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An evaluation of the use of GIS and open data in secondary school education in South Africa, with reference to QGIS and OpenStreetMap (OSM)

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Abstract

South Africa is one of only a few countries that has Geographic Information Systems (GIS) in the secondary school curriculum. Of these few, SA is even more singular in that its Geography syllabus includes GIS geoprocessing. A mixed-methods approach was used for this study and results show that only a minority of teachers teach practical GIS classes irrespective of their Examination Board or education authority, access to hardware, how resourced their school is or whether they teach at a private or a government school. The key determinants to teaching practical GIS lessons are the teacher's perceived GIS expertise and access to spatial data and time. Software, connectivity, and power supply are also identified as challenges. Teachers who participated in the study overwhelmingly agree that there are numerous benefits to using GIS in the classroom. They also expressed a keen willingness to attend GIS courses and learn more about QGIS. A sample group evaluated how OpenStreetMap (OSM) could be used to create local spatial data and how QGIS can be used to teach the GIS curriculum and used to map local data for individual research projects. There is an urgent need for more current research, both globally and locally, into how GIS can be used more in secondary school pedagogy.

Keywords: Geographic Information Systems (GIS); QGIS; OpenStreetMap (OSM); Free and Open Source for Geospatial (FOSS4G); Project-based GIS Learning (PBL)

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Introduction

Recently, researchers have shown an increased interest in GIS as a tool to teach the Geography curriculum (Mzuza & Van Der Westhuizen, 2019; Digan, 2019; Collins & Mitchell, 2019; Healy & Walshe, 2020). Geographic Information Systems (GIS) perform the function of visualisation, analysing and managing spatial map features in a database. When GIS is introduced in the classroom it can enrich the curriculum. Interest in the educational uses of GIS has mirrored society's overall interest in spatial technologies, especially with the increased demand for consumer-oriented devices and services and the ubiquitous use of social media such as Facebook and Twitter (Riihelä & Mäki, 2015). Anunti et al. (2020) commented that the development of new technological tools and increasing access to GIS resources require more flexible and alternative approaches to teaching about GIS overall and particularly in secondary education. A considerable amount of literature has been published on how GIS is increasingly recognised as a critical 21st-century skill that motivates student learning and enhances spatial thinking skills at secondary school level (see Kerski et al., 2013; Tabor & Harrington Jr, 2014; Riihelä & Mäki, 2015; Bearman et al., 2016; Rickles, 2017; Healy & Walshe, 2019; Anunti et al., 2020).

Milson et al. (2012) highlighted the importance of inquiry-based GIS teaching. In their study, they examined thirty-three case studies, the locations of which are represented in Figure 1. Nine more countries were added to this study after reviewing more recent research (compiled by QGIS).

Figure 1: Composite map showing countries where GIS is taught at secondary school level (produced with QGIS).

The Geography curriculum should encourage students and teachers to use GIS in every phase of high school Geography, focussing on higher-order thinking skills (Artvinli & Martinha, 2014). Research shows that GIS used in the classroom environment can increase students' interest and increase their inclination to technology (Scheepers, 2009; Madsen, 2012; Komlenović et al., 2013; Artvinli & Martinha, 2014; Degirmenci, 2018). The use of GIS in the classroom helps students "think critically, use authentic data, and connect them to their own community" (Baker et al. 2012, p.255). GIS has reached a new phase in its technical development where teachers are no longer limited by what the GIS software can do and instead they can develop the critical spatial thinking aspects of Geography that GIS provides (Bearman et al., 2016).

There is a body of literature available (Demirci, 2009; Scheepers, 2009; Innes, 2009; Breetzke et al., 2011; Eksteen et al., 2012; duPlessis, 2012) that covers research on GIS at secondary school level when GIS was first introduced in 2006, and later when it was revised in the Curriculum and Assessment Policy Statement (CAPS) (Fleming, 2013; Kerski, 2013), yet very few papers on the subject have been published since (Fleischmann, 2017; and Mzuza & Van Der Westhuizen, 2019). In this study, the status of GIS teaching in secondary schools was investigated to determine the possible reasons for the lack of GIS practical lessons being taught.

This study also looked at the hurdles to using GIS in the classroom in secondary schools in South Africa, such as the lack of resources (hardware and software), internet connectivity, power supply, teacher skills, IT support, time to complete the curriculum and motivated teachers with the will to teach practical GIS lessons. Research findings will hopefully allow education authorities to act swiftly to solve the issues identified and implement the solutions recommended.

Methodology

This study used QGIS (QGIS, 2019) which is part of the Free and Open Source for Geoscience (FOSS4G) tools. QGIS is free and there is no cost to download the software. This has the benefit of making it accessible to all schools. Researchers found that organisations faced problems with data acquisition when implementing GIS (Lateh & Muniandy, 2010; Osaci-Costache et al., 2017). The GIS data that was used is OpenStreetMap OSM

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which is crowd-sourced open data that is also freely available online and easy to access (Ciolli et al., 2017). A mixed-methods approach was used for this study. Firstly, a quantitative online teacher survey was conducted to determine teacher GIS skills level and their perceptions of teaching GIS (n=112). Secondly, a sample group of teachers from the first sample group were interviewed and asked to evaluate QGIS software and OSM data as a teacher intervention (n=9).

The mixed-method strategy for this research was based on Creswell's (2009) sequential quantitative approach. The teachers interviewed were first shown a demonstration of how (OSM) data could be used to capture and digitise local spatial data of their schools or communities. They were shown how to log in to OSM and how to digitise points, lines and polygons and how to add attribute data to their digitised vector data. Once the data had been validated they were shown how it could be edited and imported into QGIS. Then they were shown how QGIS software could be downloaded and used to produce maps for local research projects. The excitement about GIS's potential that Collins and Mitchell (2019) discuss once teachers were shown this demonstration was palpable as the teachers immediately offered their suggestions as to how they could use OSM data for their projects. Step by step instructions on how to use OSM and QGIS was designed by the researcher as worksheets for grade 10 to 12 learners for the teachers to test in their classrooms. These worksheets on how to use OSM data and QGIS can be found on the Southern African Geography Teachers' Association (SAGTA) website (www.sagta.org.za) under PrepShare (SAGTA, 2021).

The first sample of 112 teachers was randomly selected by sending out a survey to the Southern African Geography Teachers' Network mailing list. The majority of participants from this first sample are from schools located in Gauteng (63%), followed by KwaZulu-Natal (16%), Western Cape (9%), Eastern Cape (6%), Limpopo (2%), North West (2%), Mpumalanga (1%) and Free State (1%) and none from the Northern Cape as can be seen in Figure 2 (a) and (b).

Results

There was an almost equal number of the respondents who follow either the Independent Examination Board (49%) or the Department of Basic Education (50%) examinations (Figure

3). The sum of the total number of responses equates to 114 and this is due to two respondents teaching to both IEB and Cambridge curricula.

Figure 2: (a) Percentage of respondents from each province (n=108) and (b) The percentage distribution of respondents across South Africa (produced with QGIS).

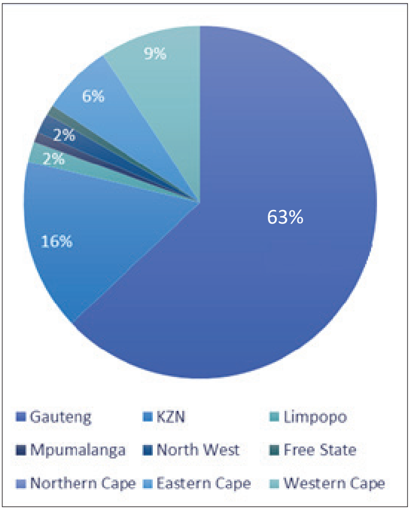

Figure 2(a)

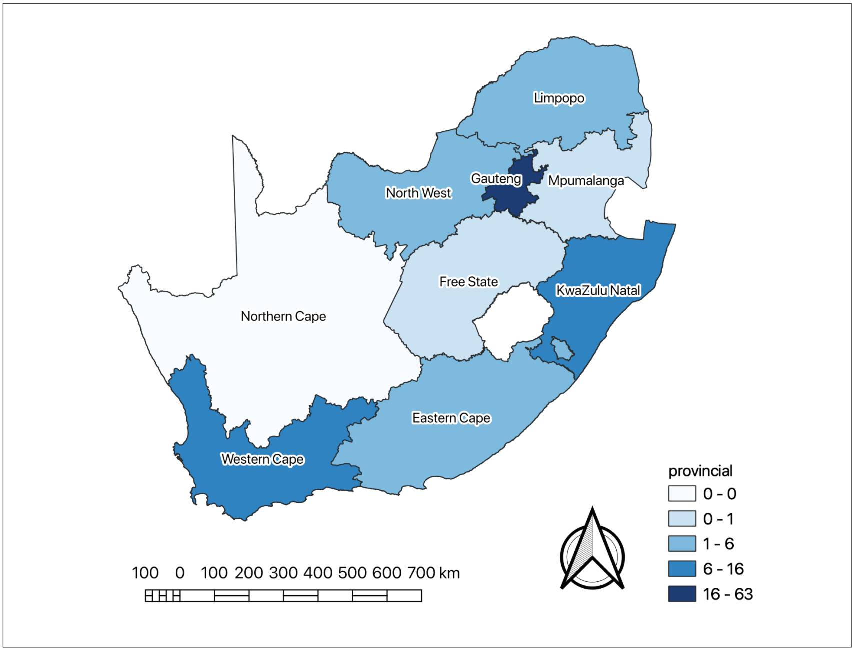

Figure 2(b)

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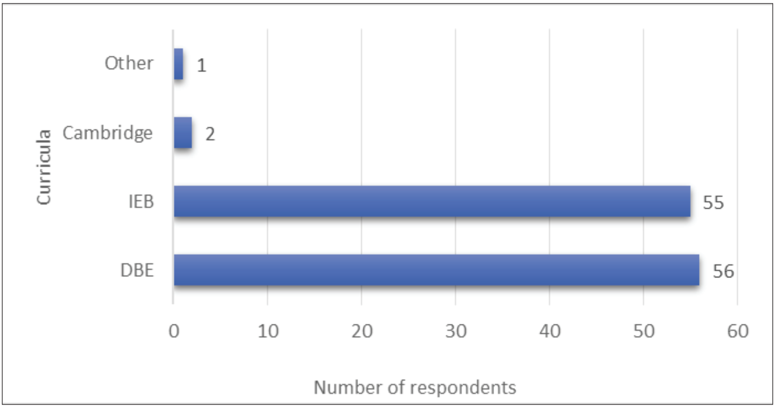

Figure 3: Number of respondents who teach to the different curricula/ Examination Boards (n=114).

The age distribution of the participants is 40 to 49 years (30.4%), followed by 50 – 59 years (25%), 30 -39 years (17%) and 20 to 29 years (13.4%). The rest (13.3%) fall into the 60 plus age group (Figure 4).

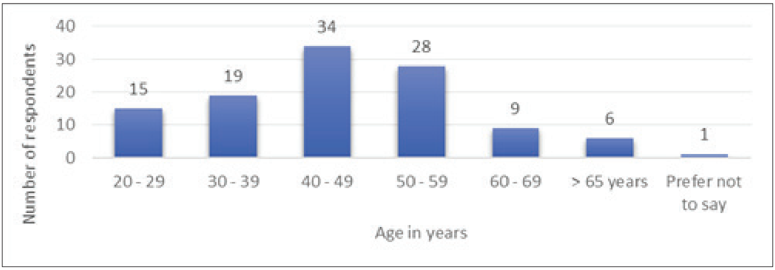

Figure 4: Age distribution of participants (n=112).

The majority of respondents have taught Geography at secondary level for either under five years (24.1%), between 21 and 30 years (25%) or over 31 years (21.4%) (Figure 5). This is significant as these results show that 52% of respondents have substantial teaching experience (over 20 years). However, a quarter of the respondents have less than five years' experience, so, a wide range of expertise is represented in the data (Figure 5). Only 29% of the respondents had 6 to 20 years of teaching experience.

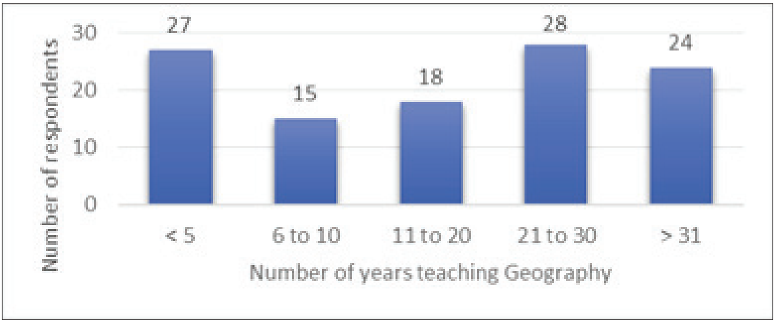

Figure 5: Number of years of teaching Geography at secondary school (n=112).

A total of 56% of the 113 respondents teach in private schools and 44% teach in the government sector. Of those teaching in the private sector, the majority teach in urban schools (94%), compared to the government sector, in which 75% teach in an urban environment. Only 14% of participants service a rural community (Figure 6).

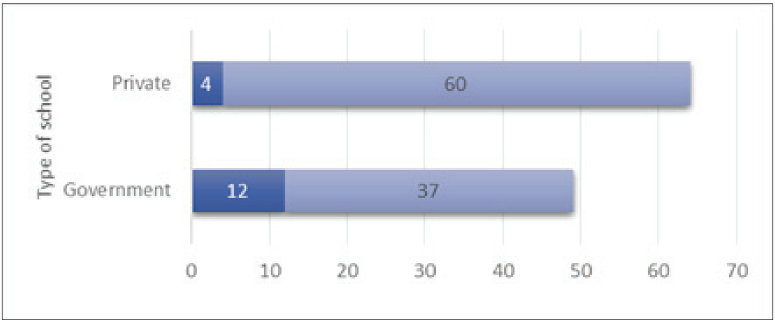

Figure 6: The number of participants who teach at government vs private schools (n=113).

The majority of schools represented in this survey have two Geography teachers (37%; 41 of 110). Twenty-four percent (26 of 110) have three Geography teachers, 19% (21 of 110) have one Geography teacher, 11% (12 of 110) have four Geography teachers and 9% (10 of 110) of the schools have five or more Geography teachers in their Department (Figure 7).

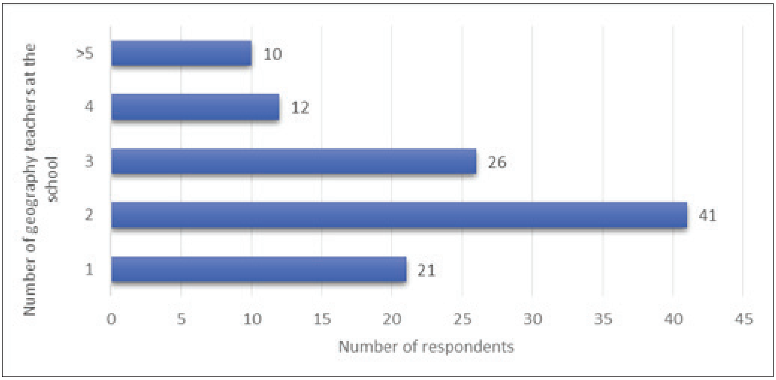

Figure 7: Number of teachers that teach Geography at the participants' school (n=110).

The results in Table 1 show a spread for the sample of participants interviewed from having less than one year's teaching experience to over 40 years. Similarly, results show a spread of participants teaching at boys-only, girls-only and co-educational schools. Two of the nine schools teach in a rural environment. Although all private schools, the majority (63%) teach IEB and 33% teach the DBE Examination Board.

Interviews n=9	**Years of teaching experience**	**Examination Board IEB/DBE**	**Type of school** (All independent schools)	**Province in SA**
A	16-20 years	IEB	Urban Co-Ed	Eastern Cape
B	< 1 year (student)	DBE	Rural Co-Ed	Eastern Cape
C	36-40 years	IEB	Urban Boys	Gauteng
D	36-40 years	IEB	Urban Co-Ed	Eastern Cape
E	> 40 years (retired)	IEB	Urban Girls	KwaZulu-Natal
F	16-20 years	IEB	Urban Girls	Gauteng
G	11-15 years	IEB	Rural Co-Ed	Western Cape
H	31-35 years	DBE	Urban Girls	Western Cape
I	36-40 years	DBE	Urban Boys	Western Cape

Respondents interviewed for the second sample come mainly from four provinces in South Africa, 33% from the Western Cape, 33% from the Eastern Cape, 22% from Gauteng and 12% from KwaZulu-Natal (KZN). The interviewees' names have been replaced with letters from A to I to ensure anonymity. The location of schools A to I are mapped using QGIS in Figure 8

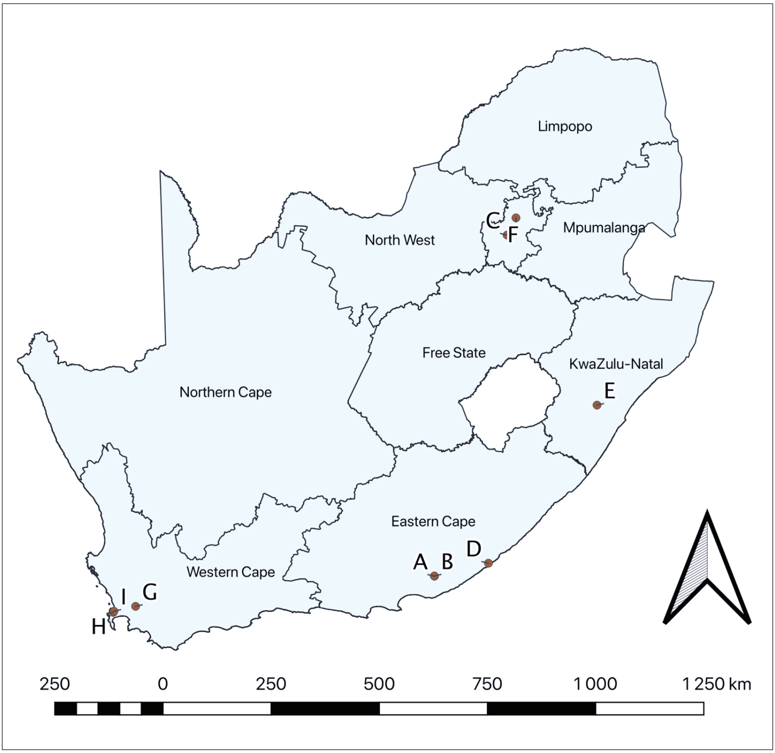

Figure 8: Location of schools (produced using QGIS).

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Use of GIS (QGIS) and teacher interventions in South African secondary school education

In South Africa, GIS-based teaching is not common and the map skills section in the curriculum is poorly understood by teachers (Innes, 2009; Wilmot & Dube, 2016). The average result for the GIS question in 2018 in Paper Two (the Geography Grade 12 final map skills practical assessment) National Senior Certificate (NSC) was 35% (DBE, 2018). Some provinces (such as KZN) had candidates failing to attempt to answer the GIS question altogether (DBE, 2018). Both the Department of Basic Education (DBE) and the Independent Examination Board (IEB) saw a decline in Geography Paper Two results in 2020 (Umalusi, 2020). DBE examiners commented that "teachers must be trained in mapwork calculation techniques and GIS. Teachers should not only teach the GIS concepts but also the application and relevance thereof in real world situations" (DBE, 2018, p. 83).

Historically in South Africa, many researchers concur that the lack of GIS teacher training is deleterious to how effectively GIS is taught in the classroom (Scheepers, 2009; Innes, 2009; Breetzke et al., 2011; Eksteen et al., 2012). Eksteen et al. (2012) conclude that the biggest challenge to the successful infusion of GIS into secondary schools throughout South Africa is adequate and continuous administrative and technological support. Ideally, three levels of support are required: support from school leadership and the school community; support from local tertiary institutions offering teacher education programs and support from government and industry.

Mzuza (2019) is one of the few studies that refer to QGIS use in Southern African classrooms and that it was thanks to the great strides in free software that it is now commonly used and generally available. Other studies only referred to proprietary GIS software. However, the study refers to how GIS software can only be used when connected to the internet which is not the case with QGIS. Once QGIS has been downloaded, the user does not need internet connectivity and it can be used offline. This study also concluded that of the four countries in southern Africa where GIS is taught as part of the curriculum (South Africa, Lesotho, Malawi and Botswana), many of their schools only offer theoretical training rather than practical (hands-on) teaching of GIS.

The study attributes this to teachers not having the know-how to present the GIS content as well as the lack of hardware and internet connectivity (Mzuza & Van Der Westhuizen, 2019). Other researchers attribute financial constraints as the major cause of many schools in Africa not having enough computers for teaching and learning purposes (Breetzke et al., 2011; Bearman et al., 2016). The review of literature in South Africa reveals the fact that there is a need to address the fundamental problem of inequalities such as GIS-enabling resources in Geography education in South Africa (Wilmot & Dube, 2016; Fleischmann, 2017; Mzuza & Van Der Westhuizen, 2019; Zondi & Tarisayi, 2020).

Respondents were asked in which grade certain sections of the GIS curriculum were completed. The data presented in Figure 9 indicate that many respondents cover grade 12 GIS curriculum concepts in the lower grades i.e. the CAPS are not being strictly adhered to and teachers are covering grade 12 GIS content in earlier grades (South African Department of Basic Education, 2011). The numbers show that only 50% of the participants teach the GIS processing core topics (statistical analysis; data integration; spatial query) in grade 11 and grade 12 and 13% of the 112 do not teach these core concepts at all.

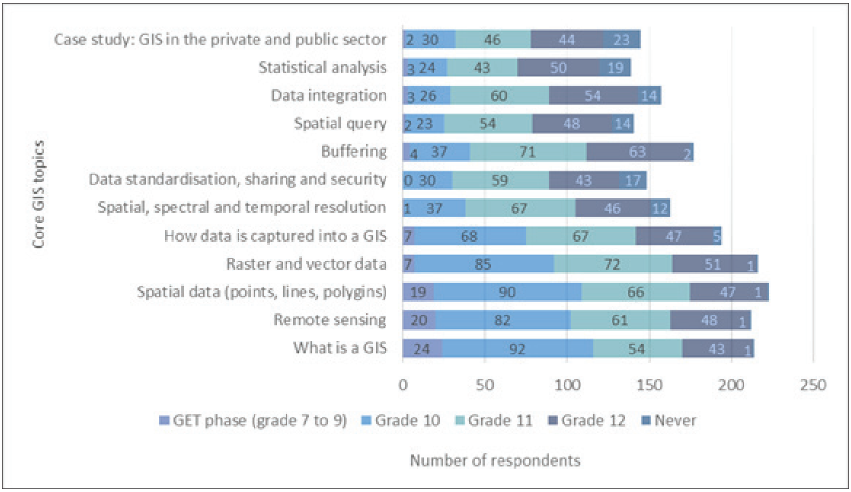

Figure 9: When GIS concepts are taught in the curriculum per grade and which core GIS curriculum topics (n=112).

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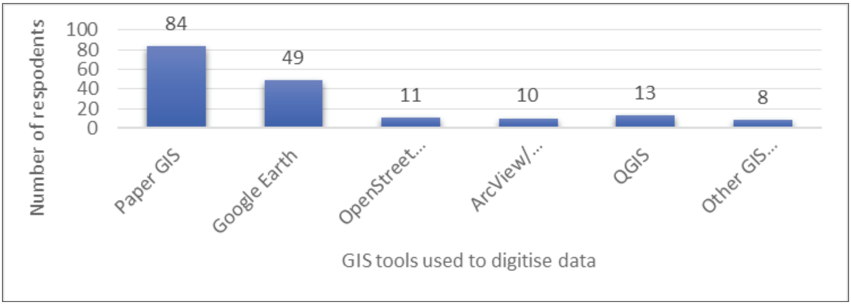

Figure 10: Techniques teachers use to digitise spatial data (n=103).

In a study of how GIS was implemented in thirty-three different countries, Kerski *et al.* (2013) stated that they found South Africa's GIS curriculum one of the few that included geoprocessing which required pupils to apply data acquisition, management, manipulation and GIS analysis. The most widely taught geoprocessing concept taught is 'buffering' (Figure 4-15). This may be due to it being directly assessed in the NSC Geography examination for both DBE and IEB. The results do show a good progression of GIS concepts taught across the grade, which is how the curriculum was designed (Eksteen *et al.*, 2012). This study concurs with Kerski's *et al.* (2013) findings and those of more recent studies (Wilmot & Dube, 2016; Akinyemi, 2016; Fleischmann & van der Westhuizen, 2017; Degirmenci, 2018; Mzuza & Van Der Westhuizen, 2019; Zondi & Tarisayi, 2020) that the reason for GIS not being taught effectively at secondary level may be attributed to lack of skills (teacher competence), time constraints, teacher perceptions of how complex the software is to use and the status of Geography at schools. By far the largest number of respondents (54.5%) selected the seldom option, indicating that they teach GIS practical hands-on lessons less than once a year, if at all (Figure 11). Thirty-eight percent of teachers who responded indicated that they teach practical lessons more than once a year and only 7.1% of participants indicated that they teach practical GIS lessons frequently (once a month or more).

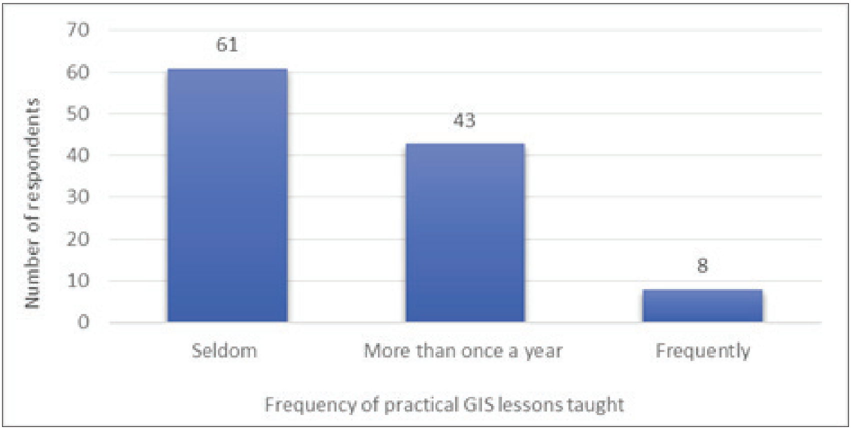

Figure 11: Frequency of practical GIS lessons taught yearly (n=112).

The results in Figure 12 show that most of the respondents have used GIS to teach map skills (85%), followed by Physical Geography (58%) then Human Geography (52%). Twenty-eight percent of teachers have used GIS to teach case studies and in research projects. Twenty-three percent of participants only teach GIS theory and do not use GIS to teach the curriculum. One respondent does not teach or use GIS at all.

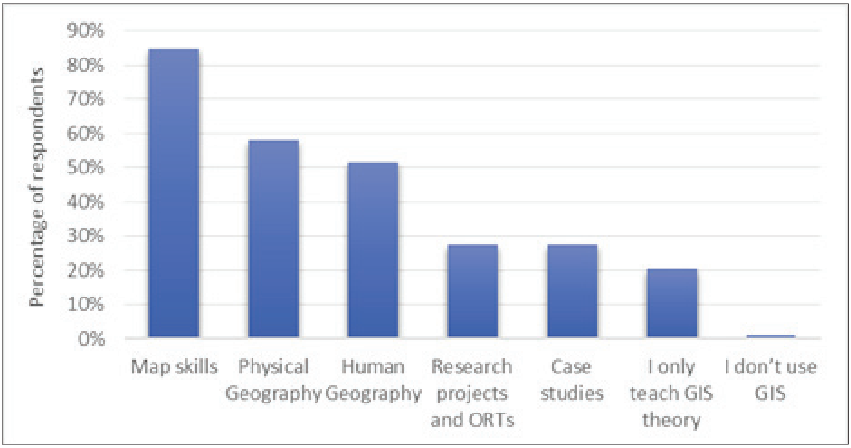

Figure 12: The section of the Geography curriculum where GIS is used to teach concepts (n=112).

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Benefits of using GIS in the classroom

Twenty years ago Audet and Ludwig (2000) said that a classroom that uses GIS as a problem-solving tool is a classroom in which 'the walls are invisible and the teacher and student assume roles that are non-traditional'. They go on to say that incorporating GIS into the classroom is not for the fainthearted and that integrating GIS into the curriculum rewards teachers by creating intellectually challenging and demanding learning opportunities (Audet & Ludwig, 2000). The current literature reviewed collectively echoes their sentiments. Singh et al. (2016) found that GIS-based teaching in the Geography classroom had a more positive effect on students' motivation and achievement levels compared to traditional teaching methods. Findings in this study show that teachers unanimously agree that students benefit from using GIS in the classroom.

The final survey question required participants to evaluate seven statements on why GIS should be used in Geography lessons using a five-level Likert scale from strongly disagree (one) to strongly agree (five). The averages and standard deviations of these values from one to five for each reason were calculated (Table 2). The highest average (4.7) indicated that most of the participants strongly agree that GIS helps students to visualise geographic data. The reason that GIS facilitates the research enquiry process had an average of 4.4 and had the most impartial counts (13). The averages for all the reasons range from 4.4 to 4.7 indicating that the majority of respondents agree and agree strongly with the reasons listed as to why GIS should be taught in the Geography classroom (Table 2).

The results for the survey question that asked teachers to evaluate reasons why GIS should be used in Geography lessons are summarised in Table 2. Results show, using a Likert 5-level scale, that an overwhelming majority (98%) of teachers agree and agree strongly that GIS adds value to Geography classes. The barriers to the implementation of GIS are similar to Scheepers (2009) and Demircis' (2011) study ten years ago and the results of the interviews show that time constraints, teacher skills and access to meaningful spatial data are some of the biggest hurdles to teaching GIS effectively. Recent studies also refer to a lack of formal training in GIS and the results in this study show the same

	strongly agree (5)	agree (4)	impartial (3)	disagree (2)	strongly disagree (1)	Total n	Ave (1 - 5)	95% Confidence Interval	Std dev
GIS allows for the comparison of geographic data	70	36	2	0	0	108	4.6	4.41 – 4.79	1.00
GIS helps students to visualise geographic data	76	33	2	0	0	111	4.7	4.57 – 4.83	0.67
GIS can be used to help explain geographic concepts	70	35	5	0	0	110	4.6	4.44 – 4.76	0.84
GIS allows for experimental learning	62	35	8	2	0	107	4.4	4.18 – 4.62	1.16
GIS facilitates the research enquiry process	62	34	13	1	0	110	4.4	4.22 – 4.58	0.94
GIS allows for student-centred teaching	59	36	10	2	1	108	4.4	4.19 – 4.61	1.14
GIS is a vital 21st-century learning skill and helps students think critically	83	18	5	2	1	109	4.6	4.37 – 4.83	1.21

Table 2: Evaluation of reasons why GIS should be used in Geography lessons using a five-level Likert scale.

(Degirmenci, 2018; Healy & Walshe, 2020). The majority of teachers interviewed in this study refer to the lack of effective teacher training and not being competent at using GIS software as being a barrier to GIS practical lessons.

A recurrent theme in the interviews was a sense amongst interviewees that teaching GIS in the classroom

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had several benefits. When asked the question what the biggest advantage was of using GIS in the Geography classroom, the first theme that was identified was that GIS engages pupils. As one interviewee put it: “GIS grabs their attention and as soon as you have their attention, they’re engaged”.

The second theme identified is that GIS captures the interest of pupils. For example, respondent C said, “…a chalk and talk approach to any kind of teaching leaves them cold”; and respondent H said, “I think the biggest advantages of GIS is it just makes Geography come alive”. The next theme is similar, that GIS evokes curiosity: respondent C said, “...as soon as technology is introduced what it does it awakens them and it actually puts the learning in their hands”. From these comments, it is apparent that the interviewees believe that GIS will enhance learning in the classroom.

Interviewees also expressed the theme that GIS connects the disciplines. For example, respondent E said, “GIS enables them (pupils) to start connecting the dots” and respondent I said, “What it does is take statistics and figures and converts them into images and it really makes it easier for the kids to understand numerous aspects of Geography”. They also identified the interactivity of GIS as a big advantage: respondent D said, “the students are good with any kind of IT, especially what they see as current or instantaneous and they want solutions.” And respondent F said, “I think the big thing in our school is that we focussed on the 4IR’s and looking at what’s ahead in the future and with GIS in the classroom when you can open those doors to the kids”. These comments suggest that GIS is a technology enabler.

The majority of interviewees talked about the fact that GIS helps to teach relevant, current and topical issues. The following are quotes from interviewees under this theme: respondent G said, “I think GIS makes Geography more relevant to pupils in today’s world …it’s no longer just about sort of outdated maps with watermarks all over them which have been used a hundred times over it’s actually about making it something that they own and making it relevant and interesting and accessible for them in the classroom, which I love”; respondent H said, “… while field trips are very important we do not always have the time to go out there so GIS means that they can see real data out there and that real people are involved”; respondent F said, “… with GIS in the classroom when you can open those doors to the kids, it's that you're taking the theory out of the book and putting it into reality" and respondent D said, "They (the pupils) are good with any kind of IT. GIS shows them the world that they are (live) in, as current". Relevancy is an important theme that emerged and most interviewees discussed this at length. Linked to this was the advantage of awareness of new career paths: respondent C said, "…grab that opportunity to show them that what is relevant today technologically will be their career tomorrow" and respondent H said, "they can see these real data out there and that there are real people involved and I think the one thing is that it opens up this whole career path that nobody knew existed". Teachers identified careers in the geospatial industry as being an exciting prospect for their pupils/learners and that was important for them to be exposed to these opportunities.

Two interviewees discussed advantages to using GIS in the classroom, which was not a common theme but noteworthy and consequently deserves to be mentioned: respondent F said, "GIS put it into a perceptive view especially for the kids that are visual learners and then I have found to be a massive advantage for GIS" and respondent G said, "…so much of our world is digital and so much of our world is no longer paper-based and it makes it more difficult to use maps and information. And data is more reachable, attainable and usable for kids. It's more "accessible", that's the word I'm looking for". Accessibility and that GIS made the subject come 'alive' was perceived as an important advantage to teaching GIS.

When compared to the results of the quantitative online survey (Table 2) ranked in order of percentage of numbers who agreed, the overwhelming majority of participants agreed that GIS helps students to visualise geographic data (98%); GIS allows for the comparison of geographic data (98%); GIS can be used to help explain geographic concepts (95%); GIS is a vital 21st-century learning skill and helps students think critically (93%); GIS allows for experimental learning (91%); GIS allows for student-centred teaching (88%) and lastly that GIS facilitates the research enquiry process (87%). The average score for these results is 4.6, showing that, when asked to comment on the five-level Likert scale from strongly agree to strongly disagree, at the 95% confidence interval, it

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is statistically significant that the majority of the participants have the same opinion (Table 2).

Hurdles to using GIS in the classroom

Since its introduction, GIS in secondary education has been met with several challenges. Despite the benefits of teaching GIS, Geography teachers avoid engaging with GIS in their classrooms (Ciolli et al., 2017; Healy & Walshe, 2019) and most educators are ill-equipped to teach the GIS section of the curriculum (Innes, 2009; Eksteen et al., 2012; Fleischmann & van der Westhuizen, 2015; Wilmot & Dube, 2016; Zondi & Tarisayi, 2020).

Other studies show that the most common challenges to teaching GIS in schools are lack of resources, lack of skills, lack of teacher motivation, time constraints, poor curriculum design and the status of Geography at secondary school level (Milson et al., 2012; Kerski et al., 2013; Akinyemi, 2016; Wilmot & Dube, 2016; Fleischmann, 2017; Degirmenci, 2018). This research concurs with these findings that this study shows how South Africa has other unique challenges such as power supply and internet connectivity. Research shows that Geography teachers are still shying away from using GIS in the classroom because of teachers' negative attitude to adopting GIS. GIS is frequently seen to be too technically complex, too difficult to integrate into an already too busy Geography curriculum or it is seen as simply impossible to do (Kidman, 2006; Demirci, 2009; Lateh & Muniandy, 2010; Komlenovićet al., 2013; Kerski et al., 2013; Lay et al., 2013; Aladag, 2014; Degirmenci, 2018; Healy & Walshe, 2020). Findings in this study show similar hurdles to these studies. It is evident that these hurdles are global and span both developed and developing countries.

Solutions to the problems of implementing GIS in the classroom

Proper training for teachers at secondary school level is important as it would give teachers the confidence to use GIS to teach the curriculum and to use GIS more in project-based learning (Baker et al., 2012; Fleming, 2016; Hong & Melville, 2018). This research and others have shown that teachers identify the lack of GIS training at secondary level as one of the biggest hurdles to teaching GIS (Eksteen et al., 2012; Zondi &

Tarisayi, 2020). Furthermore, there is unanimous agreement amongst current global studies that more research into inequalities of GIS teaching is required (Hong & Melville, 2018; Collins & Mitchell, 2019; Healy & Walshe, 2019). Teaching with GIS needs to include knowledge, skills and behaviour. It is up to those who believe in the power of spatial analysis through GIS to take active steps to ensure that educational transformation happens for the sake of the planet and society (Kerski et al. 2012).

Another solution is conducting more research, especially in the African context. Current researchers conclude that the lack of published research is one of the numerous shortcomings in the use of GIS in secondary education globally (Hong & Melville, 2018; Mzuza & Van Der Westhuizen, 2019; Holler, 2019; Healy & Walshe, 2020; Zondi & Tarisayi, 2020).

Why are practical GIS lessons seldom taught?

Figure 13 shows a comparison of the frequency of GIS hands-on lessons in the classroom (one being seldom to three being frequent) to how resourced the school is (one being under-resourced to five being very well-resourced). The number of participants who seldom teach GIS practical lessons ranges from 7 to 15. The distribution is across all schools, regardless of how resourced the school is. The same even distribution is true for the 8 participants who indicated that they teach GIS practical lessons frequently.

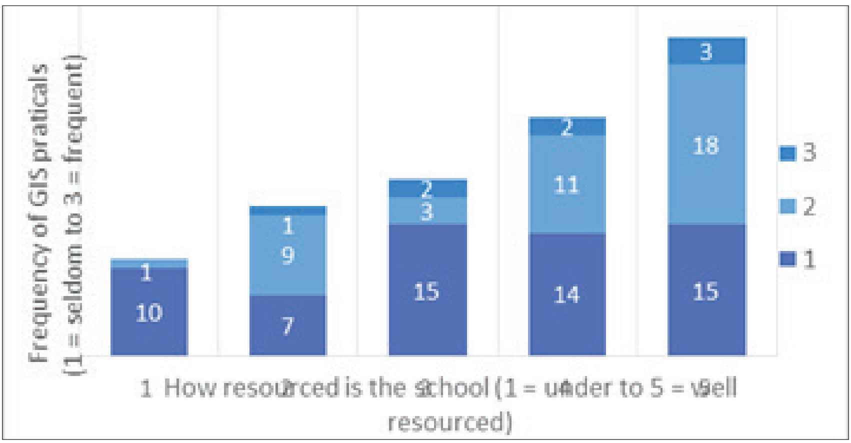

Figure 13: Comparing the frequency of practical GIS lessons (with 1 being seldom to 3 being frequent) to how resourced the school is (1 being under-resourced to 5 being very well-resourced) (n=111).

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As with the previous results, the frequency of practical lessons was compared with another set of results, in this case with the Examination Board or education authority of the participants to see if an inference could be made. The results show inconclusively that the Examination Board or the education authority makes no significant difference as to how often GIS lessons are taught practically. Forty-eight percent of the NSC as administered by the DBE and 42% of IEB participants teach GIS practical lessons once a term or less (Figure 14).

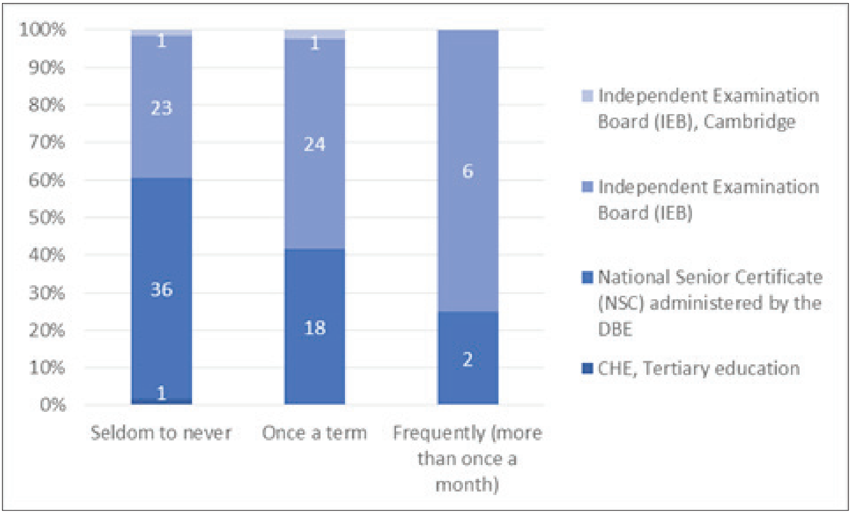

Figure 13: Frequency of practical GIS lessons taught compared to the Examination Board (n=112).

Several issues were identified as hurdles to using GIS in the classroom and these themes are summarised in Table 3. The first theme identified was the lack of hardware and access to technology. As one interviewee put it: "It's the technology, it may just be for town x (name removed for anonymity), as obviously the school has computer labs but in terms of the boys having their own laptops - maybe not even 50% have at a guess from what I saw. Maybe the Eastern Cape is just a bit more an extreme".

Respondent C argued that, "… from the point of view of gaining data secondly it was so complicated, that I myself was losing passion for the technology. And so I was actually passing on a negative aspect (attitude) to the class" and respondent D said, "When I started using ESRI (ESRI, 2020) software, I found it very complicated. I've subsequently changed maybe for the last 6 years using QGIS. I was trained on QGIS 1.0 so that is my understanding of GIS. In a two-week cycle we have one lesson where the kids go to the computer room and actually have a GIS lesson in the school but unfortunately, we use iPads and QGIS does not work on iPads. QGIS works on laptops and android tablets so that's a bit of a negative for our school". Respondent G suggested that his/her own lack of skill is a hurdle to teaching GIS when he/she said, "I think I'm the biggest hurdle at the moment because I need to learn this and I don't get enough time as teachers don't have enough time to sit and play around". Furthermore, respondent E said, "I think it would be lack of capacity from teachers who don't know enough".

One interviewee (respondent G) from a rural school stated that connectivity and power supply are significant obstacles by saying: "I think one of the things is technology sometimes is not always clear and sometimes you get caught up in the nitty-gritty of the technology and seeing if everyone has a charged device or can you get access to a computer lab when you share facilities with the whole school connectivity and no connectivity being a major thing for us out here. We've only just recently got fibre so and for a long time connectivity was not a given. Electricity (supply) is also erratic in our classroom and our part of the world in our country". Others also mentioned the high cost of data as transferring spatial data sets uses a significant amount of data.

Whilst a minority (respondent I) mentioned that "I'd say the biggest impediment would probably be the teachers lack of enthusiasm to teach

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the subject, probably because they are intimidated by it (GIS)", all agreed that this could be solved by training. The online survey showed that the overwhelming majority of teachers expressed a willingness to learn more about GIS. The findings of the current study are consistent with those of others in that teacher training in GIS is what is needed for long-term success (Tate & Jarvis, 2017; Degirmenci, 2018; Hong & Melville, 2018; Healy & Walshe, 2019). One of the teachers interviewed in Collins and Mitchells' (2020) study confessed that time, and trying to cover the curriculum, were some of the biggest hurdles to teaching GIS. In this study, the same theme was identified. One of the interviewees (respondent G) in the current study said, "the biggest hurdle is not getting caught up in the curriculum checklist".

The last theme identified is the lack of support from technical staff at school with respondent I saying "In our school, it would have been the techie staff because they know nothing about GIS, they don't understand it, they don't regularly update they only do it if we ask them to do it and nine times out of ten it's not done properly in the lab so we had to go and troubleshoot before we even got do a lesson". It becomes clear that the lack of technical support leads to teachers avoiding practical GIS lessons.

Teaching GIS in the classroom has both technological and societal

Interviewee: / Themes:	A	B	C	D	E	F	G	H	I
1 Lack of hardware access to technology	x	x			x	x			
2 Lack of software, complex to use	x		x						
3 Teacher skills			x	x	x			x	
4 Time/ only doing what the curriculum requires/ lack of enthusiasm							x	x	x
5 Connectivity/ power supply	x	x			x	x	x		
6 Mixed abilities in the classroom/ student absenteeism	x			x		x			
7 Lack of support from tech staff at school					x				

Table 3: Hurdles to using GIS in the classroom (n=9).

challenges. Technological challenges include access not only to computers that have enough internal and graphics memory, hard disk space, and the proper software to be able to handle spatial analysis but also to those computers in the school and support from the school's information technology (IT) staff (Kerski et al., 2013). One of the participants interviewed emphasised that the IT staff at their school were their biggest hurdle to using GIS.

Using OpenStreetMap data in the classroom

Half of the 111 teachers who responded to this item had heard of OSM, 43% (48 of 111) had not and another 6% (7 of 111) indicated that they had possibly heard of OSM (Figure 15). This result is similar to the qualitative interview answers when the teachers were asked the same question. Only four of the nine teachers interviewed indicated that they had heard of OSM.

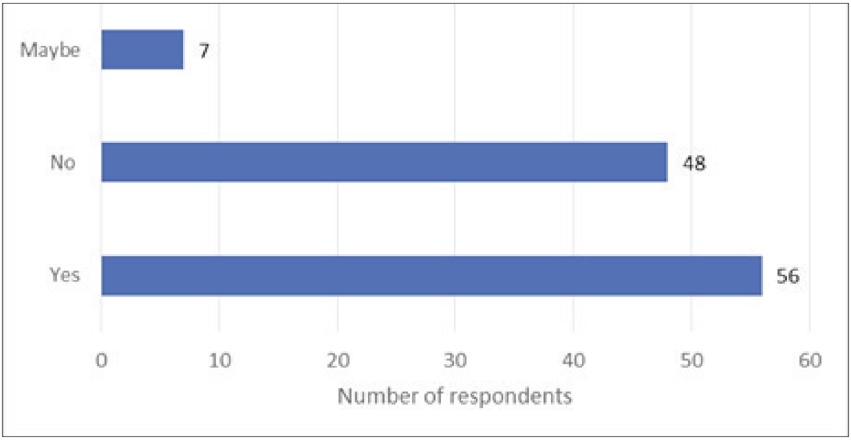

Figure 15: Familiarity with OpenStreetMap (OSM), (n=111).

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The majority of participants interviewed (67%) agree that their grade 12 learners or pupils could use QGIS and OSM data for their own research projects (Table 4). (Both the DBE and the IEB require grade 12 students to do a research project) in Grade 12 Geography as part of their school-based assessment mark (DBE, 2018; Independent Examination Board, 2020). These projects involve the students identifying a local geographic issue and then using the enquiry process to research the issue for themselves. Two of the participants said that there was a possibility, and none said not at all. All the teachers interviewed expressed an interest after the demonstration was given to use the OSM and QGIS worksheets. This may be an opportunity for future research where an additional survey is conducted with these teachers to evaluate the effectiveness of using OSM and QGIS in pupils/ learners' Geography research projects.

Interview question 4: Could your pupils/learners use OSM and QGIS for their own Geography research projects (NSC and IEB)/ ORTs (IEB) in grade 12?									
Interviewee: Answer:	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Yes		x	x	x	x	x	x	x	
No									
Maybe	x								x

Table 4: Grade 12 learners use of OSM data and QGIS for their own research projects (n=9).

Respondents were asked how GIS could be made more accessible in the Geography classroom (Figure 16). By ranking the importance of each according to how the respondents answered, an interesting picture emerges. Most respondents see access to pre-designed GIS lessons as important (66%); second is training in the use of GIS software (62%); third is access to local GIS data (54%); fourth is cheap or free GIS software (52%); fifth is better access to hardware (42%) and the last, is better Internet connectivity (41%) which correlated well to the results in Figure 17 which shows the level of Wi-Fi connectivity at the participants' school. The significance of these findings is that teachers do not perceive hardware or Wi-Fi connectivity (as the problem) but rather access to GIS lessons and training as what would make GIS more accessible in the classroom.

It is encouraging that 11% of respondents have used OpenStreetMap (OSM) and 13% have used QGIS.

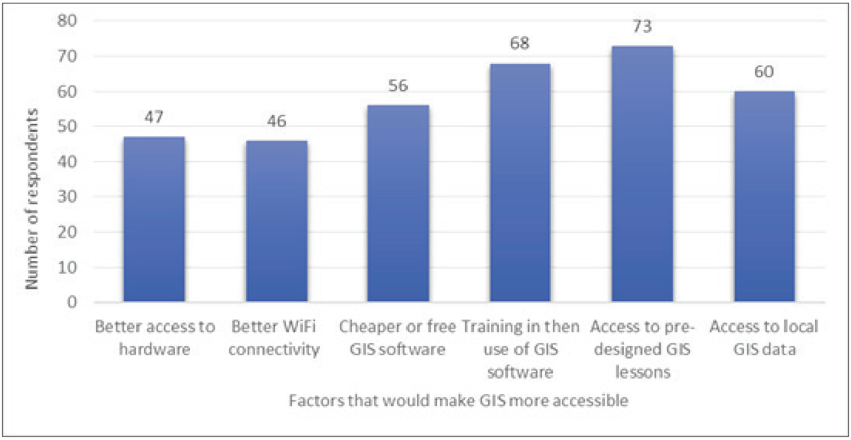

Figure 16: Factors that would make GIS more accessible in the Geography classroom (n=111).

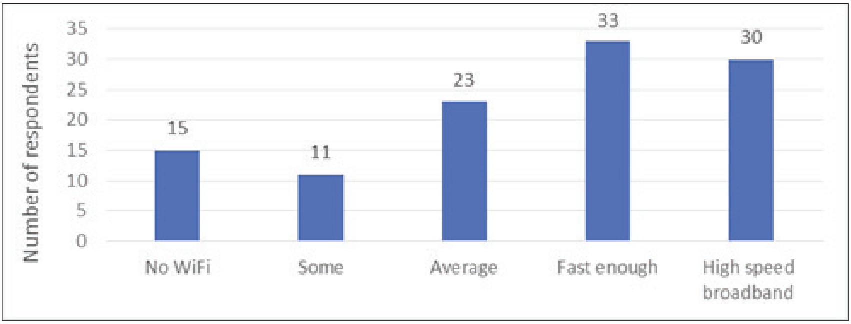

Figure 17: Level of Wi-Fi connectivity at the participant's school (n=112).

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None of the nine teachers interviewed had used OSM. Comparing this with how many teachers involved in this survey have heard of OSM (51%), it is surprising that so few have used OSM as a digitising source since OSM has the benefit of being free, accessible and is an easy way of obtaining local spatial data (Figure 16).

Seventy-eight percent of the interviewees agree that their learners or pupils could use QGIS and OSM data for their own research projects (Table 3). Many commented on how the QuickOSM plugin in QGIS would help their students to collect local data for their research projects (Trimaille, 2014). Respondent G commented: "… with this (GIS) it would make a huge difference to them and being able to generate their own information …it gives them information which they can then refer to because that's often their biggest stumbling block with ORTs and research". Twenty-two percent of the respondents agreed that there was a possibility and none said not at all. All expressed an interest to show their learners/pupils how OSM and QGIS could be used for research projects after the demonstration was given. This is significant as it provides an opportunity for further investigation.

One unanticipated finding was that the majority of respondents have used GIS to teach map skills (84.8%) (Figure 13). When compared to the qualitative interview research findings, only 11% discussed using GIS to teach map skills. 28% of teachers indicated that they have used GIS to teach case studies and in research projects. Almost a quarter of the participants (23%) only teach GIS theory and do not use GIS to teach the curriculum. Contrary to expectations considering so little practical GIS is taught, an overwhelming 75% of participants are interested in using GIS to help teach the Geography curriculum and only 8% indicated that they were not at all interested. This is significant as it highlights the willingness of teachers to learn more about GIS and the need for GIS teacher training in South Africa.

What is the future of GIS education?

Collin and Mitchell's (2019) interview methodology and analysis of teacher attitudes were useful for shedding light on the findings of this study. Many of the teacher responses in their research (United States) were similar to what teachers said in the present study, which illustrates the global similarities with teacher attitudes to GIS. Their interview sample was similar to this research (18 teachers originally participated in their research but only 8 completed the full sequence of activities) and the range of teaching experience of the sample group was from three to thirty years, as it was with the teachers interviewed for this particular research. Collin and Mitchell's (2019) paper give an interesting perspective on how common many of the issues are with teaching GIS in the classroom in South Africa and the United States such as the need for pre-service training in GIS; lack of time; pressures of the curriculum and how few schools use GIS in the classroom. Their study used ArcGIS online as a teaching tool whereas the present study used FOSS4G software and OSM data.

Student-centred learning and project-based learning (PBL) were not effective without extensive teacher training (Sinha *et al.,* 2016; Ciolli *et al.,* 2017). Others such as Hong & Melville (2018), Degirmenci (2018) and Healy & Walshe (2019) suggest that effective GIS adoption requires hands-on learning and time to master the skills. It is recommended that to achieve long-term success, training beyond merely the awareness of what GIS is, is required (Collins & Mitchell, 2019). This was a common theme when interviewing the teachers for this research and the results from the online survey corroborated this. Of all the hurdles identified, teachers overwhelmingly agree that the lack of teacher competence in using the GIS software results in the low adoption of using GIS in the classroom. The results of the present study show that the majority disagree that GIS is too difficult to learn, rather they want access to local GIS data and training in how to use the software.

Conclusion

As the current political climate is looking into decolonising the curriculum, having access to local data and maps of schools and their communities to use in the classroom is not only attractive but essential. OSM enables teachers to create their material and makes it real for their pupils and learners as they can recognise their own 'place in space'.

South Africa's Geography curriculum is one of the few curricula that includes geoprocessing (Kerski *et al.,* 2013; DBE, 2018). However, this is very difficult to teach if only a minority (21%) of the respondents teach practical GIS lessons frequently (more than once a month). What is also concerning is that a significant

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number of respondents do not teach the geoprocessing elements of spatial analysis, data integration and spatial queries in the curriculum. Results show that only 6% of respondents see themselves as GIS experts.

The lack of teacher expertise may be another reason why these geoprocessing concepts are not taught as they are complex and only fully understood if applied practically. Collin and Mitchell's (2019) paper gives an interesting perspective on how common many of the GIS teaching issues are in South Africa and the United States such as the need for pre-service training in GIS; lack of time; pressures of the curriculum and how few schools use GIS in the classroom.

A limitation of this study is that only the opinions of the teachers were taken into consideration and not those of the pupils. It would have been very valuable to interview pupils and learners in a pre-and post-survey. Another limitation was that 56% of the respondents from the online survey and 90% of the teachers interviewed came from very resourced schools. Furthermore, the minority (14%) of the respondents who answered the online survey and participants interviewed (22%) taught at schools servicing rural communities. Although there is representation nationally, there is also a bias to Gauteng and KwaZulu-Natal, although this is representative of the population distribution of South Africa. What is now needed is a cross-national study involving more schools to determine if comprehensive teacher training is what is required to make GIS practical lessons more effective.

However, findings in this study show that teachers have a very positive attitude and willingness to attend future GIS courses and to explore the possibilities of using GIS and OSM data in the classroom. An overwhelming majority see many benefits to teaching GIS and are eager to learn more. Time constraints, curriculum pressures and a lack of know-how are the biggest hurdles to teaching practical GIS lessons. Surprisingly, access to hardware, GIS software and Internet connectivity were not seen as hurdles by the majority of respondents, although all the teacher's interviews from schools in rural communities indicated power supply as their biggest concern to teaching GIS practical lessons.

Degirmenci (2018) and Digan (2019) suggest a platform where teachers can collaborate and partner with one another to share GIS best practices. Participants in both the survey and interviews mentioned the need for a sharing platform for GIS resources for teachers. The sharing of GIS resources on the SAGTA website: https://sagta.org.za/ in South Africa is a recommendation of this research (SAGTA). Another recommendation for future research is to further test the effectiveness of online teaching opportunities using FOSS4G tools on pupils/learners from a range of schools and comparing across provinces as a follow-up study.

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Ethical considerations

Ethical clearance to conduct the study was obtained from the University of the Witwatersrand (clearance certificate protocol number: H19/09/09).

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Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any affiliated agency of the authors.

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