The following is an annotated bibliography of resources that begin to touch upon answer the question of “how does mapping and maps help us to learn spatially?”

1. Harris, T., & Weiner, D. (1998). Empowerment, Marginalization, and “Community Integrated” GIS. *Cartography and Geographic Information Systems, 25:2,* p. 67-76.

This paper mentions the interesting duality of GIS, in that can either be a tool for empowerment or marginalization and tries to unbiasedly present evidence of both when using GIS within societal contexts. Of most pertinence to the research question, the article challenges the more traditional ideas of GIS, being that of handling digital, quantitative information, and suggests the inclusion of cognitive and mental maps as well as oral histories; incorporating these diverse epistemologies acknowledges and welcomes a more holistic understanding of space and meaning. GIS is ultimately suggested as a tool for community empowerment, where a bottom-up approach is taken to identifying problems and applying the technology appropriately, introducing it to community members in a way that encourages public participation, and helps to enrich and values already existing local knowledge.

2. Carano, K.T., & Berson, M.J. (2007). Breaking Stereotypes: Constructing Geographic Literacy and Cultural Awareness through Technology. *The Social Studies, 28:2,* p. 65-69.

In the United States, it is presented that there is a certain level of detachment from the relevance of geography, as a taught discipline, due to the lack of a feeling of interconnectedness and commonality with other areas of the world. Instead, understandings are established through media representations, which may not be accurate, and may need to be unlearned. It is suggested that to reengage students and encourage learning, technologies may be used, such as Google Earth or social media, to facilitate online projects; however, this does not come without its own problems, such as digital literacy or a school or student’s access to technology. If successful, though, these methods could foster understanding in physical and cultural geography as well as global citizenship.

3. Barrett, H. (2006). Researching and Evaluation Digital Storytelling as a Deep Learning Tool. *Society for Information Technology & Teacher Education International Conference, 2006:1,* p. 647-654.

Digital storytelling is said to provide the convergence of four student-centred learning strategies: student engagement, reflection for deep learning, project based learning, and effective integration of technology into instruction. Design strategies and a rubric for assessment are presented, as well as an extensive list of sources to back findings, which in themselves may be worth exploring. Though not specifically associated with maps or mapping, the connection could be made that using maps for digital story telling can help facilitate the aforementioned student-centred learning strategies.

4. Keiper, T.A. (1999). GIS for Elementary Students: An Inquiry into a New Approach to Learning Geography. *Journal of Geography, 98:2*, p. 47-59.

The article almost immediately opens with the “Geography is composed of three interrelated and inseparable components: subject matter, skills and perspectives… All three… are necessary to being geographically informed.” A suggested approach to engaging students in Geographic Inquiry into Global Issues (GIGI) can be through the use of GIS, to enhance active participation and fit well in the constructivist environment many teachers seek to facilitate. Background is then given about constructivism (building knowledge through and upon existing knowledge) and behaviourism (mechanistic learning where desired behaviour is rewarded [and undesired behaviour punished]), as two different, but relevant, learning approaches. Shortcomings of the facilitation of GIS in elementary school are discussed, but juxtaposed with initial enthusiasm and motivation from teachers. A case study is presented for teaching 5th graders GIS, none of whom have had prior experience with the software, and successes/failures of its application are discussed. Of key interest, though, are the six project design aims (1. Set the stage but have the students generate the knowledge for themselves as much as possible, 2. Anchor the knowledge in authentic situations and activities, 3. Use the cognitive apprenticeship methods of modelling, scaffolding, fading, and coaching to convey how to construct knowledge in authentic situations and activities, 4. Situation knowledge in multiple contexts to prepare for appropriate transfer to new contexts, 5. Create cognitive flexibility by ensuring that all knowledge is seen from multiple perspectives and 6. Have the students collaborate in knowledge construction) and how they were tied together by and through the use of GIS in the project. Students were then tracked in their groups, through their use and discussions around GIS, to ascertain their skills in the following: 1. Asking Geographic Questions, 2. Acquiring Geographic Information, 3. Organizing Geographic Information, 4. Analyzing Geographic Information and 5. Answering Geographic Questions. The study was fairly successful and ultimately impresses the importance of using authentic situations and problems as they encourage learning.

5. Sui, D.Z. (1995). A Pedagogic Framework to Link GIS to the Intellectual Core of Geography. *Journal of Geography, 94:6,* p. 578-591.

The fundamental message of this paper is that there is a difference between teaching *about* GIS and teaching *with* GIS. Originating from the established need to create a conceptually coherent and pedagogically stimulating framework that is capable of tying a variety of topics in GIS into a unified schema, a modified version of Berry's geographic matrix is proposed that is relevant to and incorporates GIS. A very good quote put forward is that "GIS is to geographic description and analysis what [the] microscope, telescope, and computer systems have been to other sciences." It is further postulated that GIS will penetrate more deeply into geographic research, and eventually it may revolutionize all the major branches of geography, but that it must be taught within context. This then links to the difference between teaching *about* GIS and teaching *with* GIS, which the former focuses on data representation and handling techniques and the latter on application and geographic concepts. Specifics on how to begin to appropriately apply the matrix are explored and discussed, which may be outside of the scope of the current research question; however, it is said that "By synergistically integrating GIS with other topical and regional courses, we can shift students from being passive receivers of existing theory to becoming active explorers using GIS to test the existing concepts and find new theories."

6. Tsou, M.H., & Yanow, K. (2010). Enhancing General Education with Geographic Information Science and Spatial Literacy. *URISA Journal, 22:2,* p. 45-54.

It is argued that geographic information science and technology can have a potential role in helping to develop certain skills at the general education level and that educators can act as a vehicle for advancing spatial literacy as well as quantitative problem-solving skills. The applicability of GIS to real-world problems as a way of engaging students is also noted. The case for the importance of spatial literacy is also made, through the quote that "without explicit attention to spatial literacy, we cannot meet our responsibility for equipping the next generation of students for life and work in the 21st Century." Difficulties are then laid out in trying to teach GIS at the general education level, largely linked to costs and lack of awareness of the technology, to which promising web and mobile technologies are discussed, as they may potentially begin to address the aforementioned concerns. A suggested blueprint of a sample course is then proposed and compared to existing established ones to discuss trends for enrolment and impact, to impress its relevance/importance.

7. Moller Madsen, L. & Rump, C. (2012). Considerations of How to Study Learning Processes when Students use GIS as an Instrument for Developing Spatial Thinking Skills. *Journal of Geography in Higher Education, 36:1,* p. 97-116.

As GIS has been integrated into geography curricula globally over the past 30 years, approaches such as self-directed modules, problem based learning and use of multimedia in the class room have been modes for its diffusion. GIS' ability to improve learners' spatial thinking ability is also addressed and leads to the wider point which is that "… spatial thinking is now seen as an integrator and facilitator for problem solving and a missing link across the curriculum in a wider educational sphere…", but that GIS is one of many artefacts for this (maps, globes, planimeters, etc.). That said, though, there doesn't appear to be a clear consensus on exactly what spatial thinking is, but it has been proposed that there are three types: thinking in space, thinking about space and thinking with space; all of which are highly interwoven, and addressed through the activity of learning GIS. Theoretical implications are then made on the relation between knowledge creation and scientific instruments, as well as philosophical postulations of how we perceive and represent space. A case study is then discussed, along with student learning strategies and quotes from students recounting on their experiences of the task and with the GIS. This is all tied together in the conclusion to say that 1. education should support students in making the GIS transparent and thereby a personal instrument for spatial thinking, 2. 'cookbook' style teaching material may not be the best way to support the learning process for GIS and 3. GIS gradually alters the professional outlook of being a geographer and the way they think spatially.

8. Bunch, R.L. & Lloyd, R.E. (2006). The Cognitive Load of Geographic Information. *The Professional Geographer, 58(2),* p. 209-220.

Cognitive Load Theory seeks to address the cognitive processing capacity necessary for problem solving and suggests that unnecessary material should be removed so as to not negatively impact cognitive load; in this article, it has been applied in the context of understanding geographic information and applying it to geospatial problem solving – namely through presentation and representation of information of and on a map. A number of studies mentioned highlight existing work in the area, such as on spatial abilities and memory, as well as symbols and colours on maps, all of which leading to the suggested continued work to establish a theoretical foundation in multimedia cartography to keep up with currently technological trends. More on the theoretical side, cognitive load is divided into three categories: intrinsic, extraneous and germane. Intrinsic load is based on the demand made on working memory to interact with learning materials; extraneous load is caused by ambiguous task instructions or unnecessary information that can interfere with the learning process; and germane load deals with the schemata for acquisition and automation of processing information, thus enhancing learning, which can be linked to higher motivation in performing a task. These are then applied to the concepts of multimedia cartography in how to structure materials, reduce extraneous information, and enhance motivation. An important point later made is that "The success of any educational experience involving learning with a map also needs to take into consideration the innate differences among the individuals doing the learning. A map reader's ability to execute those cognitive processes needed to acquire information from a map may depend on factors external to the immediate educational experience." (with further arguments made about biological and environmental factors).

9. Chen, X.M. (1998). Integrating GIS Education with Training: A Project-Oriented Approach. *Journal of Geography, 97:6,* p. 261-268.

The rise of popularity of GIS in university curricula is discussed, which leads into the challenges of teaching GIS, as there may be different pedagogical approaches in doing so. The case is made that this be done through project-oriented, hands-on training to bridge the gap between GIS education and GIS training (as a reference back to Sui's (1995 [included in this annotated bibliography]) differentiation of teaching *about* GIS in comparison to teaching *with* GIS). It suggests that the project include five fundamental components: project planning and design, database development and management, GIS data analyses, output generation, and project documentation. Further to that, this real-world approach of learning GIS also addresses multidisciplinary perspectives, captures students' attention and expands their horizons; however, it is argued by some that students must first know geography in order to know and use GIS. Guidance is also given to the instructor, as well, in that they themselves should be adequately adept with the software and able to answer any student queries. A classroom case study is presented and students' understandings discussed, in which they see the value of GIS as a valuable decision-making tool, and accept the importance of individual responsibility as well as cooperative teamwork for its successful application. The article closes with stating that "Although there is no universal consensus on how to teach GIS, a great need for a continued discussion and review of GIS education will always exist."

10. Lubrica, N.V.A. (2013). Triple Feedback Hybrid (TFH) GIS Learning Framework: A Learning-Crime Solution Amalgamation. *JPAIR Multidisciplinary Research, 11:1,* p. 20-35.

Learning GIS is recognised as challenging and it is almost immediately addressed that GIS requires spatial literacy and can also, conversely, enhance it. It is suggested that training be delivered through a problem based learning approach, in order to address real-world problems rather than artificial, discipline specific ones. A model was then created for a suggested training approach, which was then applied and the results discussed; having delivered this training to police officers, who themselves had no prior background in GIS, the subjects of the study found the GIS to be a useful tool in the decision making process for determining patrol routes and understanding areas of crime, and through its use, a resulting downward trend in crime has been seen since the programme's implementation. Factors derived that influence GIS learning have been identified as participants' attitude toward the software, the leadership's commitment to the programme, and the time given for mastery.

11. Coluccia, E., Bosco, A., & Brandimonte, M.A. (2007). The role of visuo-spatial working memory in map learning: new findings from a map drawing paradigm. *Psychological Research, 71:3,* p. 359-372.

The focus of this paper is on visuo-spatial working memory (VSWM) and cognitive mapping skills, such as map drawing, of which, five fundamental elements are said to be paths, edges, districts, nodes, and landmarks. A recount on recent work in the area of VSWM shows work done to understand orientation and navigation, its importance to environmental learning and processing new routes, and map learning. Three studies were carried out understand various dimensions of VSWM and their interplay with map learning. In the first study, a map drawing task was requested of 3 groups, of which they were to study a map for some time and then redraw as much of it as possible; one group simply did that, another was asked to perform a verbal interruption (saying various syllables during the test) and the last was asked to perform a spatial interruption (tap points on a grid while they worked). Results from the study showed that the spatial interruption group performed poorly in the redraw task and the other two performed similarly; thus, proving a disconnection between VSWM and verbal aspects of working memory. The second study focussed on active/passive or sequential/simultaneous aspects of VSWM; by using eight map learning ability tasks (MLATs) [Bosco, Longoni, and Vecchi (2004), as cited in the paper] these aspects were measured to show significant correlation of VSWM to MLATs and map drawing skills. The third study repeated the second study but with the map used in the first study, further supporting the findings from the second study. This is tied together in the closing of the paper where the authors state that it can be interpreted from the results that a fundamental requirement for successful map learning is the simultaneous, static, visual storage of the stimulus.

12. Richardson, A.E., Montello, D.R., & Hegarty, M. (1999). Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Memory & Cognition, 27:4,* p. 741-750.

Navigation skills of an environment were tested in three different learning conditions: from a map, direct experience, and inside a virtual environment. Each condition had the same simple and complex environments to test against, which had less or more landmarks and tested understanding of direction and distance estimations as well as alignment effects. Results largely show that performance for all of these, meaning the uptake of survey knowledge, was more quickly and accurately obtained through maps than they were in either the virtual environment or direct experience. Further to that, alignment effects more greatly impacted people's understanding in the virtual environment than they did with either the map or direct experience, highlighting that one's starting point and orientation in the virtual environment is important to understanding the environment and if changed, can be disorienting. Finally, in regards to direction and distance estimations, direct experience and virtual environment performance were roughly the same.

13. Thorndyke, P.W., & Hayes-Roth, B. (1982). Differences in Spatial Knowledge Acquired from Maps and Navigation. *Cognitive Psychology, 14,* p. 560-589.

Map learning is analysed by its aspects of aiding in spatial knowledge and orientation judgement, which can change based on how information is obtained and the context of its application. The main focus of the paper is to investigate difference in spatial knowledge and estimation procedures derived from either maps or navigation experience. The two are not wholly unrelated, in that memory representation on and of a map, or understanding of the map validated from memory can enhance estimations and judgement, but the type of knowledge learned in either (e.g. navigation tasks tap into procedural knowledge) can either be enhanced or hindered in either circumstance, based on the context of the task at hand. From conducted trials, comparing differences in Euclidean and route distance estimations, as well as orientation and location judgements, findings show that maps were better at calculating Euclidean distances than navigation experience and that the reverse was true for route distances. Further to that, navigation experience subjects performed better than map users in orientation and location judgement trials. It should be taken into consideration, though, that the results from this study could change, with a different group of participants, based upon individual ability of spatial awareness.

14. Witmer, B.G., Bailey, J.H., Kneer, B.W., & Parsons, K.C. (1996). Virtual Spaces and Real World Places: Transfer of Route Knowledge. *International Journal of Human-Computer Studies, 45,* p. 413-428.

Virtual environments for obtaining route knowledge were analysed, in comparison to real world experiences, for their effectiveness in conveying and uptake of spatial information. Their potential is acknowledged, in that it may include three-dimensional visual, localized audio, and tactual stimuli to potentially enhance the learning experience; however, it has been recognised that some may experience simulator sickness. A virtual environmental, as well as the real one, of a building were used to conduct the study, including participants from various professional backgrounds; findings show that performance inside of the virtual environment were nearly as good as the real experience in navigation and orientation and that the use of a map during the study phase of the experiments did not yield any significant effects. Ultimately, the importance of virtual environments and digital technologies is impressed in that they may be useful for training when real world environments or scenarios may not be available.

15. Guo, Z. (2011). Mind the map! The impact of transit maps on path choice in public transit. *Transportation Research Part A, 45,* p. 625-639.

London Underground's transportation network is analysed to understand how people make path choices to navigate through it, based on information delivered from its associated transit map, which is divided into four types of information: distortion, restoration, codification, and cognition. These relate to how aspects of a map are distorted to aid in understanding, restored in order to retain geographic features, codified via symbols and colour choices, and the cognitive effect of understanding the produced map as a whole. Bearing in mind the various impacts these dimensions of information may have, choice of path may be based on distance, actual or perceived, or those with fewer directional turns or interchanges, and changes to the map can result in changes to path choice. From the case study, it can be seen that map distance was more influential than actual travel time and that codification of connections affected perceived transfer convenience, and ultimately the decision of whether to take the path or not. It is suggested that these results could be impacted by future trends in using smart phones for navigation.

16. Kuipers, B. (1978). Modeling Spatial Knowledge. *Cognitive Science, 2,* p. 129-153.

Cognitive maps are built up from observations one makes of space and their environment. The author proposes the created TOUR model to deal with observations and behaviours of when one moves and begins to understand space. Sketch maps can then be produced so that those involved may reflect upon their chosen representations of space and develop spatial concepts. Working memory, and load upon it, are taken into consideration, as well as deriving meaning from representations; by understanding these, it is hoped to design better models of space to more quickly and accurately convey information. The TOUR model divides space into five aspects, which can be summarised as 1. routes, 2. topological structures, 3. positions, 4. boundaries, and 5. regions. By breaking down (cognitive) maps into these primitives, they can individually be addressed and it can begin to be understood how people construct knowledge about them. The model was coded into a computer environment creating a virtual representation of Boston, Massachusetts, and examples of navigation through it were given to understand these primitives. It is later stated that though the TOUR model itself has little to directly say about map-reading, it is acknowledged that maps are clearly an important source of common-sense spatial information and requires a complex interaction between representations of visual space and large scale space.

17. Downs, R.M., & Stea, D. (2011). Cognitive Maps and Spatial Behaviour: Process and Products. In *The Map Reader: Theories of Mapping Practice and Cartographic Representation* by *Dodge, M., Kitchin, R., & Perkins, C. (eds)*. John Wiley & Sons. p. 312-317.

It has been said that human spatial behaviour is dependent on the individual's cognitive map of the spatial environment, which contains "things" that are neither uniformly distributed, nor ubiquitous - they have a 'whereness' quality. An individual's cognitive mapping capabilities is concerned with their perceptions of these "things'" 'whereness' and their relativity in respect to them (or vice versa), which in itself is a basic component necessary for human survival. Map making encodes this information and map reading decodes it, requiring those engaging with either to be able to understand concepts such as rotation, scale, and abstraction (in the case of symbols to represent things). This is the process by where we take absolute space and transform it into relative space, leaving our own cognitive signatures on and through a map, though these can vary based on perceptions of information being represented and attitudes towards said information. It must also be asked where information is being obtained about the spatial environment, to which the authors identify sensory modalities (visual, tactile, olfactory and kinaesthetic sense) gathered by direct or indirect sources, strengthening or weakening trust in the information.

18. Uttal, D.H. (2000). Seeing the big picture: map use and the development of spatial cognition. *Developmental Science, 3:3,* p. 247-286.

The author claims that the relation between maps and the development of spatial cognition is a reciprocal one and that learning about maps can aid in this development for children. It is further claimed that this exposure to maps can help instantiate a mental mode or conception of large-scale space. Rightly identified, the term map has been used in numerous ways, and in this study is in reference to prototypical ones (e.g. atlas maps, road maps, etc.). Through exposure, children can use this cognitive tool to extend their reasoning about space in a new way, which in time, can be internalised to think about space in map-like ways, even when not looking at a map at the time. Thus it can be said that maps help us to conceive the world beyond immediate experience, making different kinds of information perceptually available, and highlight abstract space. Over time, maps and other symbolic representations leave their mark on cognitive processing, even after the actual symbols are removed, though cross-cultural understandings may need to be taken into account. Bearing in mind this knowledge is often gained through experience, children exhibit some difficulties in attaining the correct understanding of these representations, which are discussed in detail; however, a series of trials, where maps are given to one group of children before the trial, and not to another, showed that the group that was given the map performed significantly better in tasks of reasoning, memory, and navigation.

19. Gauvain, M. (1991). The Development of Spatial Thinking in Everyday Activity. In *the Biennial Meeting of the Society for Research in Child Development*. Seattle, Washington. p. 1-16.

The author postulates the role of activity theory, which proposes that neither mind nor behaviour alone should be the primary unit of analysis, but rather socially organised human activity, in psychological studies of the development of spatial cognition. For example, analysing the spatial cognitive abilities needed for processing something such as conveying in fairly explicit terms our knowledge of space to someone else (e.g. providing directions to a place) or when trying to solve that problem (e.g. where to go to run errands). The use of maps in those tasks could be said to be cultural amplifiers which may alter an individual's approaches to said tasks, had maps not been used; which means to say that such artefacts are intricately and inextricably related to thinking and its development. But these artefacts, or tools, extend beyond the map, to pen and paper used to draw cartograms, or even words used to convey directionality and engaging spatial cognitive processes. However, this divide between the external tools and the internal thinking process creates an artificial divide – both are two parts of the whole used to solve spatial problems. Thinking about wider spatial thinking questions, in respect to activity theory, the author suggests questions that may be addressed such as socio-cultural aspects that may affect spatial thinking, or those in relation to structure and task goals; some researchers have begun to address these questions, and are listed in the relevant sections, for further exploration.

20. Golledge, R.G. (1992). Do People Understand Spatial Concepts: The Case of First-Order Primitives. *Working Paper available through the University of California Transportation Center.* p. 1-19.

The main purpose of the project, described in the paper, is to begin to examine the degree to which selected processes are involved in compiling and using cognitive maps and their similarity to those using GIS in understanding geospatial concepts. The commonality for both being that spatial ability of a person to acquire and process spatial information from an environment, integrate that information into a memorised spatial layout, and to undertake behaviour on the basis of such acquired spatial knowledge builds this cognitive map (which may then be transferred to a digital representation [given sufficient skill with a GIS]). Subjects for the study were asked to study a map and perform a series of tasks to recreate the map with paper and pencil, based on memory. The results were not particularly encouraging, though, as the maps used for the task may have been too complex or confusing and the results from other variables being tested (male or female, geographer or non-geographer) didn't show any significant differences; however, the lack of performance difference between geographers and non-geographers in itself could be interesting. Further work of this kind suggests to apply this in the context of GIS and with different groups to see if similar results can be obtained and this study's ones can be repeated. A summary of findings from this study are that 1. simple spatial concepts may not be well comprehended by many people (e.g. nearest neighbour, shortest path, etc.), 2. spatial terms used to explain may not be widely used or understood, 3. people may be unaware of spatial characteristics of an environment, 4. there are many misunderstandings in "common sense" understanding of spatial information, 5. modelling criteria used by geographers are not the same as those used in common sense spatial problem solving, and 6. there appears to be a need for expert knowledge in truly understanding and solving spatial problems appropriately and that the skills associated with this knowledge need to be better understood, so geographers may be better prepared to answer these questions.

21. Gryl, I., Jekel, T., & Donert, K. (2010). GI and Spatial Citizenship. In *Learning with Geoinformation V – Lernen mit Geoinformation V*. Wichmann Verlag: Berlin. p. 1-11.

GIS is thought to support and encourage spatial thinking and in applications at the secondary school level used to encourage spatial citizenship for active involvement in society. It is argued that the understanding and appropriation of space takes place within the framework of everyday social action. GIS can be a tool that can be used to analyse these events, but has largely been inaccessible to ordinary citizens, due to cost, need for specialist knowledge, and inherent difficulties when applied to qualitative problem sets. Public Participatory GIS (PPGIS) can circumnavigate some of these issues, but a certain level of education will still be required to create and share spatial information and engage in discourse with other members of society, which is suggested to include information on how to navigate a. the physical world, b. the meanings attached to the physical objects and environment and c. the power relations involved in the production of meaning. It is suggested that the proposed learning environment for teaching these topics be linked to specific forms of human interests and knowledge; though currently often used for technical or practical human interests, few existing programmes in secondary school are able to use it in an emancipatory way, one that facilitates reflection, to be able to engage in wider citizenship goals. Therefore, it is suggested that rather than using GIS as a support tool for complex problems, that it be used in teaching as a tool that is interwoven and integral lessons, using it to solve every day problems that are relevant and understandable to all. Though a GIS does indeed make a map, traditional acquisition of 'map reading skills' need to be revised given new construction methods and ways of understanding maps in this new digital medium (for example, PPGIS).

22. Verdi, M.P., & Kulhavy, R.W. (2002). Learning with Maps and Texts: An Overview. *Educational Psychology Review, 14:1,* p. 27-46.

Maps and texts, used in conjunction, are reviewed, as well as how they are constructed and how to successfully apply them in the classroom. When presented with a map and a related text, a student must decide how to best use the information presented through use of cognitive factors, known as control processes, which are in reality elements of a metacognitive system that each learner maintains. Another factor to bear in mind is task demands when studying a map, which may positively or negatively impact students' understanding or ability to process the information. The authors state that information on the map can be either feature ("what happened there") or structural (distances between features). It was shown through studies that distinct map features helped students learn and recall related text and that structural information is used to maintain an intact image of the map without exceeding the limits of working memory, allowing attention to shift to other tasks without degradation of the original information. Prior experience with the area of interest, individual differences (gender, cognitive styles, etc.), non-traditional map representations, and representations with dimensionality may improve ability to process spatial information for some.

23. Albert, W.S. & Golledge, R.G. (1999). The Use of Spatial Cognitive Abilities in Geographical Information Systems: The Map Overlay Operation. *Transactions in GIS, 3:1,* p. 7-21.

The main study of this paper was to measure the spatial cognitive abilities in the use of GIS, specifically with map overlay operations, which was conducted with men and women, who were a mix of geographers and non-geographers. It has been said that use of GIS can be taxing on individuals' cognitive factors, as there are many aspects of geographic information which require attention and focus to process; problem-domain knowledge and tool-domain knowledge are both utilised when using a GIS, in order to ascertain geospatial problems and at the same token successfully utilise the GIS as a tool for solving them. Spatial orientation, visualization and relations are other processes in the GIS which will come with cognitive load; overlays engage all of these and hence why it was selected as the aspect to test. Findings from the study showed that the results of spatial tests yielded no significant differences between geographers and non-geographers, nor largely between men and women (though one of the test results did show slightly better performance by males). Thus it may be said that spatial abilities involved in map overlay operations may be free of sex-bias and GIS experience, which have significant implications for increasing the accessibility and use of GIS.

24. Winn, W. (1991). Learning from Maps and Diagrams. *Educational Psychology Review, 3:3,* p. 211-247.

Salomon (1979) [as quoted in the paper] proposed that learning from any medium depends on how the medium's symbol system interacts with cognitive processes; encoding of information in maps is often efficient and necessary, in comparison to leaving them as labels, and learning from them in this way can only be understood once relationships between symbol systems and psychological processes have been determined – it is the process of communicating this information that is the main topic of this paper. Concepts such as relative dominance, perceptual precedence and chunking are discussed, which all inevitably highlight and showcase the information that map producer wanted to, with relevance of concepts interwoven and compared between maps and diagrams, though cross-cultural understandings/miscommunications need to be kept in mind to maintain "meaning" to the map reader. Some argue that two dimensional representations (diagrams and maps) are better at conveying information than one dimensional ones (text) and that cognitive processes are effective in deal with these visual arguments through the spatial arrangement of components. Though much of the paper draws on the similarities of maps and diagrams, it also acknowledges that they are different things, in that maps try to represent real territories in realistic ways and require different skills for interpretation than diagrams – in particular distances, interpretation of symbols used in keys, and the literal interpretation of space. That is to say that there is an abstract schemata associated with maps that contain encoded information to convey spatial knowledge, either spatially, verbally, or both, and different encoding techniques may need to be employed based on how the information is to be conveyed, again bearing in mind the individual differences of the intended map readers.

25. Lee, J., & Bednarz, R. (2009). Effect of GIS Learning on Spatial Thinking. *Journal of Geography in Higher Education, 33:2,* p. 183-198.

It is argued in *Learning to Think Spatially* (2006 [as quoted in the paper]) that spatial thinking is universal and useful in a wide variety of everyday problem-solving situations and the authors of this paper contend that it can and should be taught at all levels in the education system. They believe that spatial thinking is a constructive amalgam requiring knowledge of three mutually reinforcing components: the nature of space, the methods of representing spatial information, and the process of spatial reasoning, of which GIS has clearly demonstrated potential as a support system for this. Spatial skills tests were conducted in the GIS to understand the skillset necessary to use it as a tool to aid in spatial thinking, with GIS and non-GIS user test subjects, in which a positive correlation was found based on those who had previously completed supporting coursework on GIS, implying that some level of an educational background in GIS can improve performance in spatial thinking in comparison to no prior experience.