European Journal of Geography Volume 10, Number 3:73-84, September 2019
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SKILLS GAINED AND THE SIGNIFICANCE THEREOF IN TEACHING WITH OR THROUGH GIS

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Abstract

Teaching through geographic information systems (GIS) is of major importance and cannot be overlooked as it is a useful tool in assisting students to gain a set of assorted skills. This systematic review article analyses some of the skills developed in teaching and learning through GIS and takes a fresh look at the significance of the skills gained. According to the results, teaching through GIS distinctively indicates the development of skills such as problem solving and spatial thinking, which can foster self-directed learning as well. This review article is, therefore, aimed at informing educators, curriculum developers and policymakers on considering GIS as one of the important tools to be promoted in different curricula of education.

Keywords: *Education, geographic information systems (GIS), problem solving, self-directed learning, spatial thinking skills*

1. INTRODUCTION

Geographic information systems (GIS) are one of the tools used when working with geographic information (Gryl & Jekel, 2018; Jackson & Kibetu, 2019; Kolesenkov & Taganov, 2019; Mzuza & Van der Westhuizen, 2019). According to Egiebor and Foster (2018), GIS as a tool that motivates students to discover, examine and interpret from a spatial viewpoint, helps with the engagement, learning and performance of students in the classroom. Furthermore, GIS contribute towards the intensification of students' motivation for geography, enhance spatial reasoning and support problem-solving skills (Collins, 2018; Egiebor & Foster, 2018; Retno, Arfatin & Nur, 2019; Srilaphat & Jantakoon, 2019; Xiang & Liu, 2018). GIS also increase content retention and contribute to having fun with learning, in addition to allowing easy access to informational data, providing hands-on learning, improving knowledge about maps and encouraging critical thinking (Egiebor & Foster, 2018; Han, 2019; Retnawati, Djidu, Apino & Anazifa, 2018; Retno et al., 2019; Srilaphat & Jantakoon, 2019; Treffers, 2019; Xiang & Liu, 2018). The imagination, inquiry, evaluation and comprehension of information about the world and of human exploits that is mainly presented on a map, are enlightened by GIS (Degirmenci, 2018; Egiebor & Foster, 2018; Gryl & Jekel, 2018; Jackson & Kibetu, 2019; Thill, 2019). It is thus apparent that there is a connection between the society and geographic information technology, which could assist teachers and policymakers to understand GIS and the significance thereof in teaching and learning in order to achieve the goal of applying learner-centred approaches in various subjects (Scholten, Hottecke & Springer, 2018; Jackson & Kibetu, 2019). GIS had previously only been used in business settings to solve problems and

convey geographical decision making, while GIS are used in almost every sector at present, including education (Anthamatten, Bryant, Ferrucci, Jennings & Theobald, 2018; Collins, 2018; Walshe, 2018; Xiang & Liu, 2018). In education, GIS are considered as one of the best tools available in teaching and learning for students to develop problem-solving skills (Hall-Beyer, 2019; Peacock, 2018; Walshe, 2018), spatial thinking skills (Collins, 2018; Fleming & Mitchell, 2017; Millsaps & Harrington 2017) and self-directed learning (SDL) skills (France & Haigh, 2018; Huynh & Hall, 2019; Jackson & Kibetu, 2019). GIS furthermore help with promoting higher-order systematic and synthetic thinking, creativeness and innovativeness (Antwi, Bansah & Franklin, 2018; Dragicevic & Anderson, 2019; Eteokleous, 2019).

A study was conducted in the United States of America (New Hampshire and Colorado) on the influence of learning, using huge state maps in the teaching and learning of mathematics and geography theories and skills in elementary schools where these two subjects were incorporated (Anthamatten et al., 2018). The results of this study indicated that there was an improvement in the way the students were responding to questions and improvement of the students' scores in mathematics and geography (Anthamatten et al., 2018). The improvement of their scores was associated with map skills, which not only reinforced the students' learning spatial skills but also assisted in their understanding of mathematics, thereby influencing the teachers to support the idea that geography and mathematics are interconnected (Anthamatten et al., 2018; Dorn et al., 2005). Giant maps were also used in the middle-level phase (Grade K through 8) in South Carolina, Columbia, where the results showed a slight improvement in spatial thinking skills, with researchers pinpointing the methodology they had employed in testing spatial concepts as the cause that affected the results (Fleming & Mitchell, 2017). Another study concerning geospatial technology was conducted in America, involving 18 volunteer teachers who had three to 31 years of teaching experience at two schools in rural areas (Collins & Mitchell, 2018). This one-year study, which involved some follow-ups, included activities for teaching professional development that were managed by geography departments from five universities and colleges of education. The participants in the study showed interest in the study because of the geography subjects, which included maps that they perceived as supportive of the increase of spatial awareness and thinking skills (Collins & Mitchell, 2018). The teachers also enjoyed the training because it helped raise their self-confidence in teaching, making use of geospatial technologies (Collins & Mitchell, 2018). The results, nevertheless, suggested that most of them were not applying what they had learnt during their training (Collins & Mitchell, 2018). The necessity for continuous follow-ups and training in the application of GIS and pedagogical strategies was regarded a recommendation in order to improve teachers' confidence before attaining skills. Researchers have also suggested the inclusion of GIS in geography for pre-service teacher education, indicating that student teachers would be able to use the skills gained in their respective schools after acquiring skills in teaching through GIS (Collins & Mitchell, 2018; Mitchell, 2018; Mitchell, Roy, Fritch & Wood, 2018).

Although studies on the importance of using GIS in teaching and learning have been carried out worldwide, no study exists that specifically discusses and summarises the skills gained when teaching and learning with or through GIS, including the significance thereof. In this review article, some of the skills gained or developed in teaching with or through GIS are analysed and the significance of the skills gained in teaching with or through GIS is discussed. The article mainly analyses problem solving, spatial thinking and SDL.

2. PROBLEM-SOLVING SKILLS AND THE SIGNIFICANCE THEREOF

Problem-solving skills are among those developed by teaching and learning through GIS (Balram, 2019; Brown, McCrackin, Cairns & Stirling, 2018; Hall-Beyer, 2019; Han, 2019; Jackson & Kibetu, 2019). Fischer and Neubert (2015) define problem-solving skills as a

package of knowledge, expertise and capabilities that are essential to efficiently solve difficult and dynamic unpredictable situations in different domains, especially when one needs to achieve a goal but is at a loss as to what modus operandi to use. Problem-solving skills can be used in almost all subjects, including social studies, mathematics, geography, history, engineering and many others (Anthamatte et al., 2018; Egiebor & Foster, 2018; Leavy & Hourigan, 2019; Retno et al., 2019; Topalli & Cagiltay, 2018; Treffers, 2019). By involving several teaching techniques, including the use of GIS, in primary or secondary school education or higher learning education, students can be assisted in gaining problem-solving skills that mostly occur in flexible learning environments (Balram, 2019; Han, 2019; Schmidt, Rotgans & Yew, 2019; Xiang & Liu, 2018). A study in the United States of America, involving eighth-grade students learning social studies aimed at understanding the perception of students learning social studies using GIS story maps can be used as an example (Egiebor & Foster, 2018). As a subject, social studies encompasses four subjects, namely civics, economics, geography and history, and is instrumental in supporting students to discover the responsibilities of citizens by examining the human scopes of the world (Barr, 2017; Egiebor & Foster, 2018). The subject social studies provides high school students with the basis of knowledge and skills for the transition into adulthood and the larger society as responsible and productive citizens (Barr, 2017). According to Egiebor and Foster (2018), geographic knowledge of, and responsiveness towards civics, history and economics are essential for decision making on both the local and international level, suggesting the reason why their study focused on students in order to examine, comprehend and appreciate how the application of GIS through the use of story maps in social studies could help to apply knowledge needed for enhancing skills such as problem solving. Story maps have thus been shown to enhance the learning of social studies, where students were wholly involved in the teaching and learning process, understood the content and could answer questions without help. The students were also able to realise a cultural and geographic connection with GIS story maps and their daily life experiences outside the classroom (Egiebor & Foster, 2018).

GIS can also be applied in project-based learning, which later facilitates gaining problem-solving skills (Brown et al., 2018). According to Brown et al. (2018), with the project-based learning teaching space, students participate in real-world settings, experiments and solving problems where an exceptional set of skills is needed; they learn to understand and collaborate with others to solve problems and master concepts. With the involvement of GIS, which are both technologically based and project-based, it is possible to increase content retention in geography, history, mathematics and science, to encourage a positive attitude towards sciences and mathematics and to help students develop teamwork, time management, creativity, critical thinking and problem-solving skills (Brown et al., 2018; Dragicevic & Anderson, 2019; Han, 2019; Jackson & Kibetu, 2019; Leavy & Hourigan, 2019). For example, a study on problem posing and problem solving, which were taught as part of a mathematics module, was conducted in Ireland, involving 415 (undergraduate) student primary school teachers (Leavy & Hourigan, 2019). For problem solving, the participants were offered different non-traditional problems to solve, using different problem-solving approaches, as discussed in their prior lectures (Leavy & Hourigan, 2019). The study included the collection and analysis of pre- and post-test data relating to the teaching method used. The results showed some improvement in the students' problem-solving skills, and the participants were able to analyse and recognise mathematics features of word problems (Leavy & Hourigan, 2019).

3. SPATIAL THINKING SKILLS AND THE SIGNIFICANCE THEREOF

GIS have been used globally as an important tool for teaching and learning spatial thinking skills (Collins, 2018a; Collins, 2018b; Ishikawa, 2016; Mzuza & Van der Westhuizen, 2019;

Nazareth, Newcombe, Shipley, Velazquez & Weisberg, 2018; Romund, 2019; Wilson, Wilson & Martin, 2019). Studies have revealed that the proper use of GIS tools in a classroom helps to improve the quality of learning by engaging the students in spatial analysis and making all geographic assumptions clear (Gryl & Jekel, 2018; Hall-Beyer, 2019; Han, 2019; Nazareth et al., 2018). A combination of graphical visualisations with interactive learning patterns and visual elements of GIS accelerates the understanding of the underlying geographic and spatial principles and, thereafter, assists in the development of spatial cognitive skills (Burte, Gardony, Hutton & Taylor, 2019; Lee et al., 2019; Nazareth et al., 2018; Romund, 2019; Ziffer et al., 2019).

Spatial thinking skills can be defined in various ways, depending on the context in which these are being used. In geography education, spatial thinking skills are defined as a group of cognitive skills, which include having knowledge of concepts of space and being able to use tools of representation and reasoning practices (Ishikawa, 2016; Jo & Bednarz, 2009; Romund, 2019). Concepts of space in a group of cognitive skills include distance, distribution, location, region, spatial linking and patterns, which are required in spatial thinking; tools of representation include maps, diagrams, graphs and the ability to use these spatial representations efficiently, which are essential in spatial thinking; and cognitive skills require complex reasoning that expands further than the information given (Bearman, Jones, Andre, Cachinho & DeMers, 2016; Jo & Bednarz, 2009; Metoyer & Bednarz, 2017; Romund, 2019; Zimmermann et al., 2019). Some scholars define spatial thinking as a mixed cluster of cognitive skills (Ziffer et al., 2019), while others describe it as having geographic knowledge that contains all the different techniques in which geography and space can be hypothesised, as well as the ability to manipulate and construct spatial information (Romund, 2019; Trumble & Dailey, 2019). Spatial thinking skills could be taught or obtained on all educational levels and in different courses such as geography, mathematics and many others (Burte et al., 2019; Jo & Bednarz, 2009; Lee et al., 2019; Mulligan, Woolcott, Mitchelmore & Davis, 2018; Trumble & Dailey, 2019; Wilson et al., 2019; Ziffer et al., 2019; Zimmermann et al. 2019). Improving spatial thinking skills is one of the objectives to be achieved in geography education; however, this depends on how the education system is encouraging students to practise or learn these skills (Ishikawa, 2016; Metoyer & Bednarz, 2017). Spatial thinking skills are of the utmost importance in geography because they enable students to comprehend geographic information in order to find solutions to a multitude of complicated spatial problems faced in the world today (Bearman et al., 2016; Gonzalez, 2019).

A study involving teenage girls, conducted in Seattle, Washington, examined interactive digital mapping (which involves GIS) as one of the environmental technologies for learning and practising spatial thinking skills (Gordon, Elwood & Mitchell, 2016). In their study, Gordon et al. (2016) indicated how interactive digital mapping methods increase students' awareness of what is occurring in urban geographies to help the students understand the interlinkages of social and spatial processes. This study also taught students how they could attend to different situations in their lives (Bearman et al., 2016; Gonzalez, 2019; Gordon et al., 2016; Jo & Bednarz, 2009). Students worked together in groups to develop a multimedia map of historically significant places, sourcing information from books, the Internet, teachers, parents, community members and classmates (Gordon et al., 2016). The results showed that by working in a group to explore and explain the spatial patterns and connections shown in the maps, the girls had developed their spatial critical thinking skills concerning social histories and geographies. The girls were thus able to experience and appreciate spatial patterns as something related to social processes and were able to link these things happening or encountered in their everyday lives (Bearman et al., 2016; Gonzalez, 2019; Gordon et al., 2016; Jo & Bednarz, 2009). This study proved that learning through GIS could assist in developing spatial thinking skills in students. Bearing in mind the advancements in technology, instruments or tools such

as GIS could be used in relation to learning processes for students to gain or develop spatial thinking skills (Jo & Bednarz, 2009; Madsen & Rump, 2012; Mayalagu, Jaafar & Choy, 2018). Students have different techniques for producing individual tools for spatial thinking. According to the National Academies Press in the United States (2006), three kinds of spatial thinking exist, namely thinking in space, thinking about space and thinking with space. Thinking in space needs thinking in a real-world context and is used to implement actions; thinking about space focuses on a scientific understanding of the environment, structure and function of occurrences; and thinking about space includes thinking about the ways in which the world is working (Jo & Bednarz, 2009; Madsen & Rump, 2012). All three these kinds of spatial thinking are intertwined. The results of Madsen and Rump's (2012) study proved that all three kinds of spatial thinking could be gained or developed when teaching and learning through GIS; for example, the students started developing their own strategies to create personal tools when they learnt through GIS. Madsen and Rump's (2012) results correspond with those of a study conducted in Malaysia (Mayalagu et al., 2018), where a GIS and spatial thinking skills module was developed to help with the improvement of spatial thinking skills and to attract students to studying geography. The results showed that the inclusion of GIS in geography facilitated the development of spatial thinking skills in the students who had been involved in the study (Mayalagu et al., 2018).

4. SDL SKILLS AND THE SIGNIFICANCE THEREOF

Various studies have demonstrated that teaching with or through GIS in geography, mathematics, nursing, fieldwork research, medical education and various other subjects assists in developing a routine of lifelong SDL skills in students, as it also helps to enhance realism, adaptability, visualisation and cooperativeness (Alharbi, 2018; Blaschke, 2018; Chang, Irvine, Wu & Seow, 2018; Cichon & Piotrowska, 2018; Collins & Mitchell, 2018; Dragicevic & Anderson, 2019; France & Haigh, 2018; Hall-Beyer, 2019; Huynh & Hall, 2019; Markuszewska, Tanskanen & Subiros, 2018; Mzuza & Van der Westhuizen, 2019; Singh, Mahajan, Gupta & Singh, 2018).

SDL is one of the teaching and learning skills that is being encouraged at present in adult learning, institutions of higher learning and secondary as well as primary schools (Baldelli et al., 2018; Chang et al., 2018; Durham, 2018; Ge & Chua, 2018; Hall-Beyer, 2019; Markuszewska et al., 2018; Marr et al., 2020; Morris, 2018; Peacock, 2018; Singh et al., 2018). SDL means identifying one's own education essentials, setting learning objectives, finding available learning resources, selecting and applying appropriate learning approaches and assessing one's learning results (Alharbi, 2018; Morris, 2018). SDL can also refer to self-created opinions, approaches and actions that motivate students achieve their objectives (Dignath & Büttner, 2018). In addition, Khiat (2017) posits that SDL is a strong factor that could be used to predict educational achievement.

Some of the achievements that self-directed students obtain, include the motivation to learn and applying goal-orientation, self-assessment and best practices in using the information accumulated (Avdal, 2013; Ge & Chua, 2019; Hamilton, 2018; Shaikh, 2013; Zhoc, Chung & King, 2018). In addition to these, self-directed students have advanced skills in managing time and pressure, preparing for tasks and examinations and taking notes (Bruillard & Baron, 2018; Dignath & Büttner, 2018; Khiat, 2017; Peacock, 2018). SDL support students to learn at their own pace and in their own way (Baldelli et al., 2018; Chang et al., 2018; Marr et al., 2020). Studies have proved that learning effectiveness is dependent on students' understanding and demonstration of SDL skills (Peacock, 2018; Singh et al., 2018). SDL empowers students to improve their critical thinking skills and ways of absorbing massive quantities of information by involving students in the active learning process (Baldelli et al., 2018; France & Haigh,

2018; Singh et al., 2018). SDL is a fundamental theoretical background in adult education research, where most adult learning is self-directed (Durham, 2018; Morris, 2018). Adult learning cannot be ignored due to the shifting of offices and the fast growth of technology because people are now focusing on the idea of lifetime education in order to keep up with the dynamic development of the working place (Baldelli et al., 2018; Brockett & Hiemstra, 2018; Durham, 2018; Morris, 2018). Institutions of higher education are playing a key role as drivers of innovation and are becoming models of best practice for the professional world (Collins & Mitchell, 2018; Huynh & Hall, 2019; Mitchell, 2018; Mitchell et al., 2018; Wise, 2018). It had been projected that there would have been a 63% need for upgrading in education in all places of work by 2018, which resulted in creating a gap in most higher learning institutions in order to accommodate adult learning, especially through distance learning, which requires students to have SDL skills (Baldelli et al., 2018; Durham, 2018). According to Baldelli et al. (2018), adult students (mostly over the age of 24) are regarded as people who are looking for a degree at any level but have had a break of three or more years from any other formal education. It is inspiring that at present, many older people, especially workers, are keen to return to their studies after having had a break due to work or for other reasons; in situations like these, SDL skills are required even more (Baldelli et al., 2018; Durham, 2018).

5. DISCUSSION

The results of various studies have shown that teaching and learning through GIS can help students with the development of particular skills such as, among others, problem-solving skills, spatial thinking skills and SDL skills (Antwi et al., 2018; Collins, 2018; Dragicevic & Anderson, 2019; Eteokleous, 2019; Fleming & Mitchell, 2017; Hall-Beyer, 2019; Jackson & Kibetu, 2019; Millsaps & Harrington, 2017; Peacock, 2018; Walshe, 2018). These skills also support the gaining of other abilities, such as time management, pressure management, task preparation, examination preparation, note taking, higher-order systematic and synthetic thinking, creativeness and innovativeness (Antwi et al., 2018; Bruillard & Baron, 2018; Collins, 2018; Dignath & Büttner, 2018; Dragicevic & Anderson, 2019; Eteokleous 2019; Fleming & Mitchell, 2017; Hall-Beyer, 2019; Jackson & Kibetu, 2019; Khiat, 2017; Millsaps & Harrington, 2017; Peacock, 2018; Walshe, 2018). Each skill has its own significance in the teaching and learning process.

Students who are skilled in problem solving are expected to be able to construct their own knowledge and exploration, process the data and combine the information with previous knowledge to solve problems in real life (Brand-Gruwel, Wopereis & Vermetten, 2005; Chatwattana & Nilsook, 2017; Fischer & Neubert 2015; Srilaphat & Jantakoon, 2019). Students with problem-solving skills have the ability to understand content and to answer questions according to the context (Egiebor & Foster, 2018; Srilaphat & Jantakoon, 2019). Students with problem-solving skills are also able to connect environmental processes or situations to what is happening or experienced in daily life (Egiebor & Foster, 2018; Srilaphat & Jantakoon, 2019). Problem-solving skills also facilitate the retention of content learnt, since what a student has managed to comprehend and solve is instilled in the brain; hence these skills encourage positive attitudes in students towards sciences, mathematics, geography as well as other subjects (Mzuza, Yudong & Kapute, 2014; Egiebor & Foster, 2018; Leavy & Hourigan, 2019; Retnawati et al., 2018; Treffers, 2019). Problem-solving skills also promote teamwork, time management, creativity and critical thinking in students, since after managing to solve a problem, students prefer to share the knowledge gained, thereby promoting teamwork (Egiebor & Foster, 2018; Retnawati et al., 2018). All of the skills necessary to be a successful problem-solver will also foster SDL when the skills of each are compared.

Spatial thinking skills, when properly applied in a classroom, help to increase the quality of learning by engaging students in spatial analysis and making all assumptions clear (Gryl & Jekel, 2018; Hall-Beyer, 2019; Han, 2019; Nazareth et al., 2018). Spatial thinking skills also assist students in manipulating and constructing spatial information (Romund, 2019; Trumble & Dailey, 2019). In addition to that, spatial thinking skills help students to accumulate information from the senses or remember information from recalls, in other words, to recognise, define, categorise and recall things (Gordon et al., 2016; Jo & Bednarz, 2009; Madsen & Rump, 2012). After having acquired information, students with spatial thinking skills will be able to go beyond that; that is, they will be able to analyse, categorise and clarify the information acquired (Gordon et al., 2016; Jo & Bednarz, 2009; Madsen & Rump, 2012). Students with spatial thinking skills will also be able to generate new knowledge from the information obtained, which requires the highest level of thinking in dealing with difficult and complicated issues, meaning that they will be able to create their own strategies in order to develop personal tools (Bearman et al., 2016; Gonzalez, 2019; Jo & Bednarz, 2009; Madsen & Rump, 2012). All of these skills are also necessary to foster SDL and are aligned to Knowles's (1975) core definition thereof.

SDL skills, which can be developed by teaching and learning through GIS, assist in enhancing realism, adaptableness, positive thinking and cooperativeness in students (Alharbi, 2018; Blaschke, 2018; Chang et al., 2018; Cichon & Piotrowska, 2018; Collins & Mitchell, 2018; Dragicevic & Anderson, 2019; Hall-Beyer, 2019; Huynh & Hall, 2019; Markuszewska et al., 2018; Mzuza & Van der Westhuizen, 2019; Singh et al., 2018). In addition, SDL skills encourage students to find their own learning essentials, setting their own learning goals, finding their own available learning resources, selecting and applying suitable learning methodologies and evaluating their own results (Alharbi, 2018; Morris, 2018; Plackle, Konings, Jacquet, Libotton, Van Merrienboer & Engels, 2018; Premkumar, Vinod, Sathishkumar, Pulimood, Umaefulam & Samuel, 2018). According to Dignath and Büttner (2018), SDL could support students to devise their own ideas, approaches and actions that can assist them in attaining their objectives. Other advantages for students who have SDL skills include students being motivated to learn, having goal-orientation and being willing to apply the knowledge gained (Alharbi, 2018; Ge & Chua, 2019; Hamilton, 2018; Zhoc et al., 2018). Furthermore, self-directed students show improved abilities of time management, pressure management, task preparation, examination preparation and note taking (Bruillard & Baron, 2018; Baldelli et al., 2018; Dignath & Büttner, 2018; Marr et al., 2020; Peacock, 2018).

6. CONCLUSION

Due to the importance of GIS in the development of skills such as problem-solving, spatial thinking and SDL, the use of GIS in education cannot be overlooked. Problem-solving skills assist with content retention, encouraging a positive attitude in students towards different subjects and promoting teamwork, time management and creativity. Spatial thinking skills help to increase the quality of learning and help students to manipulate and construct spatial information, to accumulate or acquire information and to analyse, categorise, clarify and generate new knowledge from the information obtained.

SDL is characterised and enhanced by skills such as realism, adaptableness, positive thinking, motivation to learn, cooperativeness, time and pressure management, task and examination preparation and note taking. SDL also motivate students to find their own learning essentials, setting their own learning goals and finding their own learning resources available. We can, therefore, safely argue that when teaching is done through or with GIS, a very high level of skills development is taking place with regard to problem solving and spatial thinking, which is ideal for the fostering of SDL skills in students.

This review article thus aims to stimulate educators, curriculum developers and policymakers to regard GIS as an important tool to be promoted in education. Including GIS in the school curriculum, and especially in teacher-training colleges or universities, will help student teachers to obtain knowledge that is crucial in the classroom. It is also important for students in primary and secondary schools, or even university, to gain the skills that can be developed when learning through GIS takes place. A need exists to carry out more research on the interconnectedness of these skills gained during the teaching and learning of GIS.

ACKNOWLEDGEMENTS

We thank Professor Fanuel Kapute of Mzuzu University, Malawi, for kindly accepting to proofread this work.

Disclosure statement

No potential conflict of interest was reported by the author.

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REFERENCES

Alharbi, H.A. (2018). Readiness for self-directed learning: How bridging and traditional nursing students differs? *Nurse Education Today* 61: 231-234.

Anthamatten, P., L.M.P. Bryant, B.J. Ferrucci, S. Jennings, and R. Theobald. (2018). Giant maps as pedagogical tools for teaching geography and mathematics. *Journal of Geography* 117 (5): 183-192.

Antwi, S., A.K. Bansah, and T. Franklin. (2018). The information technology challenge in teaching senior high school geography in Ghana. *Issues and Trends in Educational Technology* 6 (1): 16-38.

Baldelli, S., C. Botero, C. Ferreol, C. Horton, X. Ma, and S. Sprinkmoller. (2018). Adult learners: A targeted marketing approach. (Masters' Papers) Clark University: Clark Digital Commons.

Balram, S. (2019). Teaching and learning pedagogies in higher education geographic information science. In *GIScience teaching and learning perspectives*, ed. S. Balram and J. Boxall, 1-8. Cham: Springer.

Barr, H. (2017). Defining social studies. *Teachers and Curriculum* 1 (1): 1-12.

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

Blaschke, L.M. (2018). Self-determined learning (heutagogy) and digital media creating integrated educational environments for developing lifelong learning skills. In *The digital turn in higher education*, ed. D. Kergel, B. Heidkamp, P. Telleus, T. Rachwal, and S. Nowakowski, 129-140. Wiesbaden, VS: Springer.

Brand-Gruwel, S., I. Wopereis, and Y. Vermetten. (2005). Information problem solving by experts and novices: Analysis of a complex cognitive skill. *Computers in Human Behavior* 21 (3): 487-508.

Brockett, R.G. and R. Hiemstra. (2018). *Self-direction in adult learning: Perspectives on theory, research and practice*. London: Routledge.

Brown, D.S., J. McCrackin, J. Cairns, and M. Stirling. (2018). Using GIS as a cross-curricular vehicle for student learning. In *E-learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education*, ed. LearnTechLib, 636-641. San Diego, CA: Association for the Advancement of Computing in Education.

Bruillard, E. and G.L. Baron. (2018). Researching the design and evaluation of information technology tools for education. *Second Handbook of Information Technology in Primary and Secondary Education* 1143.

Burte, H., A.L. Gardony, A. Hutton, and H.A. Taylor. (2019). Make-a-dice test: Assessing the intersection of mathematical and spatial thinking. *Behavior Research Methods* 1-37.

Chang, C.H., K. Irvine, B.S. Wu, and T. Seow. (2018). Reflecting on field-based and technology-enabled learning in geography. In *learning geography beyond the traditional classroom* 201-212. Singapore: Springer.

Chatwattana, P. and P. Nilsook. (2017). A web-based learning system using project-based learning and imagineering. *International Journal of Emerging Technologies in Learning* 12 (5): 4-22.

Cichon, M. and I. Piotrowska. (2018). Level of academic and didactic competencies among students as a measure to evaluate geographical education and preparation of students for the demands of the modern labour market. *Quaestiones Geographicae* 37 (1): 73-86.

Collins, L. (2018). Student and teacher response to use of different media in spatial thinking skill development. *International Journal of Geospatial and Environmental Research* 5 (3): 3.

Collins, L. (2018). The impact of paper versus digital map technology on students' spatial thinking skill acquisition. *Journal of Geography* 117 (4): 137-152.

Collins, L. and J.T. Mitchell. (2018). Teacher training in GIS: What is needed for long-term success? *International Research in Geographical and Environmental Education* 1-18.

Degirmenci, Y. (2018). Use of geographic information systems (GIS) in geography lessons according to teachers' opinion. *World Journal on Educational Technology: Current Issues* 10 (3): 186-196.

Dignath, C. and G. Büttner. (2018). Teachers' direct and indirect promotion of self-regulated learning in primary and secondary school mathematics classes-insights from video-based classroom observations and teacher interviews. *Metacognition and Learning* 1-31.

Dorn, R.I., J. Douglass, G.O. Ekiss, B. Trapido-Lurie, M. Comeaux, R. Mings, and B. Ramakrishna. (2005). Learning geography promotes learning math: Results and implications of Arizona's GeoMath grade K-8 program. *Journal of Geography* 104 (4): 151-159.

Dragicevic, S. and T. Anderson. (2019). Enabling scientific research skills in undergraduate students during a spatial modeling course. In *GIScience Teaching and Learning Perspectives*, eds. S. Balram and J. Boxall, 37-52. Cham: Springer.

Durham, H. (2018). Evaluating and developing quantitative methods and technical skills in master's level online distance learning students: Experiences of a teaching enhancement project exploring transition challenges. *International Journal for Infonomics* 11(1): 1-10.

Egiebor, E.E. and E.J. Foster. (2018). Students' perceptions of their engagement using GIS-story maps. *Journal of Geography* 118 (2): 1-15.

Eteokleous, N. (2019). Robotics and programming integration as cognitive-learning tools. In *Advanced methodologies and technologies in artificial intelligence, computer simulation, and human-computer interaction,* 1085-1099. IGI Global.

Fischer, A. and J.C. Neubert. (2015). The multiple faces of complex problems: A model of problem solving competency and its implications for training and assessment. *Journal of Dynamic Decision Making* 6 (1): 1-13.

Fleming, J. and J. Mitchell. (2017). Effects of giant traveling map use on student spatial thinking. *The Geographical Bulletin* 58 (2): 67-77.

France, D. and M. Haigh. (2018). Fieldwork@ 40: Fieldwork in geography higher education. *Journal of Geography in Higher Education* 42 (4): 498-514.

Ge, X. and B.L. Chua. (2019). The role of self-directed learning in PBL: Implications for learners and scaffolding design. *The Wiley Handbook of Problem-Based Learning* 367.

Gonzalez, J.A.G. (2019). Visual and spatial thinking in the neogeography age. In *Geospatial challenges in the 21st century*, ed. K. Koutsopoulos, R. de Miguel Gonzalez, and K Donert, 369-383. Cham: Springer.

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

Gryl, I. and T. Jekel. (2018). Spatially informed citizenship education as an approach for global understanding. *Geography Education for Global Understanding* 43-56.

Hall-Beyer, M. (2019). The map is not the territory: Adding value to technical GIS education. In *GIScience teaching and learning perspectives*, ed. S. Balram and J. Boxall, 63-79. Cham: Springer.

Hamilton, N.W. (2018). Leadership of self: Each student taking ownership over continuous professional development/self-directed earning. *Santa Clara Law Review* 58(1): 1-4.

Han, R. (2019). Web GIS in development: From research and teaching perspectives. In *GIScience teaching and learning perspectives*, ed. S. Balram and J. Boxall, 103-122. Cham: Springer.

Huynh, N.T. and G.B. Hall. (2019). Navigating employment prospects for new graduates in the geospatial sciences. In *GIScience teaching and learning perspectives*, ed. S. Balram and J. Boxall, 145-169. Cham: Springer.

Ishikawa, T. (2016). Spatial thinking in geographic information science: Students' geospatial conceptions, map-based reasoning, and spatial visualization ability. *Annals of the American Association of Geographers* 106 (1): 76-95.

Jackson, C.M. and D.K. Kibetu. (2019). Emerging technologies in teaching, research, and learning: GIS technology and methods in education. In *Technology-supported teaching and research methods for educators* 201-217. IGI Global.

Jo, I. and S.W. Bednarz. (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): 4-13.

Kolesenkov, A. and A. Taganov. (2019). The usage of GIS in realizing engineering education quality. In *Handbook of research on engineering education in a global context* 126-137. IGI Global.

Leavy, A. and M. Hourigan. (2019). Posing mathematically worthwhile problems: Developing the problem-posing skills of prospective teachers. *Journal of Mathematics Teacher Education* 1-21.

Lee, A.S., W. Wilson, J. Tibbetts, C. Gawboy, A. Meyer, W. Buck, and D. Pantalony. (2019). Celestial calendar-paintings and culture-based digital storytelling: Cross-cultural, interdisciplinary, STEM/STEAM resources for authentic astronomy education engagement. *EPJ web of conferences* 200 (8): 01002.

Madsen, L.M. and C. Rump. (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): 97-116.

Markuszewska, I., M. Tanskanen, and J.V. Subiros. (2018). New ways to learn geography – challenges of the 21st century. *Quaestiones Geographicae* 37 (1): 37-45.

Marr, A.J., A. Holt and G. L. Benwell. (2020). Flexibility in GIS education – A vision. Presented at the 10th Colloquium of the Spatial Information Research Centre, University of Otago, New Zealand, 16-19 November, 1998.

Mayalagu, G., M. Jaafar, and L.K. Choy. (2018). Validity of module geographic information system-spatial thinking skills (GIS-STS). *International Journal of Engineering & Technology* 7 (4.34): 427-430.

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

Millsaps, L.T. and J.A. Harrington. (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.

Mitchell, J.T. (2018). Pre-service teachers learn to teach geography: A suggested course model. *Journal of Geography in Higher Education* 42 (2): 238-260.

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

Morris, T.H. (2018). Vocational education of young adults in England: A systemic analysis of teaching–learning transactions that facilitate self-directed learning. *Journal of Vocational Education & Training* 70 (4): 619-643

Mulligan, J., G. Woolcott, M. Mitchelmore, and B. Davis. (2018). Connecting mathematics learning through spatial reasoning. *Mathematics Education Research Journal* 30 (1): 77-87.

Mzuza, M.K. and C.P. van der Westhuizen. (2019). Review on the state of GIS application in secondary schools in the southern African region. *South African Geographical Journal* 101 (2): 1-17.

Mzuza, M.K., Y. Yudong, and F. Kapute. (2014). Analysis of factors causing poor passing rates and high dropout rates among primary school girls in Malawi. *World Journal of Education* 4(1): 48-61.

National Academies Press (US). (2006). *Learning to think spatially: GIS as a support system in the K-12 curriculum*. Washington, DC: National Academy Press.

Nazareth, A., N. Newcombe, T. Shipley, M. Velazquez, and S. Weisberg. (2018). Beyond small-scale spatial skills: Navigation skills and geoscience education. Philadelphia: Psyarxiv Preprint.

Peacock, H. (2018). Using problem-based learning (PBL) to teach geographic information science. *Teaching Innovation Projects* 8 (1).

Plackle, I., K.D. Konings, W. Jacquet, A. Libotton, J.J. van Merrienboer, and N. Engels. (2018). Students embracing change towards more powerful learning environments in vocational education. *Educational Studies* 44 (1): 26-44.

Premkumar, K., E. Vinod, S. Sathishkumar, A.B. Pulimood, V. Umaefulam, P.P. Samuel, and T.A. John. (2018). Self-directed learning readiness of Indian medical students: A mixed method study. *BMC Medical Education* 18 (1): 134.

Retnawati, H., H. Djidu, E. Apino, and R.D. Anazifa. (2018). Teachers 'knowledge about higher-order thinking skills and its learning strategy. *Problems of Education in the 21st Century* 76 (2): 215-230.

Retno, N., N. Arfatin, and A. Nur. (2019). The effect of revised Bloom's taxonomy on mathematical problem-solving skill. In *1st International Conference on Education and Social Science (ICESRE 2018)*. Atlantis Press.

Romund, G. (2019). Geography, the academy and libraries. *The Journal of Academic Librarianship* 45 (3), 318-320.

Schmidt, H.G., J. Rotgans, and E.H. Yew. (2019). Cognitive constructivist foundations of problem-based learning. *The Wiley Handbook of Problem-Based Learning*, 25.

Scholten, N., D. Hottecke, and S. Springer. (2018). Conceptualizing geography teachers` subject-specific noticing during instruction. *European Journal of Geography* 9(3): 80-97.

Singh, K., R. Mahajan, P. Gupta, and T. Singh. (2018). Flipped classroom: A concept for engaging medical students in learning. *Indian Pediatrics* 55 (6): 507-512.

Srilaphat, E. and T. Jantakoon. (2019). Ubiquitous flipped classroom instructional model with learning process of scientific to enhance problem-solving skills for higher education (UFC-PS Model). *Higher Education* 9 (1): 76-85.

Thill, J.C. (ed.). (2019). *Spatial multicriteria decision making and analysis: A geographic information sciences approach*. North America: Routledge.

Topalli, D. and N.E. Cagiltay. (2018). Improving programming skills in engineering education through problem-based game projects with Scratch. *Computers & Education* 120: 64-74.

Treffers, A. (2019). Direct instruction and problem-solving: Critical examination of cognitive load theory from the perspective of mathematics education. *The Mathematics Enthusiast* 16 (1): 607-620.

Trumble, J. and D. Dailey. (2019). Change in spatial visualization mental rotation abilities of intermediate elementary students. *Journal of Computers in Mathematics and Science Teaching* 38 (1): 77-90.

Walshe, N. (2018). Geographical information systems for school geography. *Geography* 103: 46-49.

Wise, N. (2018). Assessing the use of geospatial technologies in higher education teaching. *European Journal of Geography* 9 (3): 154-164.

Xiang, X. and Y. Liu. (2018). Exploring and enhancing spatial thinking skills: Learning differences of university students within a web-based GIS mapping environment. *British Journal of Educational Technology* 0 (1): 1-17.

Zhoc, K.C., T.S. Chung, and R.B. King. (2018). Emotional intelligence (EI) and self-directed learning: Examining their relation and contribution to better student learning outcomes in higher education. *British Educational Research Journal* 44 (6): 982-1004.

Ziffer, J., W. Morse, T. Nelson, P. Nakroshis, B.T. Rudnick, M. Brautigam, and W. Parker. (2019). Practicing spatial relationship skills using an asteroid 3-D tool. *The Physics Teacher* 57 (1): 14-16.

Zimmermann, L., L. Foster, R.M. Golinkoff, and K. Hirsh-Pasek. (2019). Spatial thinking and STEM: How playing with blocks supports early math. *American Educator* 42 (4): 22-27.