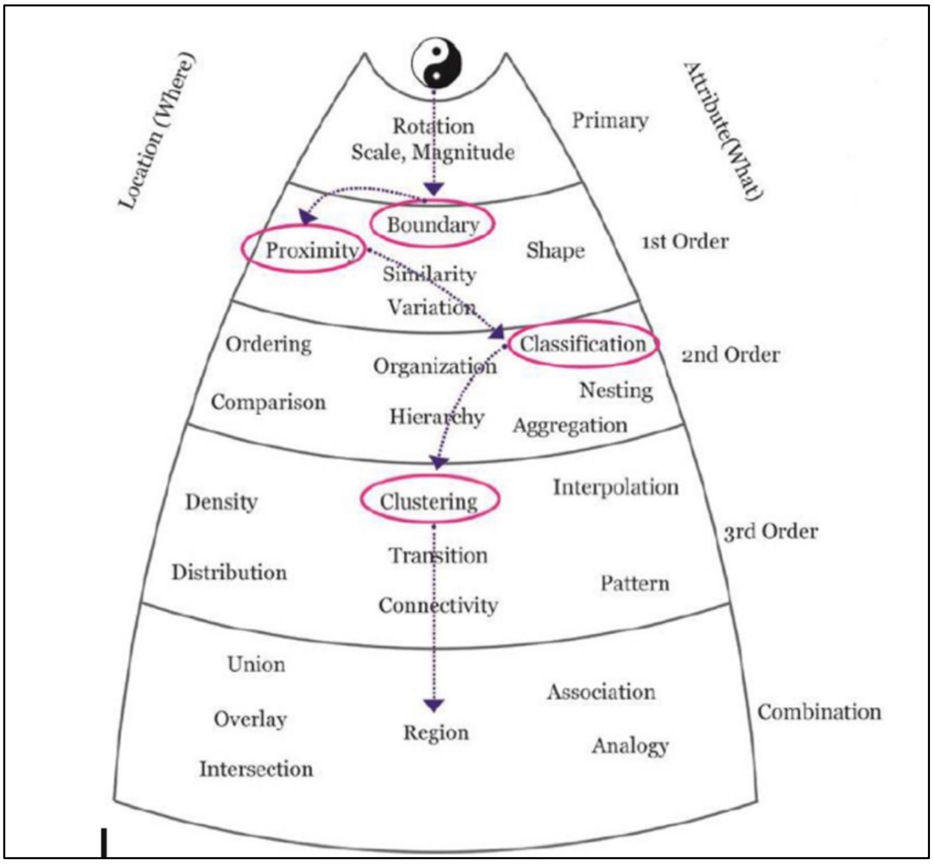

Figure 13: A spatial thinking framework (Perdue et al., 2013)

5.3 TPCK and G-TPCK

The Technological Pedagogical Content Knowledge (TPCK) framework has provided a theoretical lens for integrating technology in teaching in school (Figure 14). It conceptualizes three knowledge areas for teachers, the subject matter or disciplinary content, using technologies and digital resources and learning and teaching processes (pedagogy). Kerski et al.. (2013) suggest professional development in teacher education must be expanded and it needs to embrace the technological pedagogical content knowledge which captures the complex interplay among content, pedagogy, and technology.

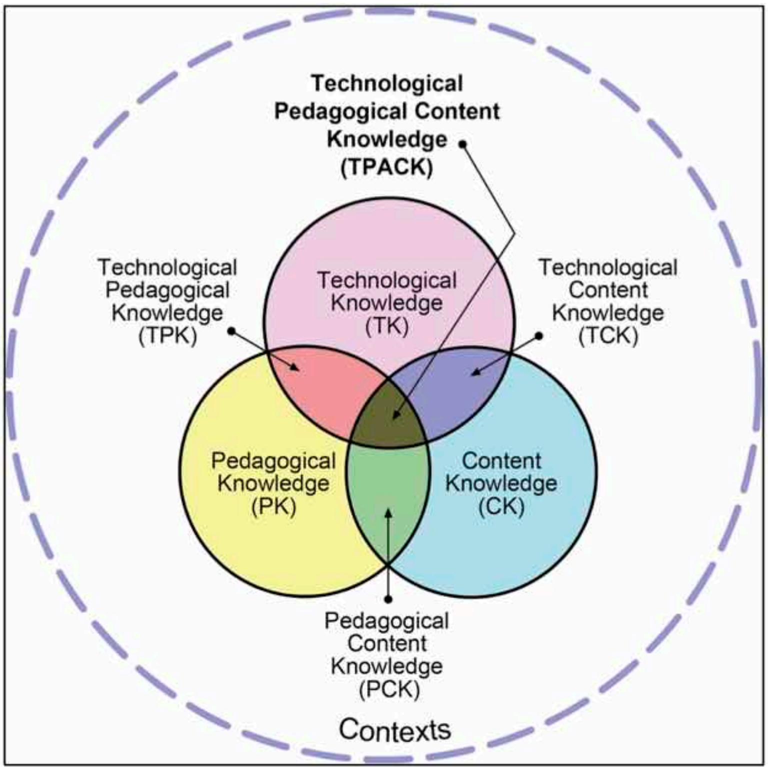

Figure 14: The Technological Pedagogical Content Knowledge (TPCK) framework (after Mishra, 2019)

Walsh (2017) says teachers often avoid engaging with GIS with research suggesting that the lack of GIS training in initial teacher education is partially responsible. She states, "Successful use of GIS in education requires that teachers have a strong understanding of geographical content knowledge, geospatial software applications, data analysis techniques, and pedagogical strategies (Coulter, 2014); as such, professional development in teacher education should be expanded to embrace the technological pedagogical content knowledge (TPCK)" (Walshe, 2017;619)

Hammond et al. (2018) explored the dynamic relationship of TPCK and found that developing teachers' geospatial TPCK is paramount for solid integration of these technologies into teaching. Simply engaging with technology is will not improve student learning, educators should consider which pedagogies will be most effective (Hicks et al. 2014). To do this the TPCK approach recommends that teachers also need technological and geographical content knowledge. In developing TPCK, Mishra and Koehler (2006) integrate effective technology use into the curriculum, based on the strength of teachers' pedagogical and content knowledge (PCK).

Roig and Flores (2014) point out that while there may be high "content knowledge" among teachers, the same does not happen with "technological knowledge". Newer teachers often rate their technological knowledge as higher than their subject / pedagogic knowledge, perhaps demonstrating a lack of confidence (Álvarez-Otero and de Lázaro y Torres, 2018).

Gómez Trigueros (2018) explores the use of the TPACK model for introducing GIS. He suggests that the teacher's own subject knowledge and their pedagogical knowledge need to be considered simultaneously. The model proposes that in order for teachers to have training to incorporate ICT in the classroom, they need not only to possess "the basic knowledge" in an isolated and independent way, but also to possess them in interaction with the approach. He proposes that only in this way will the technology be incorporated into the training process in an appropriate manner and achieve the student's intended teaching and learning objectives.

Curtis (2019) uses Mishra and Koehler's (2006) Technological, Pedagogical, Content Knowledge (TPCK) framework to examine the influence of pedagogical knowledge on teachers' decision making when teaching geography. She examined teaching that integrates professional tools in the school classroom and suggests this is supported by well-documented learning standards and studies. She describes how instruction that reflects the actions of business needs will enable geography teachers to prepare knowledgeable, critically thinking twenty-first-century students through genuine, geographical contexts that foster collaboration and the application of knowledge to realistic scenarios (Charles and Kolvoord, 2016). However, research showed that geography educators have to discover methods on their own as they are not taught pedagogical strategies for teaching with geospatial technologies.

Doering et al. (2009) recommend teachers have to develop geographical technological pedagogical content knowledge (G-TPCK). The focus changes from what teachers should know to effectively integrate technology into their classrooms to studying how their geographical knowledge should be used within the classroom for the most effective results. They propose a problem-based GeoThentic training course where teachers develop their technology knowledge using geospatial technologies, their pedagogical knowledge by investigating optimal pedagogy for geographic problem solving with geospatial technologies; and their content knowledge by developing the specific geographical content area needed to effectively teach the problem-solving modules.

Rickles, Ellul and Hacklay (2017) identified the theoretical elements of GIS concepts and connected them to the educational approaches within the TPCK framework (Figure 15). They indicate that Context Based Learning is the recommended learning approach or pedagogical knowledge. The use of context refers to both the local learning environment and the context of the problem domain for the learning activity. Identifying the platforms to use provides the technological knowledge and the content knowledge would be based on the curriculum subject or in higher education the GIS&T Body of Knowledge (Prager, 2012).

Research by Curtis (2019) revealed a possible relationship between pedagogical knowledge and the frequency of use and depth of integration of GI technology into geography teaching. She stated that it was important to develop teachers' G-TPCK for them to accept the technology and implement it in geography classrooms.

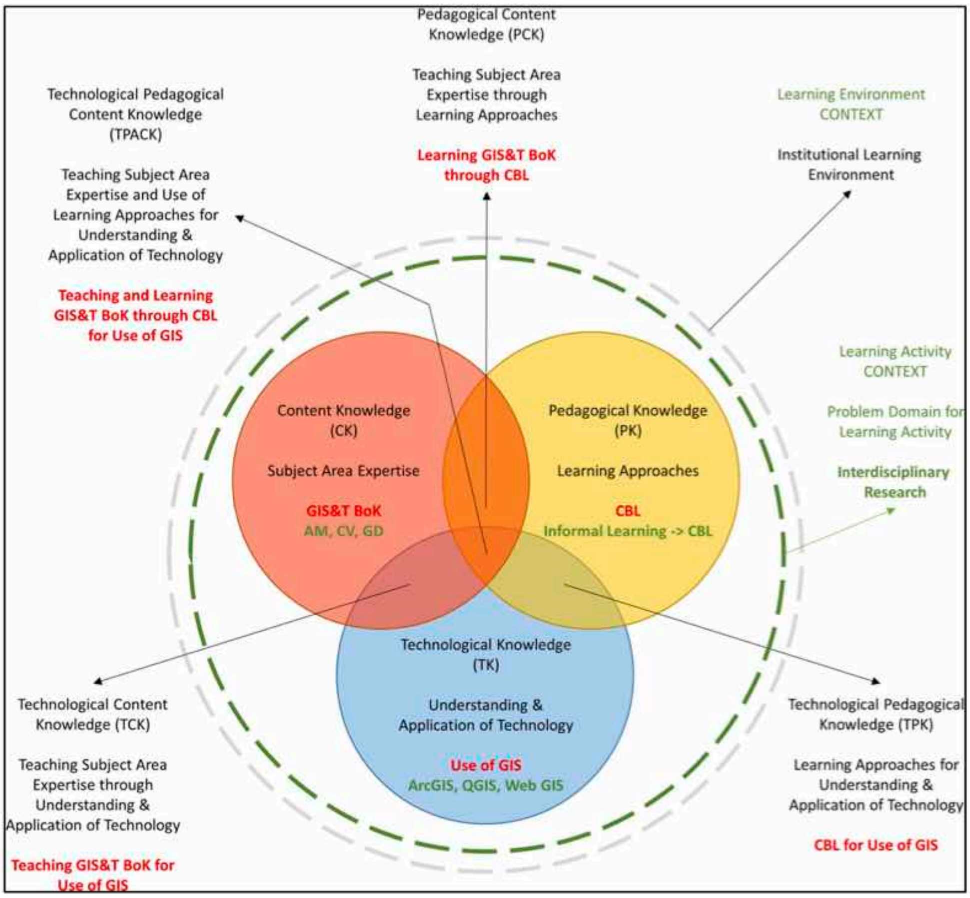

Figure 15: GIS and the TPCK) framework (Rickles, Ellul and Hacklay, 2017)

Hong, and Stonier (2015) suggested enquiry-based lessons using GIS technologies would be a way to integrate technologies using the TPACK model. Their research suggested four different useful methods to introduce GIS to students for the first time:

1. making the first activity relate to the students (e.g. “make students interested in GIS first” and “get familiar with GIS”, for instance by asking students to make an individual map to lay out their lives, such as the locations of their homes and schools”),
2. exposing students to GIS a small amount at a time, introduce it gradually so that students would not feel intimidated or overwhelmed when they start using GIS.
3. using peer leaders, creating help and support among themselves and monitoring by teachers and
4. providing tutorial videos.

5.4 Threshold concepts and powerful knowledge

Threshold concepts originated in Meyer and Land’s (2003) work assessing aspects of student learning. They are described as concepts which, once grasped, lead to a transformed view of subject matter (Figure 16). The process of grasping threshold concepts implies crossing a conceptual gateway which may result from overcoming troublesome knowledge.

Meyer and Land (2006) describe the characteristics of threshold concepts as transformative changing the way you see the world; troublesome where it might seem counterintuitive, irreversible meaning that once it is learnt it is unlikely to be forgotten; integrated as it reveals connections between the different parts of the discipline, bounded whereby the concept has defined parameters in which it applies and discursive so that it leads to the development of new language. Enser (2017) suggests that threshold concepts are an important element in checking learning, and could be a focus to help unlock a new understanding of the world.

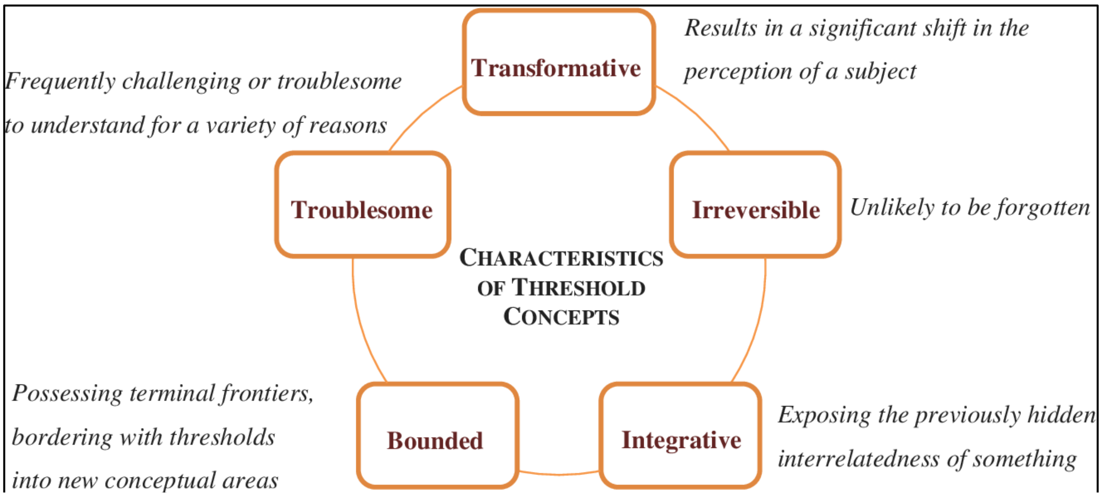

Figure 16: Key characteristics of threshold concepts (after Hamm, 2016)

Srivastava and Tait (2010) present the implementation of curriculum design principles for teaching, they say the adopted pedagogy should utilise existing pedagogical content knowledge for the course material, identify the threshold concepts for the discipline, involve students in active and authentic learning, as well as providing experience with problem-based learning, and takes into account the backgrounds of the students by offering flexible learning opportunities. Their study presents a learning-assessment-feedback model involving several curriculum design principles. The authors recommend that teaching should be based on recent education research developments. The curriculum design principles start from designing the aims and outcomes of the course followed by a sequential arrangement of learning activities, leading up to appropriate assessment. The result was the creation of a student-centred approach, with opportunities for self-direction, guided responsibility for their learning and learning/assessment opportunities offered in real-world contexts (Figure 17).

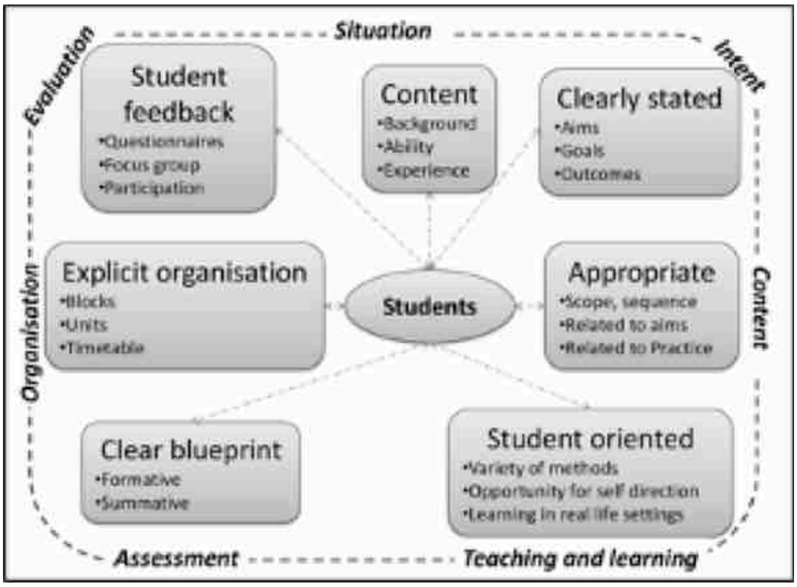

Figure 17: A GIS pedagogy model in use

Assessment was designed to develop from simple knowledge concepts and move to analysis, critical thinking and deeper examination, demonstrating how GIS can be applied in their discipline areas. Thus, students move from understanding theoretical concepts to directly linking the technology and discipline in an understanding of practical real-world application of GIS.

Srivastava and Tait (2010) offer a summary of the threshold barriers to be crossed for learning to use GIS (Figure 18). They suggest mastering the key threshold concepts will transform a student from a general map user to a GIS professional. The identification of these key threshold concepts should result in the identification of any elements of troublesome knowledge, which can form a barrier to learning. A similar summary might be useful to teachers for selecting topics when learning with GIS.

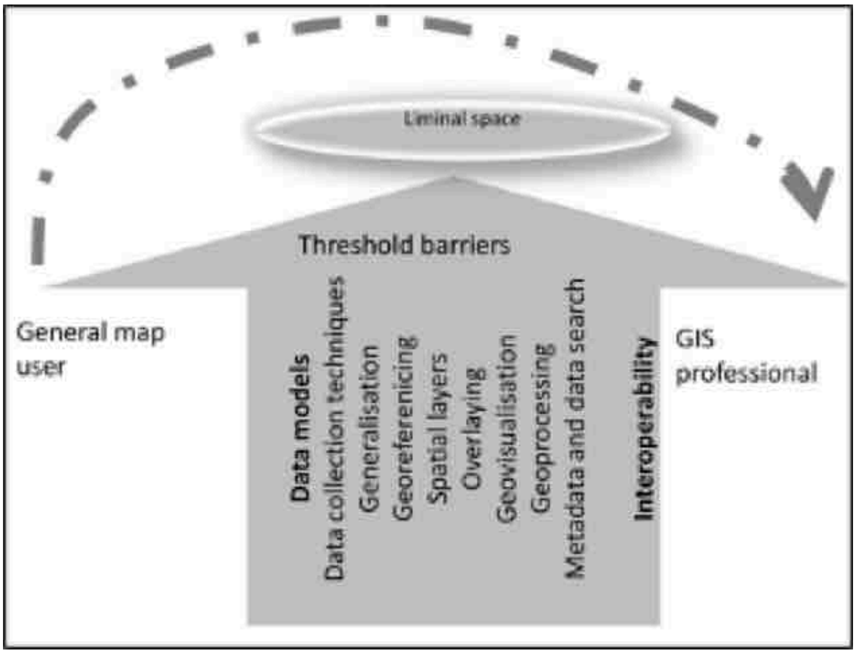

Figure 18: Threshold concepts for learning GIS

Walshe (2018) warns of the danger of GIS being reduced to just a mechanism for completing a set of skills and draws on the typology of Alaric Maude (2018) to develop powerful geographical knowledge, with reference to the GeoCapabilities project with its use of curriculum artefacts. GIS allows students to engage with opportunities to create, test and evaluate knowledge.

Maude's typology (Table 3) was used by Fargher (2018) to exemplify how a curriculum artefact, defined as "the 'key' to a series of lessons on a given topic" can be created in ArcGIS Online to construct powerful geographical knowledge. The example developed of the 2004 Indian Ocean Earthquake and Tsunami demonstrates the need for teachers to lead with their expert subject knowledge to ensure engagement with GIS is underpinned by the subject's key concepts and supports the development of students' geographical thinking.

Table 3: Typology of powerful geographical knowledge (after Maude, 2018)

Type of powerful geographic knowledge	Description
Type 1	Knowledge that provides students with 'new ways of thinking about the world'
Type 2	Knowledge that provides students with powerful ways of analysing, explaining and understanding
Type 3	Knowledge that gives students some power over their own geographical knowledge

Type 4	Knowledge that enables young people to follow and participate in debates on significant local, national and global issues
Type 5	Knowledge of the world

5.5 Geomedia, spatial citizenship and participatory GIS

According to Gryl et al. (2010) spatial citizenship is an amalgam of three main contributing areas of research, citizenship education, the appropriation of space and the links between GI and society. Spatial citizenship was thus defined as the ability to critically appropriate space by democratic means. Spatial citizenship education is therefore about learning how to navigate the world with respect to the physical world, the meanings attached to the physical objects and environment and the power relations involved in the production of meaning. Three main fields of competence were identified (Figure 19). They suggest specific strategies need to be developed for working with GIS that goes beyond technical competences widely reproduced in many curricula.

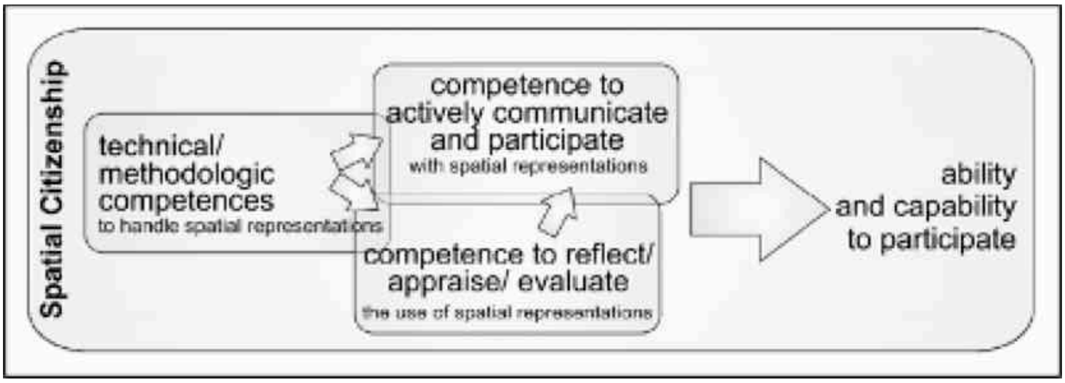

Figure 19: Competences for spatial citizenship

Geomedia is media that has consists of spatially localised information, it has become an essential part of everyday life. Technological developments enabled ordinary citizens to participate and collaborate using an increasing number of web-based applications and mobile devices for gathering, processing and visualising geoinformation and then sharing and distributing their own information. Felgenhauer and Quade (2012) explore the implications of geomedia for education, raising issues associated with the types of learning styles needed to address young people to engage in citizenship activities and the reflective and reflexive use of GI and geomedia. Gryl (2016) suggests reflexive geomedia competence and spatial citizenship are based on reflection and reflexivity. Reflection means being critical towards a certain matter, reflexivity connotes being critical regarding own thinking and acting with this matter. Spatial citizenship and reflexive geomedia competence accounts for the social construction of spaces from spatial thinking approaches from geomedia (Gryl and Jekel, 2012).

Roosaare and Liiber (2013) present the situation in Estonia where geo-media and GIS has been integrated into school education, where a list of compulsory ICT-based practical works have been added to the geography curriculum. Gryl (2016) aimed to identify teachers' different basic abilities and their willingness to further reflexivity and geomedia approaches at school and to identify ideas to further the development of teachers' abilities and willingness. Interviews of teachers were undertaken to construct a typology of teachers' ability and willingness to further reflexive geomedia competences and spatial citizenship competences among their students.

Sinha et al. (2016) explore the use of Participatory GIS (PGIS) as a powerful platform for geographic education. PGIS resulted from community engagement responses to technological developments in GIS and empowerment. PGIS produces media useful for citizen advocacy and decision making. But the pedagogical benefits of PGIS projects have received limited direct attention in the literature, understandable since PGIS projects are designed to be led by communities and the focus should remain on community development and empowerment, not on how students and researchers can benefit from the process.

While PGIS is not the only approach for teaching students geography in the field, it offers one of the most flexible and scalable options of enabling students to work with communities. PGIS projects are naturally suited for complementing classroom training because participating students must work beyond the classroom and in a host community, they have to learn collaborative and community development skills, reflect on their own situation and circumstances while striving to safeguard and promote community interests; demonstrate the application of human, physical, and geospatial geographic knowledge in the field and foster critical reflexivity in students.

PGIS approaches can help meet diverse learning objectives related to local knowledge and place-based thinking, understanding the relationships between people and landscapes through community engagement, getting practical training in field methods of collecting, managing, processing, and visualizing geographic information and gaining experiential and practical introduction to qualitative-quantitative methodologies.

Gordon et al. (2016) examine interactive participatory mapping for teaching and practising critical spatial thinking. They propose that critical spatial thinking is foundational to civic engagement and that digital geographic pedagogies are an important arena in which young people can build these aptitudes. They show how interactive digital mapping pedagogies offer students an opportunity to develop awareness of what happens in their urban geographies and guide and inform civic engagement. They illustrate how critical civic learning happens as a result of a student-guided exploratory process, collaborative work, and sharing with and learning from their peers.

5.6 The storytelling technique and web maps

Kerski (2015) includes storytelling as one of the five converging global trends that are exerting great impact on geography. The evolution of geographic tools, data, and multimedia on the web expand the ability and audience for storytelling through maps. He describes the importance of educating a geoliterate population that can assess and use geographic information to make wise decisions.

Motala and Musungo (2013) examine the effects on student learning by introducing storytelling in GIS teaching and learning activities. Incorporating storytelling into GIS analysis and mapping helped students to visualize complex concepts. They suggest that multimedia storytelling was a powerful learning method as the students were given opportunities to tell their own stories and empathise with the geography. Their own personal narratives helped the students to internalise the learning.

Sherrington (2018) summarises Daniel Willingham's (2009) explanation of the importance of narrative connections in memory-making. He says that stories have four features, causality, conflict, complications and character. It is likely that innovative pedagogies should consider how GIS resources can use the principles of stories to help students recognise and understand geographical patterns, processes and concepts (e.g. adding layers in coherent stages; story maps) and how the steps of learning a GIS technique might be taught more effectively by following the storytelling principles.

Story maps usually integrate text, multimedia and interactive functions to inform, educate, entertain and inspire people. Marta and Osso (2015) describe their project initiative “Story Maps at school: teaching and learning stories with maps”. Working with groups of teachers and their classes they found that storytelling with maps motivated students and established a positive attitude towards learning. The students were actively involved in the storymapping process, being creative in telling their own stories and encouraging them to ask questions.

Sui (2015) reflects on the uses of map stories or location-based storytelling. He says that today's maps are thus not simply used as illustrations, instead, they are increasingly used as a medium to tell stories and help learners acquire deeper meaning through their educational activities with GIS and focus on Pink's (2006) framework of the six senses of the new mind, design, story, symphony, empathy, play and meaning.

6. Pedagogies

Little research attention had been paid to pedagogical issues in using GIS (Donert, 2007; Bednarz, 2001), yet according to Mathews and Wikle (2017). surveys of employers suggest improved pedagogical approaches in teaching GIS&T are needed as the workforce is often poorly prepared to take on real-world problems. Roosaare and Liiber (2013) confirm that main influence on teaching at schools is the teaching-learning process in the classroom, which is dependent on teachers' professionalism and their enthusiasm to implement new technologies and teaching methods. Stringer et al. (2019) state that to improve learning, the technology must be used in a way that is informed by effective pedagogy.

Sanchez (2009) assessed the way geotechnologies be integrated into the geography curriculum for secondary education, and what effects they have in terms of pedagogical setting and educational goals. Evidence he gathered suggested that geotechnologies were being used in different pedagogical contexts: with the whole class through the use of a data projector, with small groups of students or individual use where a student is alone in front of a computer.

Matthews and Wikle (2019) were concerned with the way GIS courses can be designed to address learning objectives that promote creative thinking, advance problem-solving skills, and foster collaboration. Their goal is to assess the pedagogical approaches used to teach courses, as well as identify the challenges associated with such teaching, based on an Internet-based survey of 318 college and university faculty. They found active learning methods were not well integrated within classes and noted that students needed to receive a solid conceptual framework and teaching strategies would benefit from more active learning approaches and other teaching innovations. They suggested courses should be designed to address learning objectives that promoted creative thinking, advanced problem-solving skills and that fostered collaboration.

Muijs (2020) highlights the increased importance of the 'Science of learning' being used to inform classroom practice. There is a growing awareness of the potential help that self-regulation and metacognitive strategies can have on learning. Muijs supports the view that self-regulation relates to the learner's awareness of their own strengths and weaknesses, and is linked to their motivation to develop their own learning strategies. This he sees as being linked to three broader functions: cognition, which is information processing and practice; metacognition, which are the strategies that control cognition and motivation, which is linked to interest and self-belief.

Coe et al. (2020) report on the Great Teaching Toolkit, finding that a key feature of great teaching is that teachers understand the content they are teaching and how it is learnt. They suggest that teachers who want to increase their effectiveness should focus on four priority areas, i) understanding the content they are teaching and how it is learnt, ii) creating a supportive environment for learning, iii) managing the classroom to maximise the opportunity to learn and iv) presenting content, activities and interactions that activate their pupils' thinking. Allier-Gagneur et al. (2020) suggest these principles give an indication of the type of practices that could be shared with teachers during teacher development sessions.

6.1 Critical spatial thinking

According to Goodchild and Janelle (2010) education approaches must recognize the need to impart proficiency in the critical and efficient application of these fundamental spatial concepts, if students are to make use of expanding access to the growing amounts of spatial information and data processing technologies. The term critical implies being reflective or analytical of spatial perspectives and in using active questioning and examination of the data, the techniques and the context. The challenge for education is how to develop techniques of critical spatial thinking, so that students will be better prepared to use the evolving technologies, and better equipped to exploit the growing flood of spatially referenced data.

The authors suggest students should be trained that to the standards of a critical spatial thinker, including, the potential to contribute critical spatial understanding to information at the interface between disciplines; to work in a team; to explain the space–time context to non-experts; the ability to develop new and highly original spatially informed ideas; to enable sustained and successful dialog within an international community of spatially aware scientists; to disseminate spatial understanding through teaching and curriculum development at K-12 and undergraduate levels; and to transfer spatial technologies and spatial concepts across different knowledge domains and problem sets.

Willingham (2007) asks whether critical thinking can actually be taught suggesting that there is no set of critical thinking skills that can be acquired and deployed regardless of context. He suggests there are metacognitive strategies that, once learned, make critical thinking more likely and that the ability to think critically depends on domain knowledge and practice. Therefore proposing that teaching students to think critically probably lies in large part in enabling them to deploy the right type of thinking at the right time. Kaminske (2020) confirms it is context dependent and people can therefore be good at critical thinking in one domain, but bad in others.

Critical spatial thinking typically refers to a deeper understanding of relationships such as spatial dependence or spatial heterogeneity (National Research Council 2006); or to reflexivity in the use of spatial data and technologies (e.g. assessing the reliability of digital spatial data and geospatial representations or making and evaluating arguments with spatial data and maps

Kim and Bednarz (2013) suggest critical spatial thinking is a key aptitude for civic engagement via digital geotechnologies. They developed an interview-based critical spatial thinking oral test (A Critical Spatial Thinking Oral Test - CSTOT) to test problem solving on their own and used the test to investigate the effects of Geographic Information System (GIS) learning on three components of critical spatial thinking: evaluating data reliability, exercising spatial reasoning, and assessing problem-solving validity (Golledge et al., 2008). Their study demonstrated that doing a GIS course was beneficial in enhancing students' critical spatial thinking, identified as the ability to assess data reliability, use sound spatial reasoning, and evaluate problem-solving validity. They say that this could be explained by the nature of learning to use GIS, as spatial reasoning is required so students are able to apply ideas in practice and solve problems.

Milson and Curtis (2009) found that learning with GIS was an effective way to enhance students' critical spatial thinking. These researchers asked students to select a suitable location for a new business. Students had to determine criteria on which to base their decision, find data to support the criteria, and finally defend their thinking processes, all of which supported the development of critical spatial thinking. Liu et al. (2010) reported that problem-based learning with GIS developed students' higher order thinking, such as analytical and evaluation skills.

Most concepts of critical spatial thinking are either strongly oriented towards geospatial representation or concern how digital spatial data are made and disseminated. By focusing on geospatial data and representation, these notions of critical spatial thinking do not relate to what young people need to know or understand about the world around them and their civic engagement. However, it is necessary to learn from first hand reliable sources and to represent data to enable a clear and real interpretation of inequalities. Students' education must include understanding how inequalities in society are generated and how they and other social actors might intervene to challenge them.

6.2 Active pedagogies and enquiry-based learning

The use of geotechnologies in schools facilitates the implementation of enquiry-based-learning (Sanchez, 2008a) and open-ended projects for teaching (Kerski, 2008). This is probably partly due to the fact that GIS allows classroom procedures that are close to professional procedures, including modelling or simulation (Sanchez, 2008b). Pedagogic developments have echoed the "hands-on" emphasis in much Geography education, characterised by active learning in the field and laboratory, and the adoption of Kolb's experiential learning theory (Healey and Jenkins, 2000).

Mathews and Wikle (2019) found that active learning pedagogies are becoming more firmly established, supplementing or replacing traditional teaching approaches. The strategies that encourage active learning are based on interactivity in learning-by-doing (Scheyvens et al., 2008). In addition to facilitating student engagement, active learning encourages elements of critical thinking through student reflection (Scheyvens et al., 2008) and student-driven problem-solving that may involve real-world data (Conners et al., 1998). Chen (1997) applied problem-solving to active GIS learning activities (Figure 20). These student-centered approaches are also well documented outside the use of GIS (Park, 2018).

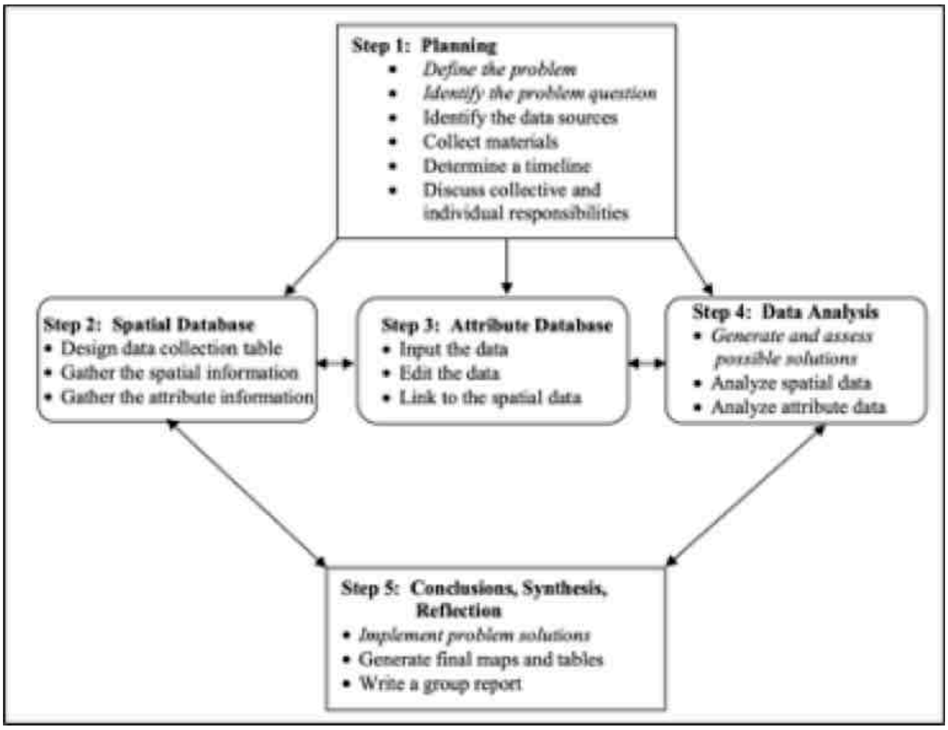

Figure 20: Problem solving and active learning with GIS (after Chen, 1997)

In terms of scope, active learning includes a range of strategies with varying levels of student engagement, such as "flipped" classrooms where meeting times are reorganized to replace traditional lectures with student-centred activities. Students in flipped classrooms review other materials in advance of class meetings, enabling class time to focus on productive open-ended discussion or collaborative learning activities (Reidsema et al., 2017). Similar active learning methods that were noted included "think–pair–share", which can be introduced using a reading assignment or presentation followed by a series of questions posed by the teacher. Students subsequently write reflective statements and then work in pairs or small groups to discuss and complete assignments. Although not focused on GIS, several other studies demonstrated the effectiveness of active learning in increasing student engagement and performance (Lee and Shahrill, 2018). Some disadvantages of active learning strategies have also been noted, such as the added time needed for preparing materials and challenges presented by large class sizes.

Despite the benefits associated with active pedagogical approaches, a recent survey of science, technology, engineering, and mathematics (STEM) fields demonstrated that the majority of college teachers continue to rely on passive, lecture-based instructional methods (Stains et al., 2018). As noted by Şeremet and Chalkley (2015), GIS courses are no exception. It is commonly accepted that when theory is combined with practice, the educational output becomes beneficial for the students' learning. Traditional teaching methods are supplemented by other approaches, such as enquiry-based learning, which involve complex problems and scenarios with fieldwork and case studies. Therefore, when used to its full potential, the use of GIS in schools can provide a learning environment with proven potential for enquiry-based activities, with students learning about geographical problems, issues and events of real-world relevance (Fargher and Rayner, 2012).

Enquiry-based learning involves exploring, analysing and acting upon geographical knowledge. Teachers need to be more critically aware of the kinds of geographical thinking that can and cannot be enhanced through GIS. Enquiry learning includes such process skills as observing, classifying, measuring, predicting, inferring, summarising, communicating, collecting data, analysing data, drawing conclusions, building models, interpreting evidence, and experimenting. Through enquiry learning, problem solving strategies are employed to identify assumptions and consider alternative explanations.

GIS enquiry is usually based on five steps (Table 4), with students are encouraged exploring spatial relations and patterns among data and drawing sensible explanations towards the observations.

Table 4: Steps to enquiry with GIS (after Fargher, 2018)

Step	What to Do	Type of Knowledge Construction
Ask a geographical question	Ask questions about the world around you	Enquiry
Acquire geographical data	Identify data and information that you need to answer your questions	Inventory
Explore geographical data	Turn the data into maps, tables, graphs and look for patterns and relationships	Spatial processing and analysis
Analyse geographical information	Test a hypothesis, carry out map, statistical, written analysis using evidence	Spatial Analysis, Modelling,
Act with geographical knowledge	Take outcomes and evidence and undertake actions to further them	Decision Making, Dissemination

These steps are intended to teach disciplinary content through the development of higher-order, enquiry-process skills (i.e., formulating research questions, designing or implementing systematic data collection, analysing and synthesising data, and so on). Such enquiry-based activities are critical to the development of problem-solving skills, which, as the world has seen must be emphasised in education so that they are prepared to effectively and efficiently solve real world challenges.

Bonnstetter (1998) described enquiry as an evolutionary learning process in which the roles of the teacher and student change as shown in Table 5. Enquiry learning can be defined as the student-based exploration of an authentic problem using the processes and tools of the discipline or content. Process skills may include observing, classifying, measuring, predicting, inferring, summarizing, communicating, collecting data, analysing data, drawing conclusions, building models, interpreting evidence, and experimenting. This approach has the potential to change geography education for the better because it can be used to provide means of accessing and analysing geographical data that can support deeper geographical understanding.

Table 5: Enquiry evolution (after Bonnstetter, 1998)

	Traditional Hands-on	Structured Inquiry	Guided Inquiry	Student Directed Inquiry	Student Research
Topic	Teacher	Teacher	Teacher	Teacher	Teacher/ Student
Question	Teacher	Teacher	Teacher	Teacher/ Student	Student
Materials	Teacher	Teacher	Teacher	Student	Student
Procedure/ Design	Teacher	Teacher	Teacher/ Student	Student	Student
Result/Analysis	Teacher	Teacher/Student	Student	Student	Student
Conclusions	Teacher	Student	Student	Student	Student

Teacher Controlled-------------------------------------Student Controlled

Exogenous------------Cognitive Development--------------Endogenous

Focus on Teaching--------------------------------------Focus on Learning

Walshe (2017), reporting on trainee teachers and their use of GIS, confirmed that with regular use they developed a more nuanced understanding of the nature of GIS, from seeing it as a method of data display to recognising its value for supporting student-centred, enquiry-based learning and the development of geospatial thinking. Their repeated exposure to GIS with increasing complexity supported the development of their practice as it gave them the opportunity to engage with it at their own pace, allowing them to 'try out' ideas in school and then share their ideas with their peers and integrating the use of GIS into their teaching. Enquiry based learning can also integrate many other techniques, such as learning in equal pairs and collaborative learning (Figure 21).

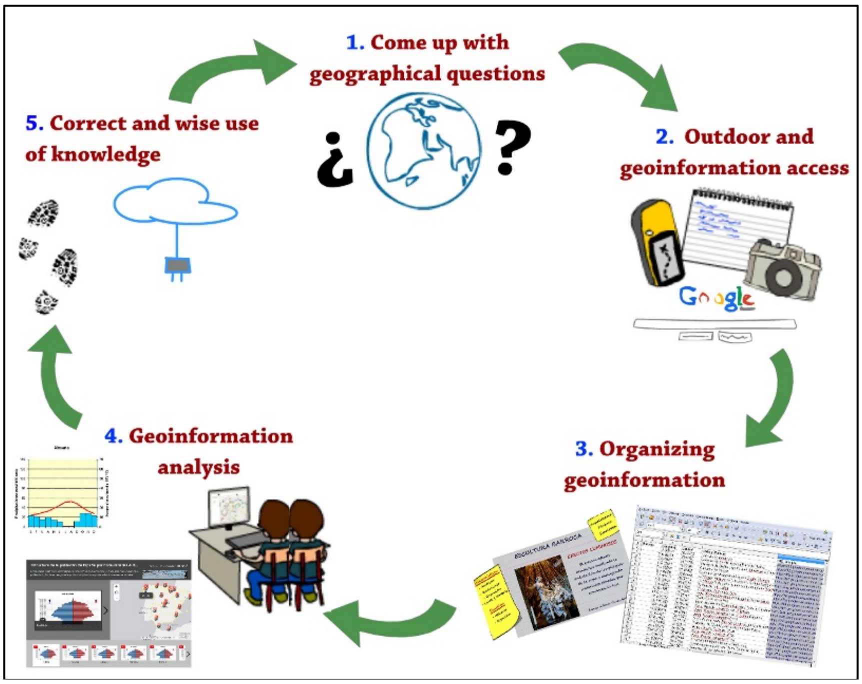

Figure 21: Steps in GIS enquiry (Source: De Lázaro, De Miguel and Buzo, 2016)

A recent survey of the geo-education community found that active learning pedagogies have become more firmly established, supplementing or replacing traditional teaching approaches (Mathews and Wikle 2019). This is consistent with the idea that the learning process being experienced by students is a dynamic and active one, and approaches by instructors that are ineffective can be counter-productive (DiBiase 2018). Project-based and problem-based learning were the most popular approaches as they most closely mimic authentic, real-world experiences (Bowlick et al. 2016, Howarth and Sinton, 2011).

6.3 Problem-based learning and context-based learning

GIS educators have largely adopted innovative approaches such as problem-based learning (Drennon, 2005) and participatory action (Elwood, 2009) in courses. Problem based learning (PBL) has become regarded as an effective and popular format for learning with GIS. Working through problems with GIS operations mimics the application of GIS to "real-world" issues. In PBL, the learning outcomes are often unstructured, with the students in control of the process through which solutions will be identified and reached. In this form, students are presented with a situation and then proceed to organize the strategies and methods for gathering information and reaching an outcome. An authentic problem is at the heart of the experience, reflecting the real-world uncertainties, messiness, tensions, and politics.

In classroom settings, according to Howarth and Sinton (2011) PBL is more structured and can take multiple forms with varying degrees of problem complexity and teacher involvement. However, the amount of time may dictate that the problems themselves are simplified, with prepared data and expected outcomes. The burden of design and preparation is on the teacher and activities are highly controlled. Sanchez (2009) suggested the pedagogical features of a problem-based-learning approach appeared to have a positive impact on the students use of geotechnologies in schools.

Hubeau et al. (2011) introduced a Supervised Self-Study (SSS) teaching approach in the practical parts of the GIS and Technology courses at KU Leuven in Belgium. The students solve and report back on a set of exercises using with Free and Open Source Software systems (FOSS), while having the possibility to receive supervision and feedback. Students use "conceptual exercises" to solve problems independently of which GIS software tools are being used. The main advantages of this teaching approach is in the time-efficiency and the stimulus for students to deal actively with the learning materials. Their research revealed that if insufficient human support, advice and feedback available then students could lose interest and motivation.

Rickles. Ellul and Hacklay (2017), focus on how to improve learning GIS in an interdisciplinary research context. Context-based learning (CBL) is described as a pedagogical methodology that, in all its disparate forms, centres on the belief that both the social context of the learning environment and the real, concrete context of knowing are pivotal in the acquisition and processing of knowledge. This concerns therefore the learning environment and the real, concrete learning activity context of knowledge acquisition. The authenticity (i.e. relevance to real-world problems) is key to engaging the learners and allowing them to reflect on the learning process when learning with GIS.

6.4 Project-based approaches

Many approaches to using GIS in school education have been related to project-based pedagogies (Milson and Earle, 2007; Kerski, 2008; Favier, et al., 2009; Demirci et al., 2011). De Lázaro y Torres et al. (2016) raise the need to integrate Geography learning technologies in schools. For this, it is necessary to train future teachers by providing relevant educational experiences. They propose an active methodology and group techniques, many of which are used in the professional world, such as problem-based learning and project-based learning.

Demirci et al (2010) introduce a nationally funded project designed to use GIS to develop social sensitivity among students through the implementation of GIS-based projects in geography lessons at secondary school. The project involves students in different activities ranging from conducting a survey of the public, identifying the main social, economic and environmental problems in society, developing projects to solve some of the current problems in cooperation with governmental agencies, using GIS to collect, store, manipulate, and analyse data, and informing public and relevant institutions about the outcome of their projects. The develop project-based learning, with the use of information and communication technologies, and development of students' social sensitivity and may also be labelled as service learning.

Esteves and Rocha (2015) analyse how Portuguese Geography Education has addressed teaching with GIS. They present some projects that have been developed in order to enhance the use of GIS in the classroom. They suggest the teacher should create procedures that would lead the students to realize that there can be multiple hypotheses in real problem solving. Therefore, the identification processes and learning of spatial-temporal transformation would be facilitated, which is fundamental to the understanding of geographical phenomena.

Esteves and Rocha (2015) describe a secondary school project called "We Propose!", in which schools identify local problems, create solutions and present these at the University of Lisbon and later to local authorities. In curriculum terms the K11 students involved are required to develop a case study during the school year. The students research local problems (within the Geography syllabus), contact local authorities to learn about more about the problems and what is happening in terms of planning at a local scale. They get GIS training so geotechnology can be used to present proposed solutions and present research-based proposals to solve the identified problems. Students thus become engaged in active citizenship: an important skill acquired in Geography Education. They develop and use GIS skills, work on real life problems and present the research they carried out to local authorities. Furthermore, the municipal authorities will implement the students' research project in the city.

Huei-Tse et al. (2016) analyse the use of a web map mind tool created for tour planning in order to assist learners' project-based learning. Students' assessment demonstrated a positive attitude toward the collaborative problem-solving learning and improvement on their cognitive skills. They confirmed the work of Jo and Bednarz (2009) which suggested the cognitive processes of spatial thinking consisted of three levels, firstly describing, specifying and observing a piece of information (thinking). Secondly, processing of information where analysis, classification and interpretation takes place to acquire understanding. The third level is where information is evaluated and integrated to create new knowledge.

6.5 Learning Progressions, Trajectories and learning lines

Learning Progressions (LP) provides an approach to studying how students advance their knowledge about a subject as their intellectual ideas and ability to communicate grow. It is a method used by education researchers to better understand and document the capabilities of students as they move along a pathway to greater understanding. To develop a learning progression, the researcher immerses herself in trying to understand the multiple pathways that students take to reach different waypoints of knowledge about a subject (Huynh et al., 2015).

An understanding of learning progressions may help understand how learners' geospatial thinking evolves over time. The development of a learning progression for geospatial thinking would include an ordering of geospatial concepts that builds toward more sophisticated geospatial understandings and reasoning skills, while providing learning strategies and learning experiences to support student development along the progression. Assessment measures to define students' progress on the learning progression will also need to be included.

Learning Trajectories (LT) are defined as empirically supported hypotheses about the levels or waypoints of thinking, knowledge, and skill in using knowledge, that students are likely to go through as they learn and reach or exceed the common goals set for their learning (Solem et al., 2014). The LPs and LTs shift the focus from the endpoint to understanding how ideas build upon one another as students develop desired knowledge, skills, and practices in a discipline. It does not imply that there is a single path through the progression, multiple paths are likely.

A Learning Progression is a road map to chart how different students proceed to the next or more sophisticated level of understanding (Larsen et al., 2018). Learning Progressions have an upper and lower anchor and levels of understanding (Figure 22). The lower anchor represents the emerging knowledge students have as novice learners of a construct or practice and the upper anchor is a depiction of what learners should know and be able to do after learning has occurred.

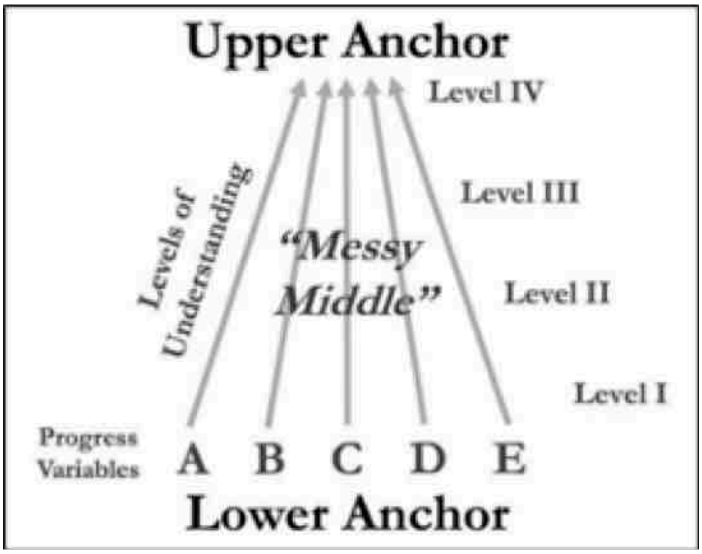

Figure 22: Learning progression components (after Larsen et al., 2018)

Huynh et al. (2015) suggest a Learning Progression typically comes in three stages. The first stage involves the creation of a hypothetical progression based on core ideas and skill sets. In the second stage, the lower and upper anchors are refined by researchers based on their experience with students and develop resources and potential assessment materials related to a particular concept. Finally, in the third stage, experiments are conducted to trace student learning over time. Student understanding is assessed through a set of progress variables (Gunckel et al. 2012). Throughout a detailed and iterative process, researchers work to edit and revise the Learning Progression based on their interactions with students (Stevens et al. 2015).

The GeoProgressions project (Solem,, Huynh and Boehm, 2015) was an initial look at the potential value of applying learning progressions to maps, geospatial technology, and spatial thinking, suggests that this line of scholarly research has significant potential to transform aspects of geography education (Huynh et al., 2015).

De Miguel González and De Lázaro Torres (2020) present the Digital Atlas for Schools (ADE) and discuss different learning methods, progression models and tools (Table 6). Empirical research on learning results and benefits from learning with ADE are described. They show how ADE is a powerful tool to help learn geography as it fosters more meaningful learning than conventional instructional resources. It helps in the goal to balance spatial thinking, geographical knowledge and spatial citizenship. School and higher education participants experienced effective learning implementing the Digital Atlas, although this was more marked in the secondary school geography students.

Table 6: Learning progression for spatial thinking with the Digital Atlas

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

Zwartjes (2018) presents the GI Learner project and the concept of learning lines. A learning line is an educational term for the construction of knowledge and skills throughout the whole curriculum, reflecting a growing level of complexity, ranging from easy (more basic skills and knowledge) to difficult (Lindner-Fally & Zwartjes, 2012). GI-Learner aimed to help teachers, and in the longer-term governments, implement learning lines for geospatial thinking in secondary schools. In order to do this, the project defined a set of 10 geospatial thinking competencies, created learning lines and translated them into learning objectives and teaching and learning materials for the whole curriculum (K7 to K12). Each block of learning builds on the previous (Figure 23).

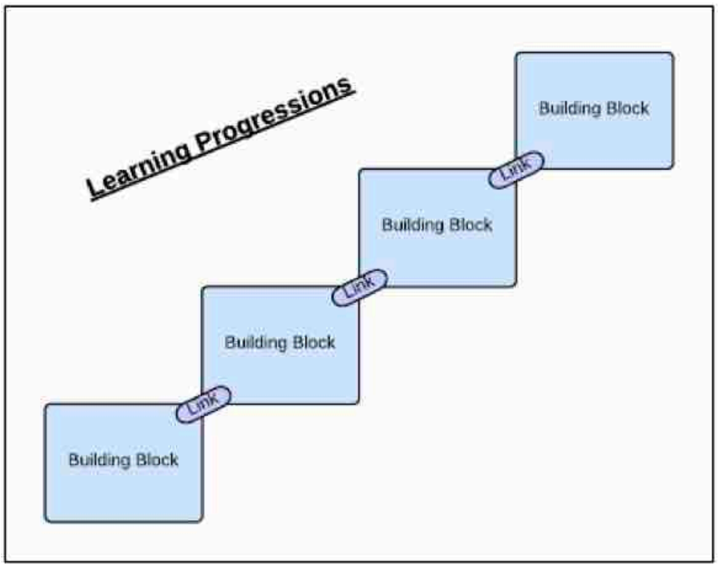

Figure 23: A learning line showing learning progression

A 'learning line' as an overall framework for education and training, with a distinct sequence of steps from beginners to experts, it is analytical; i.e. it distinguishes in detail the skills, knowledge and attitudes on several levels that may be expected. It is competence-based, as it distinguishes a set of competences that together build the overall competence in the field (Zwartjes, 2019).

De Miguel (2016) gives an overview on learning lines and the integration with the geographical inquiry process (Table 7).

Table 7. Learning lines and geographical inquiry process

	Zwartjes	Roberts	Kerski	Arayo, Souto and Herrera
Level 1	Perceiving	Creating a need to know	Asking Geographical questions	Perceiving geographical environment

Level 2	Analysing	Making sense of geographical information	Acquiring geographical resources	Analysing geographical environment
Level 3	Structuring	Reflecting on learning	Exploring geographical data	Interpreting geographical environment
Level 4	Applying		Analysing geographical information	Acting on geographical environment
Level 5			Acting on geographical knowledge	

6.6 Cognitive Load Theory

Cognitive load theory has developed into an influential learning theory based on our knowledge of human cognition supported by a robust evidence base (Sweller, 2011). The theory assumes that knowledge can be divided into biologically primary knowledge that are generic and we have evolved to acquire and secondary knowledge that is usually domain specific, important for cultural reasons and that requires explicit instruction in education contexts. Secondary knowledge, unlike primary knowledge, is the subject of teaching and learning. In terms of secondary knowledge, human cognition requires a very large information store, the contents of which are acquired largely by obtaining information from other information stores. Only very limited amounts of new information can be processed at any given time. In contrast, very large amounts of organized information stored in the information store can be processed in order to generate complex action.

A major function of cognitive load effects is to provide specific instructional design guidelines (Sweller, 2020). Intrinsic cognitive load is determined by the intrinsic properties of the information being processed. Extraneous cognitive load is determined by instructional procedures, those that use teacher materials. The extrinsic approach is understood as good instructional material. The vast majority of the cognitive load effects are due to changes in extraneous cognitive load.

Sweller (1988) suggested the cognitive load imposed on a person using a complex problem-solving strategy may be an important factor interfering with their learning. Cognitive load theory provides teaching recommendations based on our knowledge of human cognition (Sweller, 2020). Secondary knowledge is firstly processed by a limited capacity, limited duration working memory before being permanently stored in long-term memory from where unlimited amounts of information can be transferred back to working memory to govern appropriate action. The theory uses this cognitive architecture to design teaching and learning procedures relevant to complex information that requires a reduction in working memory load. Many of these procedures can be most readily used with the assistance of educational technology.

Howarth and Sinton (2011) gather strategies to reduce the difficulty of problem-based learning based on research in cognitive load theory. A major focus concerns cognitive structures (problem schemata) that allow students to recognize the categories of problem states, based on their possible solutions or allowable moves (Sweller, 1988). The acquisition of problem schemata may be affected by the intrinsic complexity of the problem, the extraneous load from the design of the learning material and the germane load, resulting from activities that facilitate the acquisition of schemata into long-term memory (Sweller, 2010). Problem-based learning should be designed to manage these sources of cognitive load in order to facilitate the learning of problem schemata. Didau (2019) describes schema theory, where the ability to reclaim items in memory is dependent on cues and prompts that help us to retrieve some connected information.

Solving problems with GIS is a complex undertaking as students must learn and apply general spatial concepts (e.g. location, distance, hierarchy), concepts of spatial representation and analysis with GIS (e.g. raster, vector, buffer), and spatial representation and analysis that are specific to particular GIS platform Howarth and Sinton, 2011). Students must also deal with the subject content and concepts that are specific to the problem. It is suggested that teachers may reduce the problem-solving complexity with GIS by carefully providing a learning sequence (Shibli and West, 2018). Coe (2020) describes retrieval practice, which can be done using a variety of activities. It has been found to be one of the most useful techniques to improve student learning in various contexts, justifying its wide spread use by teachers (Dunlosky et al., 2013). Research has shown that rereading and creating concept maps is not as effective as the testing effect of quizzes, despite many students using these approaches (Sumeracki and Weinstein, 2018).

Repeated retrieval using activities of increasing difficulty has been found to be very beneficial for learning, although it is important that teachers monitor and adjust strategies accordingly (Kapler et al, 2015). There is little difference between using short answer (which are harder) and multiple choice questions (which are easier to mark), or a hybrid format, nor does the timing of the questions within the lesson make a difference long term (Little et al, 2012) – but what is key for learning, is the importance of providing sufficient opportunities for retrieval whether it be interspersed quizzes throughout the lesson or afterwards. In reality, the teacher has to have the skills to ask good questions. Teachers therefore need guidance to help them develop their capabilities to establish what works.

Cognitive Load Theory suggests that the more intermediate steps a problem has, the greater the strain on working memory to keep all of the variables organized and the greater the challenge to anticipate how they will interact with one another as solutions are envisioned. Methods for sequencing material can be based on the types of task and strategies for chunking problems can be based on the length and structure of solutions (Doering and Veletsianos, 2007). The level of guidance provided by the teacher during problem solving is a further issue as research has shown that teaching through worked examples, where students are presented with a problem and work through its solution prior to having students solve problems independently, can facilitate more effective learning (Sweller, 1988).

Sweller (2020) seeks to provide guidance concerning which educational technologies are likely to be effective and how they should be used to identify those aspects of human cognition and evolutionary psychology that are relevant to instructional design. The major function of the cognitive load effects is to provide specific teaching guidelines that are directly relevant to technology-based education.

Sweller and Sweller (2006) propose five principles in which humans can acquire novel, secondary information:

- Randomness as genesis, randomly selecting a possible solution and testing it for effectiveness closer to the goal
- Borrowing and reorganising principle, dealing with secondary information from others for which we do not have previously acquired knowledge, combining it with previously stored information before the new information is itself stored.
- The narrow limits of change principle, describes the manner in which that information is initially processed by working memory.
- The information store principle, once processed by working memory, domain-specific, secondary information can be stored in long-term memory for later use.

- The environmental organising and linking principle, on receiving appropriate signals, information previously stored in long-term memory can be transferred to working memory to generate action.

Sweller (2020) summarises the instructional effects generated by Cognitive Load Theory (Table 8) and confirm that Cognitive Load Theory is directly applicable to technology-assisted learning and that many of the instructional procedures generated by the theory are difficult to use without the assistance of educational technology.

Table 8: A summary of some instructional effects generated by Cognitive Load Theory

Instructional Effect	Description
Worked example	Studying worked examples is superior to solving the equivalent problems
Split-attention	If multiple sources of information need to be considered simultaneously, physically integrating them is superior to requiring learners to split their attention between them
Modality	If a diagram and text need to be considered simultaneously and the text is simple and short, presenting the text in spoken rather than written form is superior
Transient	High element interactivity information should be presented in permanent rather than transient form or presented in smaller chunks
Redundancy	Eliminating unnecessary information results in superior learning
Expertise reversal and element interactivity	With increases in expertise and decreases in element interactivity, information that is essential for novices becomes redundant for more expert learners, decreasing learning
Working memory depletion	Working memory use depletes working memory resources that recover after rest

A better understanding of the design of multimedia learning materials is one of the ongoing research areas (Mayer, 2008). The effectiveness of visual methods for teaching spatial concepts will support less experienced learners. But may impede learning for more advanced students (Kalyuga, 2020). Chandler and Sweller (1991) discuss the split attention effect, which can be caused if a diagram and the text are not physically separated and so requires the learner to integrate them, increasing the cognitive load and consequently reducing the capacity of the working memory. So, according to Chandler and Sweller (1991; 293), "Cognitive Load Theory suggests that effective learning materials facilitate learning by directing cognitive resources towards activities that are relevant to learning", practically implemented for instance by designing visuals like Powerpoint to avoid overload Tharby (2019).

Castro-Alonso et al. (2019) examine Cognitive Load Theory in relation to visualisations, both in static (e.g., illustrations and photographs) and in dynamic formats (e.g. animations and videos). They found that though students enjoy these materials, their emotions and opinions are not always related to learning taking place. Effective learning under these conditions is working memory processing. They showed that instructional visualizations can optimize cognitive processing, and thus be effective tools for learning about health and natural sciences. They described cognitive methods for increasing the effectiveness of these visualisations; and portray how visuospatial processing impacts on science learning through visualizations (Table 9).

Table 9: Methods to optimize visualizations and examples for visuospatial information (after Castro-Alonso et al., 2019)

Cognitive load theory	Cognitive theory of multimedia learning	Example of solution

Split attention effect	Spatial contiguity principle	Physically integrate the visuospatial information
Modality effect	Modality principle	Present some information auditorily
Redundancy effect	Coherence principle	Delete unimportant visuospatial information
	Signalling principle, using visual cues to the main focus	Signal important visuospatial information
Transient information effect		Avoid fast-paced visuospatial information

CESE (2018) identify and illustrate seven teaching strategies that can help teachers to maximise student learning (Figure 24). These strategies work by optimising the load on students' working memories.

Figure 24: Teaching strategies from cognitive load theory (CESE, 2018)

Related to Cognitive Load Theory, Enser (2019) explains some implications for teachers, they need to manage the intrinsic difficulty of learning and tasks and 'extraneous' load, by providing steps, with scaffolding, over time, teachers should gradually remove the scaffolding to enable students to move towards independence. Worked examples should be used which eliminate non-essential information and dual coding should be used presenting oral and visual information together and regularly review the learning taking place.

Brookman-Byrne and Thomas (2018) discuss the important links for learning between neuroscience and education. They suggest its relevance to better understand the processes that underlie the mechanisms of learning. Ways of understanding the brain have included measuring oxygenated blood flow to link functions to energy used, brain activity and eye tracking and the concept of left and right brain learners.

According to Sherrington (2019), based on the simple model of how the brain works, as the working memory is so limited, learning needs to develop schema in the long-term memory able to connect new information to existing knowledge (Figure 25). This can then be reinforced by practice in recalling newly learn material which helps to reduce cognitive overload, and the more fluent this retrieval of stored information becomes the greater capacity the working memory will have for new learning, which describes the difference between novice and expert learners. Sequencing concepts and modelling requires advanced planning as ideas should be presented in small steps, one at a time and supported with clear and detailed explanations. Teachers should model these steps by thinking 'out loud' and reteaching bits, if needed.

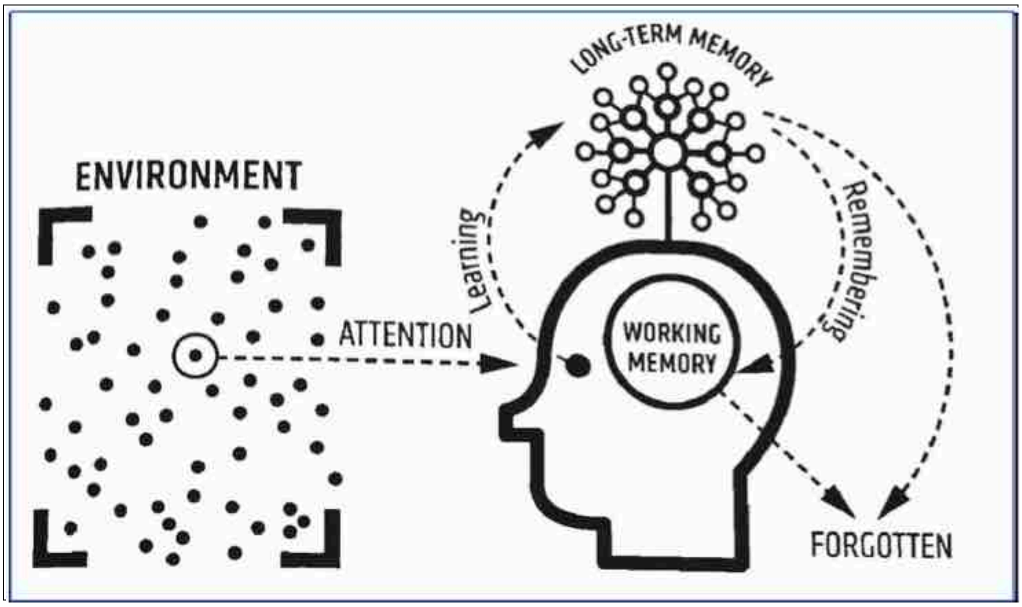

Figure 25: Modelling the brain (Sherrington, 2019)

Practice lies at the heart of learning, and needs to be guided using a variety of learning activities which 'rephrase, elaborate and summarise new material' making sure that there is a high success rate, which is important for the less knowledgeable students, to help them form schema early on, and build confidence.

Sherrington (ibid) suggests that planning of resources should take place so all students can achieve success in their learning. The ultimate goal of teaching should be independence, with a transition from guided scaffolded practice. The students can start to set their own goals for improvement based on feedback as support is reduced. Sherrington suggests involving the students in well-structured collaborative learning tasks, which Rosenshine (1986) called cooperative learning, so they can practice by explaining and questioning one another.

According to Howard-Jones et al. (2018), the 'Science of learning' provides a useful framework for classroom practice, and is a good starting point for breaking down learning into different component processes for analysis (Figure 26). Teachers focus on specific aspects of the learning such as learner engagement, which involves subcortical processes influencing cortical brain activity and readiness to learn through praise and reward; building knowledge and understanding by activating working memory, where effective teachers concisely communicate two-way meaningful connections between new and prior knowledge; consolidation of learning by creating recall efforts moving knowledge to long term memory. They suggest that as the engage – build – consolidate processes occur simultaneously, they can be used as a simple means of understanding learning better rather than a prescriptive model for classroom practice. These principles are only starting to be applied to teaching, so there is still a need for teachers to base their decisions on their own ideas about how the learning they observe takes place in their own classrooms and not simply on these scientific terms. There are considerable gaps that exist with this theoretical base.

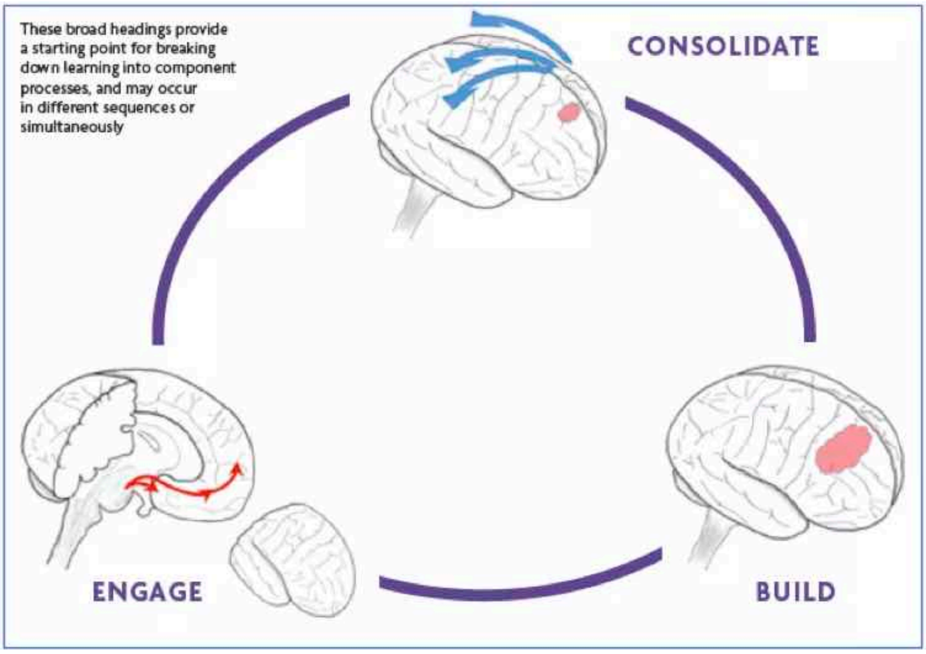

Figure 26: Learning process categories (Howard-Jones et al., 2018)

7 Training teachers for GIS

Crespo (2019) raised the need to train competent teachers capable of creating digital content and use learning environments. He said the knowledge of the numerous digital cartographic resources offered online and recognising their didactic potential would be a necessary first step for such training. He stated that online mapping tools not only represent a significant advance in the possibilities of analysing landscape, but their use also contributes positively to developing skills that can help students demanded today and in the future. The use and application of technology therefore should be integrated into curricular content.

Höhnle et al. (2016) presented research about optimising the use of geoinformation in geography classrooms in Germany through the improvement of teacher training. They address the features of effective training activities and present the result of their research project aiming at improving implementation of GIS in German schools. They provided a list of features of effective professional development activities were compiled for teacher training and GIS (Table 10).

Table 10. Empirically deduced recommendations for the conception of GI training activities in continuing teacher education (adapted from Höhnle et al., 2016)

Teacher education features	Requirements for training activities	Training activity design
duration, time budget	structured as continuing cumulative events	support over a longer period of time / regular refresher courses / reduction of lessons for participating teachers / ongoing support
professional learning communities	Participation of teacher teams	cooperation between teachers / integration of different subjects / ongoing support of learning community / regular face-to-face meetings in online-based communities
institutional framework conditions	formal support for training; activities promoted, provision of tools, software and data	training organization at school / offer general technology training for teachers as a precondition for GIS
integration of different expertise	abilities of teacher trainers	inclusion of different experts and experienced teachers
subject-matter knowledge, reference to curriculum	focus on concrete reference to the classroom and to teaching practice	two-step model: first technical introduction, then didactical introduction / formulation of standards for each age group / common GIS curriculum / individual assistance for development of curricular plans / learn how to customize lesson plans
close consideration of findings of classroom research	demonstration of didactical added value	non computer-based introduction to GIS concepts / discussion of opportunities for GIS in learning of students / orientation of principles for inquiry-based learning
Making co-creation possible		work on a student project with local reference for teachers / time to exchange ideas and experiences between teachers / know experience of participants before start / use stages with interim results / program flexibility to meet teacher interests and needs
phases of input, development, testing, and reflection	inclusion of practical exercises; promote contact, exchange, and cooperation between teachers; make a	make concrete teaching examples available for orientation / creation of video clips of successful projects for presentation / own design of teaching units, training activities according to

	detailed handout available with all the materials	inquiry-based learning principles / exchange of materials / integrate field trip for acquiring and preparing data / hands-on activities / working with own laptop / divide program into various sessions so teachers can check out things in their own classroom in between / integrate homework for the teachers / detailed handout, video tutorial, software tutorial ...
experiencing own efficacy, feedback, coaching	intense personal support and advice	discuss questions / discuss own teaching units or experiences / technical and moral support

Hong, and Melville (2018) introduce an approach to designing effective GIS professional development based on six features: (1) collective participation, (2) practice time, (3) time for lesson development and presentation, (4) state and national standards, (5) district support and direct involvement, and (6) professional support. They concluded that practice time, time for lesson development and presentation, and district support and direct involvement appeared to be crucial to making GIS professional development successful.

Mitchell et al. (2018) highlighted the importance of establishing well-structured professional development that builds community, integrates diverse content and pedagogical expertise, provides feedback and coaching, and is of sufficient duration to effect change. They indicated professional development would take more time than expected and require follow-up and coaching for greater effectiveness. Developing geographic thinking and working with traditional geographic concepts (scale, pattern, region, diffusion, etc.) should be equally important to developing technological proficiency.

Millsaps and Harrington (2017) used the TPACK and SAMR model to create a teacher training framework (Table 11).

Table 11: The SAMR model for training teachers (Millsaps and Harrington, 2017)

SAMR Model		
Transformation	Redefinition	Technology allows for the creation of new tasks, previously inconceivable
	Modification	Technology allows for significant task redesign
Enhancement	Augmentation	Technology acts as a direct tool substitute, with functional improvement
	Substitution	Technology acts as a direct tool substitute, with no functional change

Hong (2017) reports on a case study about designing GIS learning materials for K-12 teachers, based on a User Centred Design (UCD) approach (Figure 27), which assumes that knowledge is constructed by active learners (Sharp et al, 2007). A UCD approach is a framework to design and develop a user-friendly product, system or interface based on considerations of user needs, objectives and their specific circumstances (Baek et al., 2008).

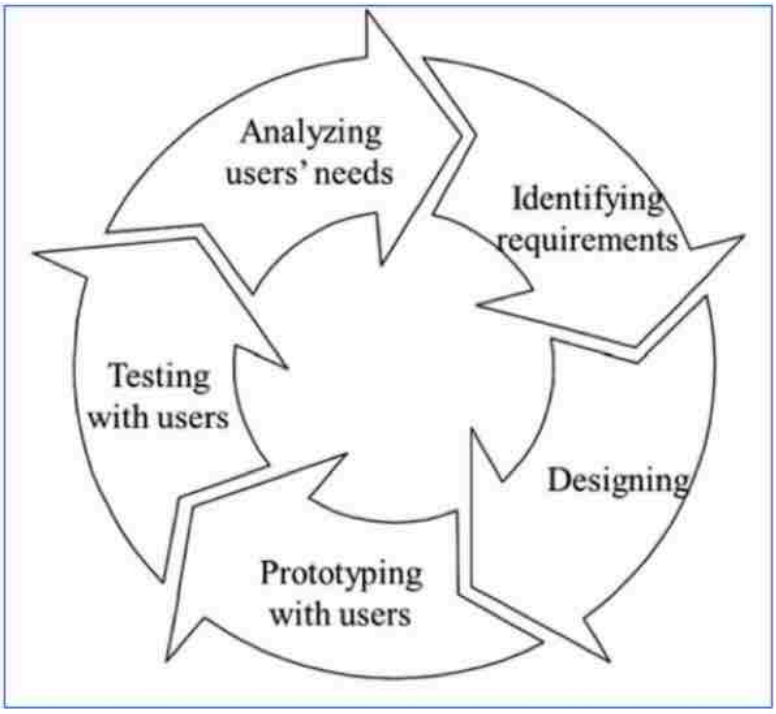

Figure 27: The User Centred Design (UCD) model (adapted from Sharp et al., 2007)

Donert et al. (2016) introduce the GI Learner approach that models how secondary schools could adopt a GIScience learning line from age groups K7 to K12 taking into account the age and capabilities of students. This can be achieved by the integration of spatial thinking and the translation of spatial competences into real learning objectives. The article presents GI-Learner competences based on a broad literature review and establishes a roadmap for support activities for geospatial learning in schools.

Walshe (2017) explored the responses of trainee geography teachers to a GIS training programme (Table 12) across their postgraduate education year.

Table 12: Training programme for Geography trainee teachers (Walshe, 2017)

	Activity	Overview	GIS focus
September	Introduction to GIS	Practical introduction using open source data to explore recent Chilean earthquake, analysing a global event	Set up accounts, basic skills including measuring distance, adding map notes, importing external data (from USGS) into GIS, creating cross sections using elevation profile app, create simple Story Maps
November	GIS fieldtrip	Two days exploring the use of ArcGIS Online in field-based geographical enquiry, trainees consider how GIS can develop critical spatial thinking during full enquiry sequence.	Introduction to Collector app for ArcGIS, adding fieldwork data, using a range of mapping options, such as heat maps to display data, planning routes using proximity tools
December	GIS training	Advanced data analysis workshop with specific referenced to drainage basin river flooding	Use a range of find location tools, including creating watersheds and tracing rivers downstream, use a range of external data including flood risk data to

		analysis. Development of TPCK through designing enquiry-based lesson plans.	examine risks, use Scene to view 3D topography
December	Training for school mentors	Introduction to GIS	Setting up accounts, basic skills, measuring area distance and adding map notes, importing external data into GIS as csv files
January	Story Map activity	Trainees produce a StoryMap on the geography of their school'c catchment to include a range of socio-economic data such as Index of Multiple Deprivation	More complex Story Maps, sourcing socio-economic data and importing into GIS, creating choropleth maps from different indicators
March	GIS training day	Practical training and support session by a practising teacher	Accessing crime data, importing into GIS, spatial analysis tools including the interpolation tool to produce isoline maps, hot spot analysis, surface density mapping, use proximity tools buffer and find nearest. Use mobile devices to support GIS: Collector app and Snap2Map.
May	ESRI conference	Optional participation to develop expertise in using GIS and observing industry-based applications.	Observe industry-based applications of GIS, supporting existing teachers, Introduction to ArcGIS Online Sways
June	Geography students train biologists	Plan and run a training session o GIS for biologists.	Access Story Map gallery, Importing external data and adding internal map layers e.g. relating to ecosystems, flora and fauna populations, patterns of disease
June	Dissemination event	Share examples of their practice to each other.	Share ideas and resources
June	GIS training for mentors	Training for mentors with presentation by a trainee teacher	Basic skills, including measuring distance and adding map notes, importing external data into GIS as csv, creating cross-sections using the Elevation Profile app, creating simple StoryMaps using templates, working with IMD data and producing choropleth maps, using Collector app to support fieldwork

The most successful trainee teachers had previous experience with GIS making then more self-confident. All trainees quickly learned the potential GIS has for supporting enquiry-based learning using geospatial data. It was very important for them to deal with practical, relevant examples of how GIS can be used to support learning in the classroom. Being aware of the relevance and usefulness of GIS and web-based GIS were more important that knowing about the different applications of GIS in schools. Nevertheless, the appears to be strongly on learning GIS skills, learning about GIS, rather than the geography or learning with GIS, or effective pedagogy for both e.g. what pedagogical model is most effective for teaching with or about GIS; how can teaching with or about GIS help to improve a teacher's pedagogy?

Kuijpers (2019) examined the extent to which it is possible to support teachers from secondary education with the introduction of GIS in their classes, for instance by using university teachers to help them integrate content, pedagogical and technological knowledge. After a test with a class, students were positive about the lesson, the teacher was inspired, and the GIS specialist thought it was an educational experience to be able to transfer his knowledge to the teacher and students.

Tate and Jarvis (2017) were concerned with Communities of Practice (CoP) and the importance of informal social participation for learning. They explored how CoPs and in particular virtual CoPs might assist with learning to use GIS as some of these communities are linked with MOOCs and particular qualification programmes.

8 Conclusions

Teachers are the "gatekeepers" of educational change and educational innovation. It is therefore important to devote time and care to their training in pedagogical developments such as those associated with learning with GIS. Much of the research gave information about teacher practices using geotechnologies, but most teachers had not benefited from adequate training and support and they had not mastered most of the concepts embedded in GIS material.

Stringer et al. (2019) gave four key recommendations for using technology:
1. Consider how technology is going to improve teaching and learning before introducing it.
2. Develop a clear rationale for improving the learning.
3. Consider ways to improve the impact of pupil practice.
4. Address improving assessment and feedback.

From this review it is the pedagogy associated with applying the technology that matters most, as learning is affected by how the technology has been used in the classroom (Quinn, 2019). Writing about the GI Learner Project, Donert et al. (2016) confirmed that "„…there is still a need for much more training, additional learning and teaching materials, more examples of good practice, and a comprehensive and well-structured compilation of digital-earth tools."

8.1 Recommendations for GI Pedagogy

Stringer et al. (2019) illustrated issues from academic literature concerning the impact of GIS technology and offer evidence about implementation and effective teaching practice. They suggest poor implementation is the main reason why technology has not realised its potential to improve learning. The challenge is to synthesise from the literature how this can be achieved.

The following are clearly identified recommendations from the literature produced for consideration:

Planning
- Plan training based on real needs and link GIS use to curriculum planning (Stringer et al., 2019).
- Model a way to naturally incorporate GIS tools into teaching (Curtis, 2019).
- Involve teachers in the process of developing instructional materials, using a user-centred design (UCD) method (Hong, 2014).
- Plan to integrate technology fully using it with other resources, rather than use it a one-off learning activity (Luckin et al.., 2012).
- Concerning Rosenshine's principles, subjects should draw on a variety of lesson types and activities which may well lead to subject specific models for developing knowledge, giving practice and checking understanding, and that to get better at any of them, this needs to focus on one at a time (Sherrington, 2019).
- Create inclusive educational practice, organise learning into levels based on the learner's knowledge background and learn how to appropriately construct teaching materials (Rickles and Ellul, 2017).
- "programmes need a balance between training which provides clear examples of how GIS can be used in the classroom on the one hand, and instruction that requires trainees to learn at a higher, more abstract level in order to support learning for understanding and transfer (Bednarz, 2004) on the other" (Walshe, 2017;620)
- Develop teacher training for teachers with similar levels of expertise and knowledge sets to enhance their ability to connect geospatial technologies with their curricula (Curtis, 2019).

Approach

- Use many types of active learning approach, from situations where students worked with a local organisation (Benhart, 2000), problem-based learning where students solved a problem (King, 2008), field based techniques where students were involved in a field based enquiry (Carlson, 2007) and web-based interactive learning modules (Clark et al., 2007).
- Learning design should consider threshold concepts, be problem based, offer flexible learning pathways in an authentic learning context with active learning approaches and encourage multidisciplinarity (Srivastava and Tait, 2010).
- Make GIS use in education enquiry-driven, problem solving and standards-based with a set of tasks that incorporates fieldwork (Baker et al., 2012).
- Integrate technical aspects of GIS with case studies (Bearman et al., 2016).

Pedagogy

- Develop critical spatial thinking from a pedagogical point of view (Bearman et al., 2016).
- Develop a flexible pedagogical framework that teaches not only about GIS but associated concepts (Rickles and Ellul, 2017).
- Use GIS to help develop critical spatial thinking, by using authentic data and connect students to their own community (Baker et al., 2012).
- Use elements related to spatial citizenship and the Spatial citizenship Web site http://www.spatialcitizenship.org/ (Gryl et al., 2010)

Practical recommendations

A) Based on student learning

- Include Cognitive Load Theory principles as ~~a~~ foundation for training teachers (Rosenshine, .
- Adapt practice by increasing the challenge of questions and providing new contexts for pupils to apply their skills (Stringer et al., 2019).
- Give support for retrieval practice and self-quizzing to increase retention of ideas and knowledge (Stringer et al., 2019).
- Provide meaningful learning through identification of geographical problems, geographical skills and geographical knowledge (De Miguel, Koutsopoulos, and Donert 2019).
- Adapt pedagogical practice so that it takes account of the findings of cognitive science and especially the interaction of working memory and long-term memory, building of schema; notion of novice and expert (Rosenshine, 2012; Sherrington, 2018)
- One way to do this is to follow
- Rosenshine's Principles of Instruction.
- Look at the impact of the pedagogy and approach, as well as the subject being taught and the specifics of the school context (Stringer et al., 2019), including narrative and the power of stories.
- Motivate student learning through employability skills like analysis of spatial information, georeferencing, visualisation or mobile applications (MYGEO).

B) Based on tools

- Use web maps and their analysis, Web-based GIS and create web map applications (Kerski and Baker, 2019).
- Use geotechnologies to improve the capacity to handle geographic information as a part of their digital culture (Sanchez, 2009).
- Use visuals correctly for communicating complex ideas in an efficient way, leaving more cognitive resources free to engage in higher order thinking (Caglioli, 2018).
- Compile ArcGIS materials suitable for national conditions and student characteristics and provide supporting materials for teachers, and set up relevant websites (Wu, 2018).

- Collect data using collaborative mapping tools based on citizen contributions, to allow mapping real time data (Kerski and Baker, 2019).

Networking

- Develop a “Community of Practice” to support teachers learning (Tate and Jarvis, 2017), involving teachers mentoring teachers.
- Develop a school network of geospatial classrooms with the mission for making geospatial education accessible to all, similar to GeoForAll (Donert et al., 2016).
- Establish a GeoMentoring programme for teachers with teachers and trainers (Healey et al., 2018)

References

Alibrandi, M. and Palmer-Moloney, J., (2001). Making a place for technology in teacher education with Geographic Information Systems (GIS). Contemporary Issues in Technology and Teacher Education, 1(4), pp.483-500.

Allier-Gagneur, Z., McBurnie, C., Chuang, R. and Haßler, B., (2020), Characteristics of Effective Teacher Education in Low-and Middle-Income Countries. What Are They and What Role Can EdTech Play.

Álvarez-Otero, J., and de Lázaro y Torres, M.L. (2018) Education in Sustainable Development Goals Using the Spatial Data Infrastructures and the TPACK Model. Education Sciences, 8(4), 171.

Ardissono, L., Lucenteforte, M., Mauro, N., Savoca, A. and Angioletta, V., (2017). Personalised community maps. Int. J. Electronic Governance, Vol. 9, Nos. 1/2, 156-178

Arslan, S., (2015). Evaluation of Usability of Web-based Geographic Information System (GIS) Applications in Secondary School Geography Lessons (Doctoral dissertation, Fatih University, Turkey).

Attard, M., (2010). Thematic networks as toolboxes: The case of the HERODOT Network for Geography in Europe. Documents d'anàlisi geogràfica, 56(2), pp.325-337.

Baddeley, A D. (1992) Working memory. Science 255: 556-559.

Baek, E. O., Cagiltay, K., Boling, E., and Frick, T. (2008). User-centered design and development. Handbook of Research on Educational Communications and Technology, 1, 659–670.

Baker, T. R., Battersby, S., Bednarz, S. W., Bodzin, A. M., Kolvoord, B., Moore, S., Sinton, D., and Uttal, D. (2015). A Research Agenda for Geospatial Technologies and Learning, Journal of Geography, 114:3, 118-130

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

Baker, T.R., Kerski, J.J., Huynh, N.T., Viehrig, K. and Bednarz, S.W., 2012. Call for an agenda and center for GIS education research. Review of International Geographical Education Online, 2(3), pp.254-288.

Bartle, E. (2015), Personalised learning: an overview, The Institute for Teaching and Learning Innovation, Queensland University, https://itali.uq.edu.au/files/1279/Discussion-paper-Personalised_learning_an_overview.pdf

Bearman, N., Jones, N., André, I., Cachinho, H. A., and DeMers, M. (2016). The future role of GIS education in creating critical spatial thinkers. Journal of Geography in Higher education, 40(3), 394-408.

Bednarz, S. W. (2004). Geographic Information Systems: A Tool to Support Geography and Environmental Education? GeoJournal 60(2): 191-199

Bednarz, S.W. (2001) Thinking spatially: incorporating geographic information science in pre and post secondary education, vol. 2008, Geographical Association, Sheffield, UK

Belgiu, M., Strobl, J., & Wallentin, G. (2015). Open geospatial education. ISPRS International Journal of Geo-Information, 4(2), 697-710.

Benhart, J. (2000) 'An approach to teaching applied gis: Implementation for local organizations'. *Journal of Geography,* 99(6), 245-252

Bonnstetter, R. J. (1998). Inquiry: Learning from the past with an eye on the future. Electronic Journal of Science Education, 3(1). http://ejse.southwestern.edu/article/view/7595/5362

Bowlick, F. J., Bednarz, S. W., and Goldberg, D. W. (2016). Student Learning in an Introductory GIS Course: Using a Project-Based Approach. Transactions in GIS 20(2): 182-202

Brookman-Byrne, A. and Thomas, M.S., (2018). Neuroscience, psychology and education: Emerging links. Impact, 2, pp.5-8.

Brooks, B.L. (2018), Student Engagement Capabilities in Mobile GIS: A Framework for Mobile GIS Education, Thesis Presented to the Faculty of the USC Graduate School. 58 pp.

Caeiro, S., Martinho, A.P., Matta, H., Amador, F. and Oliveira, C., (2011). The use of videos within GIS e-learning. An experience in an undergraduate program in Environmental Science. In Hubeau M, Steenberghen T, Van Balen K and Van J, p.49-56. LeGio Workshop: GIS-education in a changing academic environment, Leuven Belgium

Caglioli, O (2018), An introduction to Dual Coding Theory - Oliver Caglioli; Future Learn

Caldwell, T., 2019. Tech for Understanding: An Introduction to Assistive and Instructional Technology in the Classroom. Montview Liberty University Journal of Undergraduate Research, 6(1), 5-33.

Camburn, E., Rowan, B. and Taylor, J.E., (2003). Distributed leadership in schools: The case of elementary schools adopting comprehensive school reform models. Educational evaluation and policy analysis, 25(4), pp.347-373.

Carlson, T. (2007), A field-based learning experience for introductory level GIS students. *Journal of Geography,* 106(5), 193-198.

Castro-Alonso, J.C., Ayres, P. and Sweller, J., (2019). Instructional visualizations, cognitive load theory, and visuospatial processing. In *Visuospatial processing for education in health and natural sciences* (pp. 111-143). Springer, Cham.

CESE (2018), Cognitive load theory in practice: Examples for the classroom, New South Wales Government, Australia,
https://khsbpp.files.wordpress.com/2018/11/cognitive_load_theory_practice_guide_aa.pdf

Charles, M. T., and R. A. Kolvoord. (2016). Geospatial semester: Developing students' 21st century thinking skills with GIS: A three-year study. Pyrex Journal of Educational Research and Reviews 2 (6):67–78.

Chen, M. X. (1997). Integrating GIS education with training: A project-oriented approach. Journal of Geography, 97, 261-268.

Christensen, R. and Knezek, G., (2017). Readiness for integrating mobile learning in the classroom: Challenges, preferences and possibilities. Computers in Human Behavior, 76, pp.112-121.

Coe, R. (2020) Does research on retrieval practice translate into classroom practice? Impact Journal of the Chartered College of Teaching, Issue 8. P12-13.

Coe, R., Rauch, C.J., Kime, S. and Singleton, D. (2020), Great Teaching Toolkit: Evidence Review, Cambridge Assessment International Education.

Colvin, J. C., and M. C. Tomayko. (2015). Putting TPACK on the radar: A visual quantitative model for tracking grown of essential teacher knowledge. Contemporary Issues in Technology and Teacher Education 15 (1):68–84

Conners, F. A., McCown, S. M., and Roskos-Ewoldsen, B. (1998). Unique challenges in teaching undergraduate statistics. Teaching of Psychology, 25(1), 40–42.

Coulter, B. (2014). Moving out of flatland: Toward effective practice in geospatial inquiry. In J. G. MaKinster, N. M. Trautmann, and M. Barnett (Eds.), Teaching Science and Investigating Environmental

Issues with Geospatial Technology: Designing Effective Professional Development for Teachers, pp. 398–423. Dordrecht, The Netherlands: Springer

Crespo, J.M. (2019). El visualizador Iberpix 4 del Instituto Geográfico Nacional: un recurso didáctico para la interpretación de los componentes físicos del paisaje. En: Enseñanza de las Ciencias de la Tierra, 2019 (27.2.), pags. 182 – 191.

Curtis, M.D. (2018), Professional Technologies in Schools: The Role of Pedagogical Knowledge in Teaching With Geospatial Technologies, Journal of Geography, 118:3, 130-142.

De Lázaro y Torres, M. L., De Miguel, R., and Buzo, I. (2016). Outdoor Learning and Geography on the Cloud: A Challenge for the European "School on the Cloud" Network. The International Journal of Technologies in Learning, 23(3), 1-13.

De Lázaro y Torres, M. L., De Miguel, R., González, M.J. (2018), Flipped Teaching: A Useful Method for Cloud-Based GIScience Learning, Handbook of Research on Educational Design and Cloud Computing in Modern Classroom Settings, chapter16, pp. 342–367

De Lázaro y Torres, M.L., De Miguel González, R. and Morales Yago, F.J., (2017), WebGIS and geospatial technologies for landscape education on personalized learning contexts. ISPRS International Journal of Geo-Information, 6(11), p.350.

De Lázaro y Torres, M.L.; Álvarez, J. Y. and González, M.J. (2016). Aprender Geografía de España empleando SignA. En Sebastiá, R.; Tonda, E.M. (Eds.). La investigación e innovación en la enseñanza de la Geografía. San Vicente del Raspeig: Universidad de Alicante, pp. 27-39.

De Miguel González, R., Buzo, I. and De Lázaro, M.L., (2016). New challenges for geographical education and researching: The Digital School Atlas. In Crisis, Globalization and Social and Regional Imbalances in Spain; Spanish Contribution to 33rd IGU Congress Beijing, pp. 187-197.

De Miguel González, R. and De Lázaro Torres, M.L., (2020), WebGIS Implementation and Effectiveness in Secondary Education Using the Digital Atlas for Schools. Journal of Geography, 119(2), pp.74-85.

DeMers, M.N., 2016. Geospatial technology in geography education. The Geography Teacher, 13(1), pp.23-25.

Demirci, A., Karaburun, A., Ünlü, M. and Özey, R., 2010. How does GIS mobilize students to work for society? Conducting GIS-based projects in geography lessons. Istanbul, Turkey, 8, p.13-21

DiBiase, D. (2018). Stop teaching GIS. AAG Newsletter. April. http://news.aag.org/2018/04/stop-teaching-gis/

Didau D (2018), How to explain …. Schema, https://learningspy.co.uk/featured/how-to-explain-schema/

Doering, A., Veletsianos, G., Scharber, C. and Miller, C., (2009). Using the technological, pedagogical, and content knowledge framework to design online learning environments and professional development. Journal of Educational Computing Research, 41(3), pp.319-346.

Doering, A. and Veletsianos, G. (2007), Multi-Scaffolding Environment: An Analysis of Scaffolding and Its Impact on Cognitive Load and Problem-Solving Ability, Journal of Educational Computing Research, 37(2), 107-129.

Donert, K (2007), Geoinformation in European education: a revolution waiting to happen. In: Donert, K., Charzynski, P., Podgorski, Z. (eds.) Teaching geography in and about Europe, HERODOT network for geography in higher education, Torun, p. 117

Donert, K., (2013), digital-earth. eu: a European network for Digital Earth education. In First International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2013) (Vol. 8795, p. 879504). International Society for Optics and Photonics.

Donert, K., Desmidt, F., Lázaro y Torres, M.L., De Miguel González, R., Lindner-Fally,M., Parkinson, A., Prodan, D., Wołoszyńska-Wiśniewska, E., and Zwartjes, L. (2016), The GI-Learner Approach: Learning Lines for Geospatial Thinking in Secondary Schools, GI_Forum 2016, Vol.2, Page: 134-146

Donert, K. and Charzyński, P., (2005). Changing Horizons in Geography Education, 326 p, Toruń Poland, Herodot Network with arrangement of Association of Polish Adult Educators.

Doulamis, N., Yiakoumettis, C. and Miaoulis, G., (2013), June. Personalised 3D navigation and understanding of Geo-referenced Scenes. In 2013 IEEE 14th International Symposium on" A World of Wireless, Mobile and Multimedia Networks"(WoWMoM) (pp. 1-6). IEEE.

Drennon, C. (2005). Teaching geographic information systems in a problem-based learning environment. Journal of Geography in Higher Education, 29, 385–402.

Dunlosky, J and Rawson, K. (eds) (2019) The Cambridge Handbook on Cognition and Education. New York: Cambridge University Press.

Dunlosky J., Rawson K.A. and Marsh E.J. (2013), Improving students' learning with effective learning techniques: Promising directions from cognitive and educational psychology. Psychological Science in the Public Interest 14(1): 4–58.

Education Endowment Foundation (2019), Six myths of digital technology, Impact Journal of the Chartered College of Teaching, special issue

Elwood, S., (2009). Integrating participatory action research and GIS education: Negotiating methodologies, politics and technologies. Journal of Geography in Higher Education, 33(1), 51-65.

Engeström, Y., (1999), Activity theory and individual and social transformation. Perspectives on activity theory, 19(38), pp.19-30.

Enser, M. (2019) How useful is cognitive load theory for teachers; Times Educational Supplement 10 October 2019. https://www.tes.com/news/how-useful-cognitive-load-theory-teachers

Enser M (2017), Crossing the Threshold, https://teachreal.wordpress.com/2017/10/22/crossing-the-threshold/

Esri (2016), Esri Pledges to Help Boost Digital Skills in Europe, https://www.esri.com/about/newsroom/insider/esri-pledges-to-help-boost-digital-skills-in-europe/

Esteves, M.H. and Rocha, J., (2015). Geographical information systems in Portuguese geography education. European Journal of Geography, 6, pp.6-15.

European Commission (2019), Key Action 2: Cooperation for innovation and the exchange of good practices, https://eacea.ec.europa.eu/erasmus-plus/actions/key-action-2-cooperation-for-innovation-and-exchange-good-practices_en

Fagin, T.D. and Wikle, T.A., (2011). The instructor element of GIS instruction at US colleges and universities. Transactions in GIS, 15(1), pp.1-15.

Fargher, M. (2018), WebGIS for Geography Education: Towards a GeoCapabilities Approach, International Journal of Geo-information 7, 111, https://www.mdpi.com/2220-9964/7/3/111/pdf

Fargher, M. and Rayner, D., (2012). United Kingdom: Realizing the potential for GIS in the school geography curriculum. In International perspectives on teaching and learning with GIS in secondary schools (pp. 299-304). Springer, Dordrecht.

Favier, T., and van der Schee, J. (2014), The effects of geography lessons with geospatial technologies on the development of high school students' relational thinking, Computers & Education 76, 225–236

Favier, T. (2011). GIS in inquiry-based secondary geography education. VU University Amsterdam. Retrieved from http://www.timfavier.com/dissertation.html

Favier, T. (2013). Geo-informationtechnologie in het voortgezet aardrijkskundeonderwijs: Een brochure voor docenten, Vrije Universiteit Amsterdam, 80 p

Feddern, L., Belham, F.S. and Wilks, S., (2018). Retrieval, interleaving, spacing and visual cues as ways to improve independent learning outcomes at scale. Profession, 18, p.19.

Felgenhauer, T. and Quade, D., (2012). Society and geomedia. Some reflections from a social theory perspective. GI_Forum 2012, pp.74-82.

GeoBuiz, (2018), GeoBuiz 2018 Report: Geospatial Industry Outlook and Readiness Index, https://geobuiz.com/geobuiz-2018-report.html

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

Gómez Trigueros, I. M. (2018). New learning of geography with technology: the TPACK model, European Journal of Geography, 9(1), 38-48.

Goodchild, M. F. and Janelle, D. G. (2010), Toward critical spatial thinking in social sciences and humanities. GeoJournal, 75 (1), 3-13

Gordon, E., Elwood, S. and Mitchell, K., (2016). Critical spatial learning: participatory mapping, spatial histories, and youth civic engagement. Children's geographies, 14(5), pp.558-572.

Grunwald, S., Ramasundaram, V. and Jesseman, D.K., (2005). A modular e-learning environment to teach GIS to on-campus and distance education students. NACTA journal, pp.6-13.

Gryl, I., Jekel, T. and Donert, K., (2010). GI and spatial citizenship. Learning with GI, GI Forum V, pp.2-11.

Gryl, I. (2016), Reflexivity and Geomedia–Going Beyond Domain-specific Competence Development, https://www.researchgate.net/profile/Inga_Gryl/publication/274192541_Reflexivity_and_Geomedia_-_Going_Beyond_Domain-specific_Competence_Development/links/55c25e8508aeca747d5dcdec.pdf

Gryl, I. and Jekel, T. (2012), Re-centering GI in secondary education: Towards a spatial citizenship approach. Cartographica, 47 (1), 2-12.

Gunckel, K. L., B. A. Covitt, I. Salinas, and C. W. Anderson. (2012). A learning progression for water in socio-ecological systems. Journal of Research in Science Teaching 49 (7): 843–868.

Hamm, S.B., (2016). A Foundation for Spatial Thinking: Towards a Threshold Concept Framework in GIScience and its Implications for STEM Education (Master's thesis, University of Waterloo).

Hammond, T. C., A. Bodzin, D. Anastasio, B. Holland, K. Popejoy, D. Sahagian, S. Rutzmoser, J. Carrigan, and W. Farina. (2018). You know you can do this, right?": Developing geospatial technological pedagogical content knowledge and enhancing teachers' cartographic practices with socio-environmental science investigations. Cartography and Information Science 45 (4):305–18.

Hartig, J. and Klieme, E., (2007). Possibilities and requirements for technology-based competence diagnostics: Expertise on behalf of the Federal Ministry of Education and Research . BMBF, Public Relations Department.

Healey, M., and Jenkins, A. (2000). Kolb's experiential learning theory and its application in geography in higher education. Journal of Geography, 99, 185–195.

Healy, G., Hall, K., Whelan, L.J., Scarlett, D. and Dowd, L., (2018). Using GIS in A-level Geography to support geographical enquiry and develop students' geographical knowledge. Geography Matters, 25-32.

Healy, G. and Walshe, N., (2019). Real-world geographers and GIS: relevance, inspiration and developing geographical knowledge. Teaching Geography, 44(2), pp.52-55.

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.178-196.

Hicks, D., J. Lee, M. Berson, C. Bolick, and R. Diem. (2014). Guidelines for using technology to prepare social studies teachers. Contemporary Issues in Technology and Teacher Education 14 (4):433–50.

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

Hong, J. E., and Melville, A. (2018). Training social studies teachers to develop inquiry-based GIS lessons. Journal of Geography, 117(6), 229-244.

Hong, J. E., and Stonier, F. (2015). GIS in-service teacher training based on TPACK. Journal of Geography 114(3), 108-117

Hong, J. E. (2017). Designing GIS learning materials for K–12 teachers. Technology, Pedagogy and Education, 26(3), 323-345.

Hong, J.E. (2014) Promoting Teacher Adoption of GIS Using Teacher-Centered and Teacher-Friendly Design, Journal of Geography, 113:4, 139-150.

Howard-Jones, P., Ioannou, K., Bailey, R., Prior, J., Yau, S.H. and Jay, T., (2018). Applying the science of learning in the classroom. Profession, 18, p.19. https://impact.chartered.college/article/howard-jones-applying-science-learning-classroom/

Howarth, J.T. and Sinton, D., (2011). Sequencing spatial concepts in problem-based GIS instruction. Procedia-Social and Behavioral Sciences, 21, pp.253-259.

Hubeau, M., Steenberghen, T., Van Balen, K., Van Orshoven, J. and Vileikis, O., (2011. Software-independent tutorials for supervised self-study of Geographic Information Science and Technology: In GIS-education in a changing academic environment. LeGIO 18/11/2011, Leuven, Belgium.

Huei-Tse Hou, Tsai-Fang Yu, Yi-Xuan Wu, Yao-Ting Sung and Kuo-En Chang (2016). Development and evaluation of a web map mind tool environment with the theory of spatial thinking and project-based learning strategy. British Journal of Educational Technology, 47 (2), 390–402

Huynh, N.T., Solem, M. and Bednarz, S.W., (2015). A road map for learning progressions research in geography. Journal of Geography, 114(2), pp.69-79.

Hwang, S. (2013). Placing GIS in sustainability education. Journal of Geography in Higher Education, 37(2), 276-291

Jackson, C.M. and Kibetu, D.K., (2019). Emerging Technologies in Teaching, Research, and Learning: GIS Technology and Methods in Education. In Technology-Supported Teaching and Research Methods for Educators (pp. 201-217). IGI Global.

Jadallah, M., Hund, A.M., Thayn, J., Studebaker, J.G., Roman, Z.J. and Kirby, E., (2017). Integrating geospatial technologies in fifth-grade curriculum: Impact on spatial ability and map-analysis skills. Journal of Geography, 116(4), pp.139-151.

Jakab, I., Bearman, N., Jones, N., André, I., Cachinho, H.A. and DeMers, M., (2016). The future role of GIS education in creating critical spatial thinkers. Journal of Geography in Higher education, 40(3), pp.394-408

Jakab I., Grezo, H., and Sevcík, M. (2016), Inquiry Based and Blended Learning Using Geographical Information System, ECEL 2016-Proceedings of the 15th European Conference on e-Learning, pp 287–295

Jant, E.A., Uttal, D.H., Kolvoord, R., James, K. and Msall, C., (2020). Defining and Measuring the Influences of GIS-Based Instruction on Students' STEM-Relevant Reasoning. Journal of Geography, 119(1), pp.22-31..

Jo, I. and Bednarz, S.W., (2009). Evaluating geography textbook questions from a spatial perspective: Using concepts of space, tools of representation, and cognitive processes to evaluate spatiality. Journal of Geography, 108(1), pp.4-13.

Kalyuga, S. (2020) The expertise reversal effect and its instructional implications. Impact Journal of the Chartered College of Teaching, Issue 8, pp18-21

Kaminske, A. N. (2020), Can We Teach Critical Thinking?, The Learning Scientists, https://www.learningscientists.org/blog/2019/2/28/can-we-teach-critical-thinking

Kapler, I., Weston, T. and Wiseheart, M. (2015), Spacing in a simulated undergraduate classroom: Long-term benefits for factual and higher-level learning. Learning and Instruction 36: 38–45.

Karolčík, Š., Zilinskiene, I., Slotkiene, A. and Čipková, E. (2019). Analysis of e-Learning Environment for Geography: Opportunities for Personalized Active Learning. Baltic Journal of Modern Computing, 7(3), 405-418.

Kerski, J.J., (2015). Geo-awareness, geo-enablement, geotechnologies, citizen science, and storytelling: Geography on the world stage. Geography Compass, 9(1), pp.14-26.

Kerski, J.J., Demirci, A. and Milson, A. J. (2013). The Global Landscape of GIS in Secondary Education, Journal of Geography, 112:6, 232-247.

Kerski, J.J. (2008), The role of GIS in Digital Earth education. International Journal of Digital Earth 1, 326

Kerski J.J., and Baker T.R. (2019) Infusing Educational Practice with Web GIS. In: de Miguel González R., Donert K., Koutsopoulos K. (eds) Geospatial Technologies in Geography Education. Key Challenges in Geography. pp. 3-19. Springer, Cham.

Kim, M. and Bednarz, R. (2013). Development of critical spatial thinking through GIS learning. Journal of Geography in Higher Education 37(3):350-366.

King, E. (2008) 'Can pbl-gis work online?'. *Journal of Geography,* 107(2), 43-51.

Kluzer S., Pujol Priego L. (2018). DigComp into Action - Get inspired, make it happen. In S. Carretero, Y. Punie, R. Vuorikari, M. Cabrera, and O'Keefe, W. (Eds.). JRC Science for Policy Report, EUR 29115 EN, Publications Office of the European Union, Luxembourg, 2018.

Kolvoord, B., K. Keranen and S. Rittenhouse. (2019). The Geospatial Semester: Concurrent Enrollment in Geospatial Technologies. Journal of Geography 118:3-10.

Koutsopoulos, K.C. and Papoutsis, P., (2016). School on Cloud: Transforming Education. Educational Policy Analysis and Strategic Research, 11(1), pp.31-46.

Kuijpers, T. (2019), Docent en GIS-expert leren van elkaar, Tijdschirft Geografie, Oktober 2019

Lambrinos, N. and Asiklari, F., (2014). The introduction of GIS and GPS through local history teaching in primary school. European Journal of Geography, 5(1), pp.32-47.

Larsen, T.B., Millsaps, L., Harrington Jr, J.A. and Lefferd, R., (2018). Learning Progression Research in Geography: What Teachers Need to Know. The Geography Teacher, 15(2), pp.55-67.

Lee, C., and Shahrill, M. (2018). Utilising the think–pair–share technique in the learning of probability. International Journal on Emerging Mathematics Education, 2(1), 49–64.

Lindner-Fally, M. and Zwartjes, L., (2012). Learning and teaching with Digital Earth–Teacher training and education in Europe. GI_Forum, pp.272-282.

Little, J., Bjork, E. and Angello, G. (2012), Multiple-choice tests exonerated, at least of some charges: Fostering test-induced learning and avoiding test-induced forgetting. Psychological Science 23: 1337–1344.

Liu, Y., Bui, E. N., Chang, C.-H., and Lossman, H. G. (2010). PBL-GIS in secondary geography education: Does it result in higher-order learning outcomes? Journal of Geography, 109(4), 150–158.

Luckin R, Bligh B, Manches A, et al. (2012) Decoding Learning: The Proof, Promise and Potential of Digital Education. London: Nesta.

Mac Aoidh, E., Koinis, A. and Bertolotto, M., (2006), December. Improving archaeological heritage information access through a personalised GIS interface. In International Symposium on Web and Wireless Geographical Information Systems (pp. 135-145). Springer, Berlin, Heidelberg.

Marta, M. and Osso, P., (2015). Story Maps at school: teaching and learning stories with maps. J-Reading-Journal of Research and Didactics in Geography, (2), 4, 61-68

Maseleno, A., Sabani, N., Huda, M., Ahmad, R., Jasmi, K.A. and Basiron, B., (2018), Demystifying learning analytics in personalised learning. International Journal of Engineering & Technology, 7(3), pp.1124-1129.

Mathews, A. J., and Wikle, T. A. (2017). Assessing professional benefits of GIS certification. Cartography & Geographic Information Science, 44(5), 452–462.

Mathews, A.J. and Wikle, T.A., (2019). GIS&T pedagogies and instructional challenges in higher education: A survey of educators. Transactions in GIS, 23(5), pp.892-907.

Maude, A. (2018). Geography and powerful knowledge: A contribution to the debate. International Research in Geographical and Environmental Education, 27(2), 179–190

Mayer, R. E. (2008), Applying the science of learning: Evidence-based principles for the design of multimedia instruction., American Psychologist. 63(8), pp. 760-769.

Mayer, R.E. (2009), Multimedia learning (2nd edition). New York: Cambridge University Press.

Mayer R.E. (2019), How multimedia can improve learning and instruction. In: Dunlosky J, and Rawson K, editors. The Cambridge Handbook on Cognition and Education. New York: Cambridge University Press.

Metoyer, S. and Bednarz, R., (2017), Spatial thinking assists geographic thinking: Evidence from a study exploring the effects of geospatial technology. Journal of Geography, 116(1), pp.20-33.

Meyer, J and Land, R (2006), Overcoming Barriers to Student Understanding: Threshold Concepts and Troublesome Knowledge, Abingdon: Routledge-Falmer, pp.19-26

Michel, E. and Hof, A., (2013), Promoting Spatial Thinking and Learning with Mobile Field Trips and eGeo-Riddles, GI_Forum 2013: Creating the GISociety (Eds. Jekel, T., Car, A., Strobl, J., Griesebner, G.), Wichmann Verlag Berlin, 378-387.

Millsaps, L.T. and Harrington, J. A. (2017). A time-sensitive framework for including geographic information systems (GIS) in professional development activities for classroom teachers. Journal of Geography, 116(4), 152-164.

Milson, A.J., and Curtis, M. D. (2009). Where and why there? Spatial thinking with geographic information systems. Social Education, 73(3), 113–118.

Milson A.J. and Earle B. D. (2008), Internet-Based GIS in an Inductive Learning Environment: A Case Study of Ninth-Grade Geography Students, Journal of Geography, 227-237

Mishra, P., and Koehler, M. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. Teachers College Record, 108, 1017–1054.

Mitchell, J.T., Roy, G., Fritch, S., and Wood, B. (2018). GIS professional development for teachers: lessons learned from high-needs schools. Cartography and Geographic Information Science, 45(4), 292-304.

Motala, S. and Musungu, K., (2013). Once upon a place: Storytelling in GIS education, GeoConference on Informatics, Geoinformatics and Remote Sensing, http://digitalknowledge.cput.ac.za/bitstream/11189/2404/3/Motala_S_Musungu_K_Eng_2013.pdf

Muijs, D. (2020) Cognition, Learning and educational research. Impact Journal of the Chartered College of Teaching, Issue 8. p1-4.

National Research Council (2006), Learning To Think Spatially, Washington, DC: National Academy Press

Nguyen N.A., Muniz-Solari O., Dang D.T., and Nguyen T.P. (2019), Reviewing Spatial Thinking in Geography Textbooks Questions from The Perspective of Spatial Thinking. InIOP Conference Series: Earth and Environmental Science Nov, 338(1), p. 012042). IOP Publishing.

Nikolov, R., Shoikova, E., Krumova, M., Kovatcheva, E., Dimitrov, V. and Shikalanov, A., (2016). Learning in a Smart City environment. Journal of Communication and Computer, 13, pp.338-350.

Pánek, J., and Glass, M. (2018). Gaining a mobile sense of place with collector for ArcGIS. Journal of Geography in Higher Education, 42(4), 603-616.

Park, C. (2018). Technology and the new pedagogy in higher education. Retrieved from http://thesextantgroup.com/technology-and-the-new-pedagogy-in-higher-education-by-principalcraig-park-fsmps-assoc-aia/

Perdue, N. and Lobben, A., (2013). The Challenges of Testing Spatial Thinking Skills with Participants who are Blind or Partially Sighted. Sharing knowledge, In: Reyes Nuñez J. J.. Sharing knowledge. Joint ICA Symposium, http://lazarus.elte.hu/ccc/2013icc/skproceedings.pdf#page=112

Petras V., Petrasova A., Harmon B.,.Meentemeyer R.K. and Mitasova H. (2015), Integrating Free and Open Source Solutions into Geospatial Science Education Int. J. Geo-Inf. 2015, 4, 942-956

Pink, D. H. 2006. A Whole New Mind: Why Right-Brainers Will Rule the Future. New York: Riverhead Trade.

Poslad, S., Laamanen, H., Malaka, R., Nick, A., Buckle, P. and Zipl, A., (2001). Crumpet: Creation of user-friendly mobile services personalised for tourism, https://www.isip.piconepress.com/projects/mobile/reviews/papers/geoMobile/ref23.pdf

Prager, S., (2012). Using the GIS&T Body of Knowledge for curriculum design: Different design for different contexts. Teaching geographic information science and technology in higher education, pp.63-80.

Prain, V., Cox, P., Deed, C., Dorman, J., Edwards, D., Farrelly, C., Keeffe, M., Lovejoy, V., Mow, L., Sellings, P. and Waldrip, B., (2013), Personalised learning: Lessons to be learnt. British Educational Research Journal, 39(4), 654-676.

Quinn, M (2019) Digital Schools? Teachers Still Matter. Impact Journal of the Chartered College of Teaching, Special Issue p12-13

Reidsema, C., Kavanagh, L., Hadgraft, R., and Smith, N. (Eds.) (2017). The flipped classroom: Practice and practices in higher education. Singapore: Springer Nature.

Rickles, P., Ellul, C. and Haklay, M. (2017). A suggested framework and guidelines for learning GIS in interdisciplinary research. Geo: Geography and Environment 4 (2), e00046

Rickles, P. and Ellul, C. (2017) Innovations in and the changing landscape of geography education with Geographic Information Systems. Journal of Geography in Higher Education, 41(3), 305-309.

Roberts, J. (2006). Limits to communities of practice. Journal of Management Studies, 43, 623–639.

Roig R. and Flores, C. (2014). Conocimiento tecnológico, pedagógico y disciplinario del profesorado: el caso de un centro educativo inteligente. EDUTEC, Revista Electrónica de Tecnología Educativa, http://edutec.rediris.es/Relevec2/Relevec47/n47_Roig-Flores.html

Roosaare, J. and Liiber, Ü., (2013). GIS in school education in Estonia–looking for an holistic approach. J-Reading-Journal of Research and Didactics in Geography, 1(1).

Rosenshine, B. (2012) 'Principles of Instruction: Research-based Strategies that all Teachers Should Know'. American Educator Spring.

Rosenshine, B.V. (1986), Synthesis of research on explicit teaching. Educational leadership, 43(7), pp. 60-69.

Roulston, S. (2013), GIS in Northern Ireland secondary schools: Mapping where we are now, International Research in Geographical and Environmental Education 22.1: 41-56.

Rubio, J.C.C., Gassó, H.H. and Engen, B.K., (2019). Digital Competence for Teachers: Perspectives and foresights for a new school. Comunicar, 61(XXVII), 2019.4

Sanchez, E., (2009), Innovative teaching/learning with geotechnologies in secondary education. In IFIP World Conference on Computers in Education (pp. 65-74). Springer, Berlin, Heidelberg.

Sanchez, E. (2008a) Quelles relations entre modélisation et investigation scientifique dans l'enseignement des sciences de la Terre. Education & Didactique 2, 97

Sanchez, E. (2008b), Les globes virtuels, des outils pour l'enseignement des sciences de la vie et de la Terre. Géomatique Expert 59

Scheyvens, R., Griffin, A. L., Jocoy, C. L., Liu, Y., and Bradford, M. (2008). Experimenting with active learning in geography: Dispelling the myths that perpetuate resistance. Journal of Geography in Higher Education, 32(1), 51–69.

Schulze, U. , Kanwischer, D. and Reudenbach, C. (2013), Essential competences for GIS learning in higher education: a synthesis of international curricular documents in the GIS&T domain, Journal of Geography in Higher Education, 37:2, 257-275

Schulze, U., Gryl, I., Kanwischer, D. 2012. A Competence Model for Spatial Citizenship education, SPACIT Project, http://www.spatialcitizenship.org/media/WP2_report_D2_1-final_.pdf

Şeremet, M., and Chalkley, B. (2015). Student perspectives on the teaching of geographical information systems (GIS) in geography degrees. Journal of Geography in Higher Education, 39(1), 18–36.

Sharp, H., Rogers, Y., and Preece, J. (2007). Interaction design: Beyond human–computer interaction (2nd ed.). Chichester: Wiley.

Sherrington, T. (2018) Great Teaching The Power of Stories; teacherhead.com, https://teacherhead.com/2018/09/23/great-teaching-the-power-of-stories/

Sherrington, T. (2019) Rosenshine's principles in action. Woodbridge: John Catt Educational Ltd.

Sherrington T (2018), Exploring Barak Rosenshine's seminal Principles of Instruction: Why it is THE must-read for all teachers, TeacherHead Consulting, https://teacherhead.com/2018/06/10/exploring-barak-rosenshines-seminal-principles-of-instruction-why-it-is-the-must-read-for-all-teachers/

Shibli, D. and West, R., (2018). Cognitive load theory and its application in the classroom. Impact Journal of the Chartered College of Teachingfrom.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. Harvard Educational Review, 57, 1–22.

Sinha, G., Smucker, T.A., Lovell, E.J., Velempini, K., Miller, S.A., Weiner, D. and Wangui, E.E., (2016), The Pedagogical Benefits of Participatory GIS for Geographic Education, Journal of Geography, 116:4, 165-179

Sinton, D. S. and Kerski, J. J. (2020). GIS&T Education and Training. The Geographic Information Science & Technology Body of Knowledge (1st Quarter 2020 Edition), John P. Wilson (ed.). https://gistbok.ucgis.org/bok-topics/gist-education-and-training

Solem, M., Tu Huynh, N., and Boehm, R. (2014). Geoprogressions. Learning Progressions, for Maps, Geospatial Technology, and Spatial Thinking: A Research Handbook. Washington DC, Association of American Geographers.

Somekh, B. (2008), Factors affecting teachers' pedagogical adoption of ICT, pp. 449-460, In: Voogt, J. and Knezek, G. eds., International handbook of information technology in primary and secondary education (Vol. 20). The Netherlands, Springer

Srivastava, S.K. and Tait, C., (2010). The utilisation of the existing GIS model curricula to innovate a GIS pedagogy for the 21st Century. Pedagogical research in maximising education, 4(2), pp.25-37.

Stains, M., Harshman, J., Barker, M. K., Chasteen, S. V., Cole, R., DeChenne-Peters, S. E., and Young, A. M. (2018). Anatomy of STEM teaching in North American universities. Science, 359(6383), 1468–1470.

Stevens, S., A. W. Gotwals, H. Jin, and J. Barrett. (2015). Learning progressions research planning and design. In Learning progressions for maps, geospatial technology and spatial thinking: A research handbook, eds. M. Solem, N. T. Huynh, and R. Boehm, 23–44. Washington, DC: Association of American Geographers

Stoltman, J.P. and De Chano, L., (2003). Continuity and change in geography education: Learning and teaching. In International handbook on geographical education (pp. 115-137). Springer, Dordrecht.

Stringer, E Lewin, C and Coleman, R. (2019) Using Digital Technology to improve learning: Guidance Report. Education Endowment Foundation. Available at: https://dera.ioe.ac.uk/33229/1/EEF_Digital_Technology_Guidance_Report.pdf, (Accessed: May 2020)

Sui, D., (2015). Emerging GIS themes and the six senses of the new mind: is GIS becoming a liberation technology?. Annals of GIS, 21(1), pp.1-13.

Sumeracki, M.A. and Weinstein, Y., (2018). Optimising learning using retrieval practice. Profession, 18, p.19.

Sweller, J., (1988). Cognitive load during problem solving: Effects on learning. *Cognitive science*, *12*(2), pp.257-285.

Sweller, J., (2010). Element interactivity and intrinsic, extraneous, and germane cognitive load. Educational psychology review, 22(2), pp.123-138.

Sweller, J., (2011). Cognitive load theory. In Psychology of learning and motivation (Vol. 55, pp. 37-76). Academic Press.

Sweller, J., (2020). Cognitive load theory and educational technology. *Educational Technology Research and Development*, *68*(1), pp.1-16.

Sweller, J. and Sweller, S., (2006), Natural information processing systems. Evolutionary Psychology, 4(1), pp.434-458.

Tate, N. J., and Jarvis, C. H. (2017). Changing the face of GIS education with communities of practice. Journal of Geography in Higher Education, 41(3), 327-340

Tharby, A. (2019). Using cognitive Load Theory to improve slideshow presentations. Impact Journal of the Chartered College of Teaching, Special Issue. p10 – 11

Walshe, N. (2017). Developing trainee teacher practice with geographical information systems (GIS). Journal of Geography in Higher Education, 41(4), 608-628.

Walshe, N. (2018). Spotlight on ... Geographical information systems for school geography. Geography, 103(1), 46–49.

Willingham, D.T., (2007), Critical thinking: Why it is so hard to teach?. American federation of teachers summer 2007, p. 8-19.

Willingham, D.T., (2009). Why don't students like school?: A cognitive scientist answers questions about how the mind works and what it means for the classroom. John Wiley & Sons.

Wu, L. (2018). Application of ArcGIS in Geography Teaching of Secondary School: A Case Study in the Practice of Map Teaching. Wireless Personal communications. 102:2543–2553

Zwartjes, L., (2009). iGuess: Introducing GIS Use in Education in Several Subjects. In: Donert, K., Ari, Y., Attard, M., O'Reilly, G. and Schmeinck, D., Celebrating Geographical Diversity., p.275-280.

Zwartjes, L., (2018). Developing geospatial thinking learning lines in secondary education: the GI Learner project. European Journal of Geography, 9(4), pp.138-151.

Zwartjes, L., Berankova, T., Bosse, I., Brotankova, Z., Colaiuda, C., Contiu, L., Donert, K., Doppler, G., Elpida, C., Georgiades, E. and Jenal, F., 2015. A literature review of personalized learning and the Cloud, School on the Cloud Project, https://biblio.ugent.be/publication/8623287/file/8623292

Zwartjes, L. and Lazaro y Torres, M.L. (2019). Geospatial Thinking Learning Lines in Secondary Education: The GI Learner Project. In Geospatial Technologies in Geography Education (pp. 41-61). Springer, Cham.