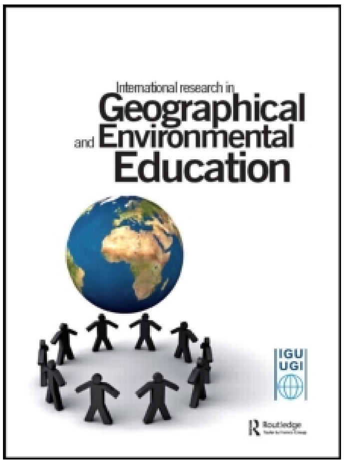

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Learning geography by combining fieldwork with GIS

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Geographic information systems (GIS) offer many possibilities for supporting student research projects. This paper deals with the results of the first phase of a design study on student research projects that combine (quantitative) data collection in the field with data visualisation, manipulation and analysis in GIS. In this study, we try to identify the characteristics of a successful design. In the first phase of the study, four student research projects that combine fieldwork with GIS were designed and tested. The design and test rounds were primarily focused at identifying the characteristics of feasible and potentially rich student research projects. On the basis of the design and test rounds, we identified five features of feasible student research projects that combine fieldwork with GIS.

Keywords: fieldwork; geographic research; GIS; secondary education

1. Introduction

In the past decades, the focus in the curricula of many countries has shifted from the acquisition of knowledge to the development of skills required to gain knowledge. Modern curricula promote the development of skills combined with active and independent learning. Students should be active learners and teachers should be coaches rather than instructors (Novak, 1998; Wood, 1998). Learning research skills is an important component of the Dutch geography curriculum for the upper levels of secondary education. For geography in secondary education at least two research projects are compulsory. Students have to conduct at least one, but preferably more, practical assignment (approximately 10 hours) in which they do geographic research. In the last or next-to-last year, they have to do an independent discipline-based or (inter)disciplinary main research paper (40–80 hours). Doing good geographic research is difficult. Students should develop general and domain-specific research skills to be able to do a research project in geography more or less independently. An inventory among Dutch teachers by Wildschut and Van der Schee (2007) showed that the majority of the teachers value domain-specific (geographic) knowledge and skills (asking geographical questions, applying geographical thinking skills, applying map skills, using geographical concepts and gaining regional knowledge) higher than general research skills (using different information sources, using information and communication technologies (ICT), constructing good presentations, applying general research skills) and motivation. According to Dutch teachers, a good geographic research paper should ask and answer questions like "where?" and "why there?", should focus on one or more regions and should contain maps. Teachers prefer research papers based on data collected in fieldwork

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(interviewing, mapping, etc.). Although the inventory provided insight into the prerequisites for good geographic research, not much is known about the best way to teach geographic research skills. Even less is known about teaching geographic research skills using modern technology like GIS.

GIS stands for *geographic information systems*. Although there is some confusion about the concept and there are many definitions, GIS is generally regarded as software for working with digital geographic data. Traditionally, GIS is seen as a system that allows the user to store, visualise, manipulate and analyse large sets of geographic data in a fast, accurate and flexible way.

Several authors (Baker & White, 2003; Kerski, 2003) suggest that teaching with GIS could benefit students' development of geographic knowledge and geographic thinking skills. Geographic knowledge refers to declarative knowledge about the characteristics, structures and functioning of (parts of) the earth, including the physical and social phenomena that are present at or near the surface of the earth. Geographic thinking skills are skills like recognising spatial patterns and spatial relations. Many authors rave about the potential benefits of GIS for secondary geography education. However, the use of GIS in secondary education proceeds slowly. Inventories by Kerski (2003), Morell (2006) and Pleizier (2007) show that only a small part of the teachers uses geo-ICT. One of the main barriers to the spreading of GIS is that little is known about *how* teaching geography with GIS should be done in order to be effective (Baker & Bednarz, 2003). The international literature presents some interesting examples of student research projects that combine data acquisition with data visualisation, for example, about traffic noise (Falk & Nöthen, 2004), noxious weeds (Zanelli English & Feaster, 2003a), dead trees (Loudon, 2000), water quality of creeks (Coulter, 2000; Zanelli English & Feaster, 2003b), damage levels of trees (Schleicher & Schrettenbrunner, 2004) and safety issues (Paul & Hamilton, 2000). In each of these projects, students collect data and plot it into maps. Students subsequently (mentally) read, analyse and interpret the data. GIS-supported data manipulation and data analysis is limited. In most of these projects, the collected data are incidental measurements, so a complete spatial image cannot be constructed. The question is whether these student research projects could be done with analogue techniques (drawing) and analogue materials (pen, paper and maps) or not and what the advantages of GIS are. We think that student research projects that combine the acquisition of quantitative data in the field with the visualisation, manipulation and analysis of the data in GIS have more possibilities for stimulating the development of geographic literacy. However, little is known about the characteristics of an effective design for these kinds of student research projects. So far, only some attempts have been made to develop student research projects that combine the acquisition of quantitative data with data visualisation, manipulation and analysis in GIS (e.g. Smith & Dunn, 2007), but empirical research in this field is scarce.

2. Research questions

In order to contribute to the development of knowledge about secondary geography education with GIS, a Ph.D. study was started at the VU University Amsterdam in 2006. This study aims at identifying the characteristics of effective instruction methods (including software, instruction materials and teacher strategy) for teaching with GIS. With "effective" we mean that the projects should be feasible for teachers and students and should contribute to the development of geographic literacy.

A part of this Ph.D. study focuses on student research projects that combine fieldwork with GIS. In this part of the study, we try to identify the characteristics of an effective design for student research projects that combine quantitative data collection in the field with data visualisation, manipulation and analysis with GIS. The educational aims of these student research projects regarding the development of geographic literacy are defined as: (1) the development of declarative geospatial (thematic-geographic as well as regional-geographic) knowledge; (2) the development of geographic thinking skills including the development of skills in asking and answering geographic questions; (3) the development of skills in collecting different kinds of (quantitative) data in fieldwork and methods in presenting and analysing the data in maps; (4) the development of map production skills; and (5) the development of skills in constructing research plans, including formulating research questions and hypotheses and data acquisition methods. Requirements for the design of the student research projects are: (1) the research questions and the research methods should resemble questions and methods used in professional geography (geography practised in science, business and government) as much as possible; (2) GIS takes a central position; (3) the student research project should clearly show the benefit of using GIS over using analogue techniques and analogue materials; and (4) the student research projects should be limited to approximately six hours including a GIS skills training.

This paper deals with the results of the first phase of this part of the Ph.D. study. The aim of the first phase is to identify the characteristics of student research projects that combine fieldwork with GIS, that are feasible and potentially contribute to the domain-specific educational aims as defined above. The second phase aims at the improvement of the potential educational benefits of student research projects that combine fieldwork with GIS.

3. Research design

In the first phase of the research, four different student research projects were designed and subsequently tested in classroom settings, adapted and tested again. The themes of the student research projects are: (1) shops and their customers; (2) opinion of citizens about their neighbourhood; (3) traffic and road safety; and 4) microclimates. The student research project designs consist of six phases: (1) instruction; (2) data acquisition; (3) data entering; (4) data visualisation; (5) assignments; and (6) discussion. In the *instruction phase*, the teacher and researchers provided information about the theme and the aim of the student research project and gave instruction on the data acquisition methodology. In the *data acquisition phase*, students went in pairs to their research objects or research areas and collected the data. The students subsequently entered the data in the *data entering phase*. In two of the student research projects, the entered data were automatically combined to form a large data set. In the *data visualisation phase*, students loaded the data into *ArcGIS* and changed the symbology. In some of the projects, students applied data analysis tool in order to create new map layers. In the *assignment phase*, students were presented a number of questions. In two student research projects, the students also had to load some (prepared) map layers to answer the questions. In the final phase, the *discussion phase*, students and teacher participated in a discussion about the maps produced by the students.

Three Dutch schools participated in the research: the Sint Nicolaas Lyceum in Amsterdam, the Baudartius College in Zutphen and the Oosterlicht College in Vianen. Teachers of these schools were closely involved in the design of the instruction methods. The test rounds were carried out in 2007 and 2008. The first three student research projects were tested with 15-year-old grade upper level of secondary education students. The fourth student research project was tested with 14-year-old grade lower level of secondary education students. During the research project tests, the teacher and the researchers provided instruction, guided students during the data analysis and organised a discussion afterwards. During the research projects, the students were observed by the researchers, and afterwards interviews with the teachers and students were organised.

4. Description of the four student research projects

4.1. Stores and their customers

The concept of market areas is the focus of the first student research project. The market area of a retail store is the area from which the store draws its customers. In this student research project, we consider market areas to be simple concentric circles in which the radius is defined by the median of the distance between the home address of customers and the store. Different stores have differently sized market areas. The spatial variability in the size of the market areas can be explained with theories about spatial behaviour of people and local or regional characteristics. The student research project takes four hours. The design of the student research project was tested with 14 upper secondary students of the Sint Nicolaas Lyceum in Amsterdam. In the first step of the student research project, seven pairs of students went to stores of the same category (e.g. toy stores, news stands, shoe stores) in three neighbourhoods of Amsterdam. At each store they asked 20 customers for their Zip code. Back at school, the students entered the Zip codes in a spreadsheet that automatically calculates the X and Y coordinates of the centre of the street where the customers lived. Next, they loaded the data file into ArcGIS and constructed a dot map that displayed the origin of the customers of the different stores (Figure 1A). The students then engaged in further GIS analysis. They calculated the average distance for the customers to each of the three stores. On the basis of average distance, the students constructed buffers (circles) around the three stores that represented their market areas (Figure 1B).

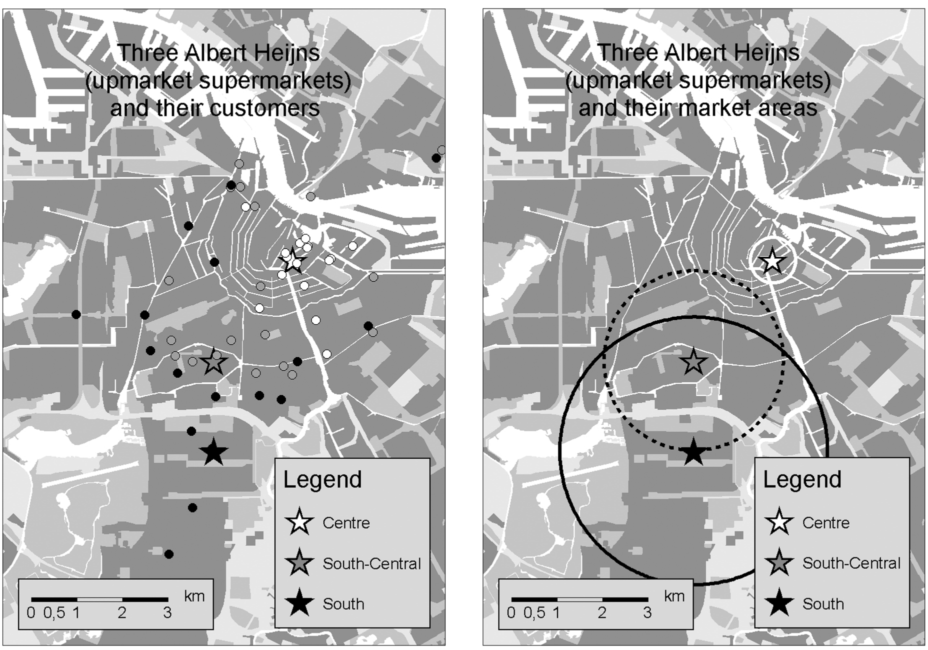
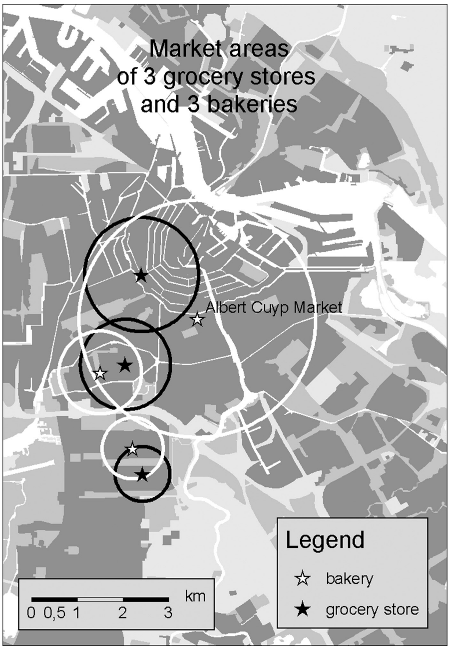


Figure 1. Maps produced by students: (A) distribution of three Albert Heijns (upmarket supermarkets) and their customers; (B) market areas of the three Albert Heijns.



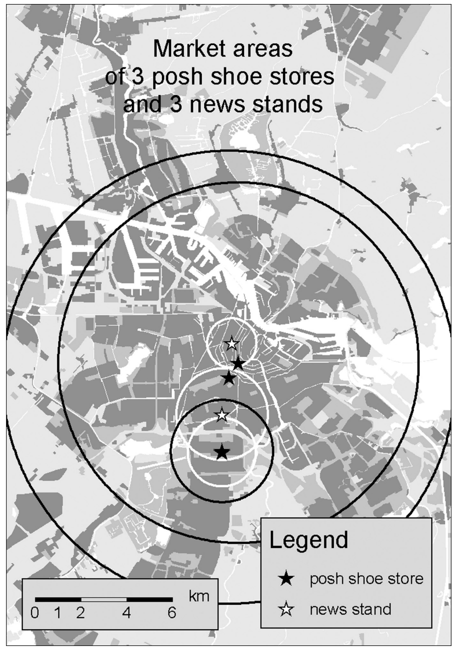


Figure 2. Maps produced by students: (A) market areas of posh shoe stores and newsstands; (B) market areas of grocery stores and bakeries.

The maps show some interesting patterns. For example, the maps of the supermarkets clearly show that customers of the supermarket in the city centre live nearby, while those of the supermarket in the southern part of Amsterdam come from a much wider area. According to the students Moundir and Thomas, who collected the data and constructed the map, this is because the supermarket in the southern part of Amsterdam is very large and does not have a parking fee. People get here by car to do grocery shopping for a full week. The supermarket in the centre is more like a local store. People get here walking or by bike, and buy a couple of products only.

In a discussion afterwards, the teacher loaded the map layers of the different market areas on the teacher computer, projected them on a big screen and discussed with the class the reasons for the differences in the size of market areas between stores of different types. The posh shoe stores (Figure 2A) had the largest market areas of all investigated stores. Joyce and Laura, who collected the data of the shoe stores, found out that many of the customers of the shoe stores in district Centre and South-Central originated from other towns as Haarlem and Bussum. The discussion focused on differences between stores of the same type in different neighbourhoods and on the specific characteristics of the stores and their customers. According to Joyce, the relatively small size of the shoe store in district South can be explained by the customers: “Lots of old people here. Old people don’t like to travel very far, so they only go to a store if it’s nearby”. The market areas of some types of stores showed similar spatial patterns. For example, the map of the market areas of grocery stores and bakeries (Figure 2B) shows that the size of the market areas increases towards the centre of Amsterdam. In the discussion, the teacher focused on general patterns but also on stores that formed an exception to the rule. According to Abel en Simon, who investigated the bakeries, the relatively large size of the market area of the bakery at the

Albert Cuyp can be explained as follows: “There are many day-trippers at the Albert Cuyp market. These people visit the bakery to get a sandwich. Loafs of bread are probably only sold to people who live nearby”.

4.2. Opinion of citizens about their neighbourhood

The second student research project focuses on the question how people value the neighbourhood they live in. The design of the research project is based on the notion that the opinion of people on their neighbourhood depends on the characteristics of the neighbourhood and the characteristics of the people. Both characteristics show some spatial variability. This project takes about four hours. The design of the student research project was tested with the same group of 14 students as in the market area project. In the first phase of the student research project, students formulated survey questions about different aspects of neighbourhoods. The best questions were selected in a discussion with all 14 students and incorporated in a list of final survey items (Figure 3A). Next, pairs of students went to two neighbourhoods and asked 15 citizens for their opinion about these aspects. The citizens had to answer these questions by giving marks ranging from 1 (bad) to 10 (good). After finishing the inquiries, the students went home and entered the data in an online form, which automatically saved it (and combined the data of different students) in a spreadsheet. The spreadsheet also calculated average marks for each of the aspects.

Next day, the students saved the spreadsheet with the combined, manipulated and transformed field data table and loaded the table in *ArcGIS*. They also loaded a map layer of neighbourhoods of Amsterdam in *ArcGIS*. The students then joined the table with the field data to the map layer and created quantities maps. Separate map layers were made for every aspect (Figure 3B). Students also loaded some prepared thematic map layers, among

Give a mark for:
• Availability of public gardens
• Availability of sport facilities
• Availability of public transport
• Availability of parking spaces
• Availability of restaurants and bars
• Availability of shops
• Availability of playgrounds for children
• Nuisance caused by young people
• Safety (crime)
• Safety (traffic)
• Tidiness of pavements and streets (litter)
• Community spirit

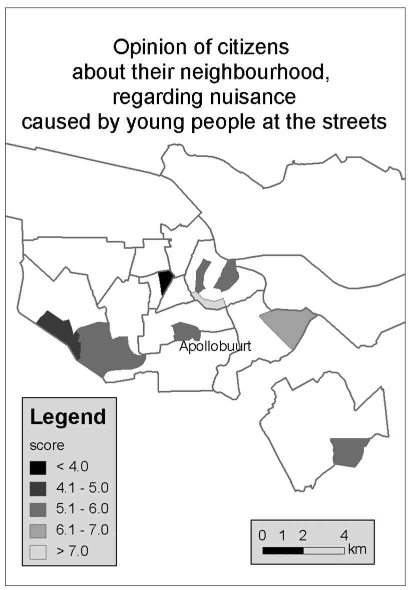


Figure 3. Survey items used in the fieldwork (A), and an example of a map created by the students (B). The map shows the citizen opinion about nuisance caused by young people hanging around on the streets.

others a map layer showing the average age per neighbourhood and a map layer showing the crime reporting per neighbourhood. After finishing the GIS assignments, the students received a list of questions about the maps they had constructed.

In the discussion afterwards, the teacher focused on general patterns in citizen opinion and on the causes of high and low values in specific neighbourhoods. Thomas and Devon, who surveyed the neighbourhood "Apollobuurt", were surprised by the low average mark regarding nuisance caused by young people hanging around on the streets. Thomas: "I always thought that Apollobuurt was one of the best neighbourhoods in Amsterdam, so I didn't expect there'd be so many problems with young people there". Devon: "I think there are no real problems. The value may be low because this neighbourhood has a lot of rich and old people. And rich and old people get annoyed very easily". Teacher: "Let me remind you that there are two secondary schools in that neighbourhood. Would that have affected the citizen opinion regarding this subject?"

The other thematic map layers were also used in the discussion. Students investigated, for example, the match between perception of safety and actual crime rates and whether the safety perception was related to the age structure. Eva: "The map shows that there's a lot of crime in the city centre. Still, people feel relatively safe". Jan: "That is because there people are not the main target of pickpockets. They always focus on tourists".

4.3. Traffic and road safety

The third student research project is a project on traffic and road safety. This student research project takes more time and has a more open character than the other student research projects.

The design of the project is based on the notion that the traffic intensity depends on the position of the road in the road network, relative to different residential areas, working areas, transport areas, recreation areas, etc. Infrastructure development guided by spatial planning has resulted in three categories of roads: (1) roads that access areas; (2) roads that connect areas; and (3) main roads. The type and number of traffic accidents at a specific road or crossing depends on the amount and type of traffic and the local road safety conditions.

The design of the student research project was tested with 15-year-old upper secondary students of the Baudartius College in Zutphen, a town with 30,000 inhabitants in the eastern part of The Netherlands. Forty students participated in the project. Before the start of the project, we obtained a digital map of the road system from the regional authorities and a database (which contained *X* and *Y* coordinates) of traffic accidents that occurred in the past five years from the Ministry of Traffic. In consultation with the teacher, we selected the 130 most important road sections from the road map. In the first phase of the student research project, students collected data of traffic (pedestrians, cyclists, scooters, motorcyclists, cars, trucks and busses) in the field. Each pair of students sampled four road sections (in both directions) for 15 minutes. The measurements were spread across two days and were carried out around 1 pm. As 40 students participated in the student research project, the 20 student pairs sampled in total 80 road sections. Back at school, the students entered the data in an online form that automatically saved it and combined it in a spreadsheet.

Next, the students loaded the digital map layer of the road system and the traffic data file in *ArcGIS*. On the basis of the traffic data and the road map layer, they calculated the traffic magnitude at 50 other, non-sampled road sections. The resulting database of 130 road sections formed the starting point of the mapping procedure. Students created quantities maps that showed the magnitude of the flow of cyclists, cars, etc. They also created maps

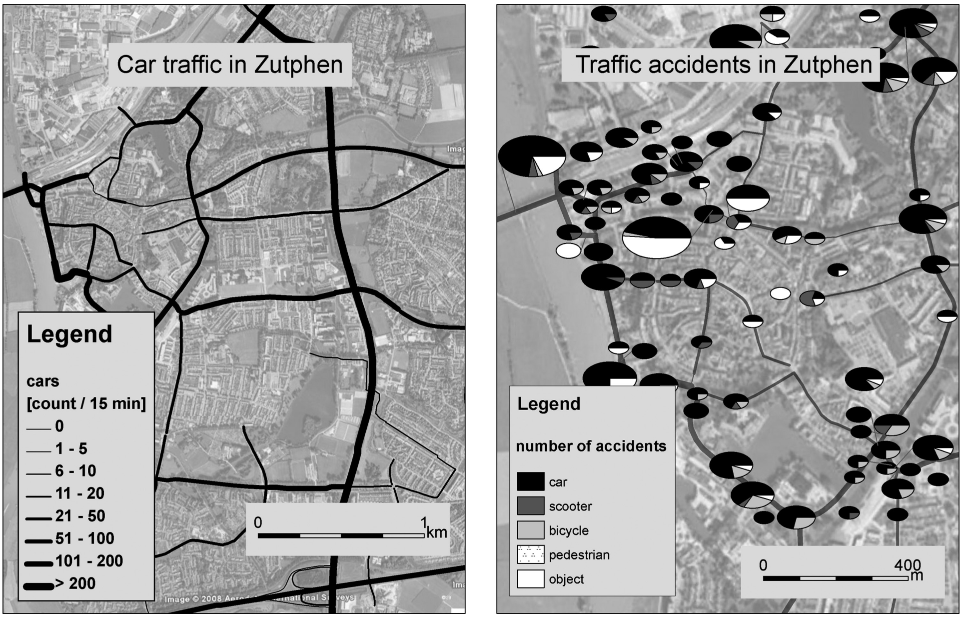


Figure 4. Maps produced by students: (A) Map of the magnitude of car traffic; (B) Map of accidents in and around the city centre.

of car accidents and other types of accidents using the data file supplied by the Ministry of Traffic.

The following assignment was more open. Students were asked to choose a theme of traffic and road safety and set up a small research. Some students choose a thematic approach, focussing for instance on the pattern of car traffic (Figure 4A) or the cause of accidents between cars and objects (Figure 4B), while others followed a regional approach, for instance by investigating specific crossroads with a large number of accidents. Other students tried to formulate solutions for specific unsafe sites. In the last assignment of the student research project, students made PowerPoint presentations and presented their results to each other. After each presentation, the teacher asked questions about the subject, the students' conclusions and their research methods. Anna and Irene, who constructed the map of the traffic accidents, had to explain why there are so many accidents in the city centre that involve cars and objects. According to Anna, this is because "the city centre has many small lanes, with small poles on the sides of the street". And why are there so many cyclists involved in accidents just south of the city centre? Irene: "This is the main bicycle route for students to go to school. The situation is not very safe, as cars drive pretty fast there".

4.4. *Microclimates*

The fourth student research project focused on microclimates. In this student research project, students investigate the differences in the air temperature in the direct surroundings of their school. The design of the project is based on an instruction method described by Smith and Dunn (2007). The student research project takes only three hours and is especially interesting in suburban neighbourhoods.

The geographic framework of the research project is based on the notion that the air temperature may show spatial variability at a resolution of several meters to tens of meters. The temperature at a specific location and specific day and moment in time depends on the land use. Some kinds of surfaces heat up more quickly than others. Next to this, it also depends on the wind speed, which may show a spatial variability depending on, among others, the land use and the aspect to the wind. Next to this, the air temperature at a specific location may also change in time (during the year or during the day). During the day, surfaces that heat up quickly may show larger differences than surfaces that heat up slowly. The temperature also depends on the cloud cover and general wind speed pattern. Temperature differences between locations will be lower on cloudy and/or windy days than on sunny and/or calm days.

The design of the student research project was tested with 14-year-old lower level secondary students of the Oosterlicht College in Vianen, a town with 30,000 inhabitants in the centre of The Netherlands. At the start of the student research project, pairs of students were formed and each pair was assigned to a different study area of about 200 m $\times$ 200 m. The students collected data with a digital thermometer and a GPS. There were two fieldwork sessions: one early in the morning and one in the middle of the afternoon. In each of the sessions, students went to their own study area and measured the air temperature at 15 places. At each place they added a waypoint in their GPS and entered the measured temperature in a form. These waypoints were stored in a shapefile. Back at school, students loaded a digital topographic map and a satellite image of the surroundings of their school in *ArcGIS*. The students subsequently uploaded the two data files from their GPS and constructed a dot map. They then transformed the dot map into a quantities dot map by importing a legend file (Figure 5A). Next, they interpolated the dot maps to create two continuous fields, one representing the early-morning air temperature and one representing the mid-afternoon air temperature (Figure 5B). Although the weather conditions were less then optimal, the maps showed some interesting patterns. For example, the map of the temperature in the mid-afternoon clearly shows that woodlands are relatively cool and build up areas are relatively warm. According to Kim and Bas, who constructed the map, there's a logical explanation for this: "Stone heats up more quickly than water".

After finishing the GIS assignments, the students had to answer several questions. In the meanwhile, the teacher with help from the researcher combined the different data sets and constructed a map of all study areas together. In the discussion, the teacher presented the temperature maps of the surroundings of the school. Students could see that the conclusions they drew on the basis of their own study area applied to other study areas too. In most study areas, the woodlands and fields were significantly colder than the build up areas, and the mid-day air temperature showed larger differences than the early-morning temperature. In the discussion, the teacher also addressed the issue of reliability of data and discussed with the students how to minimise error.

5. Results

5.1. The theme of the student research project

It is important to find ways to motivate students because motivation is an important factor in the process of learning (Leat, 1998). Therefore, the theme of a student research project should be interesting, real and relevant. In the design of the student research projects, we tried to design simplified but realistic versions of research carried out by geographers

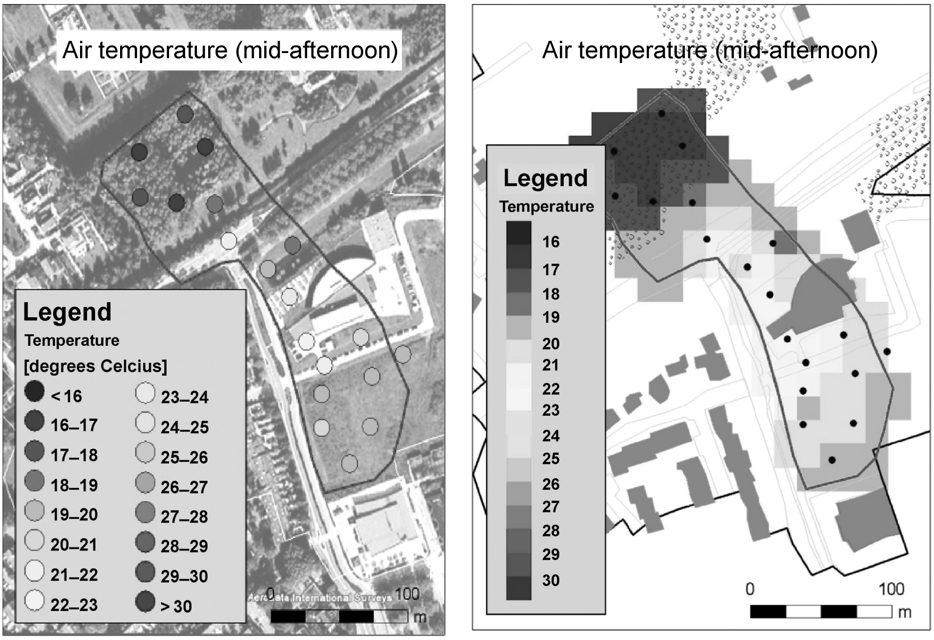


Figure 5. Maps produced by students: (A) Map showing the temperature measurements; (B) continuous field of the temperature during mid-afternoon.

in business, government and science. The questions and the methods of data collection and data analysis used in the four student research projects are very realistic. From the observations and interviews we learned that the students and teachers appreciated this aspect very much.

There are four other aspects that we learned from the student research project with GIS. Firstly, a good design of a student research project should be based on a clear and simple geographic framework. As the geographic theories that underlie research projects in professional geography are often too complex to be a starting point of a student research project, the complex theories have to be simplified. Secondly, the phenomenon that is going to be mapped should show distinct and explainable patterns, and should have strong causal relationships with other phenomena, preferably phenomena that can be visualised in GIS too by loading prepared map layers. A good theme is a theme that challenges students to ask geographic key questions about the mapped phenomenon by themselves. Thirdly, the phenomenon should also be easy to sample, and, fourthly, it should be easy to construct reliable maps of the phenomenon on the basis of the data gathered in the fieldwork. We choose for phenomena that could be sampled everywhere and used as a base map that could be downloaded from the Internet or could easily be obtained from the local or regional authorities. Student research projects like these can therefore be carried out in the surroundings of every school in The Netherlands.

5.2. Data handling

In the four student research projects presented in this paper, students use not only their own data, but also the data collected by other students. This offers some interesting possibilities.

In student research project "stores and their customers", the combination of different data sets allows students to investigate general patterns (in particular the change in the size of market areas between the city centre and the suburbs) and to compare the market areas of different kinds of stores. In student research project "microclimates", data combination allows students to learn about other places too and allows them to check their findings with other data. The student research projects "opinion of citizens on their neighbourhood" and "traffic and road safety" would be impossible without the combination of the different data sets.

The problem with data combination is that manual combination of data sets takes a lot of time and is very boring. Furthermore, the teacher (or students, if they do the data combination) always has to wait until the slowest student has finally entered the data before he or she can start combining the data sets. In student research projects "opinion of citizens on their neighbourhood" and "traffic and road safety", we designed an online data entry form that was linked to an online spreadsheet. This spreadsheet automatically combined the data entered by the different students.

In these student research projects, students were asked to enter the data at home, directly after the fieldwork, so they could start with the data visualisation and analysis of the next lesson (next day) right away. In student research project "stores and their customers" and "microclimates", students created map layers and saved these map layers on a directory that was open to all other students. In this way, the students were able to load and view the map layers created by other students. The teacher was able to combine the map layers and project them on a big screen. The combined map layers formed the input for the discussion afterwards.

Manual data manipulation and transformation, just like data combination, takes time, is boring and takes away the attention from what is really important: the learning of geography. Furthermore, manual data manipulation by the teacher or the students means they have to follow extensive procedures, and if they do not follow these procedures exactly, things will go wrong. In student research projects "stores and their customers", "opinion of citizens on their neighbourhood" and "traffic and road safety", we used prepared spreadsheets that automatically manipulated the collected data and put it into the right format for loading it into *ArcGIS* and using it in further analysis. The spreadsheets do give students insight into the calculations, but take away the burden of doing the manipulation and transformation themselves. Student research "microclimates" required only one transformation operation: the interpolation of point data to a continuous field. This is an interesting operation that could easily be performed by the students themselves.

Regarding data visualisation we observed that many students liked to play around with the symbology editor and to construct thematic maps on the basis of the data they collected themselves. However, in case students had to construct multiple map layers of similar phenomena (e.g. the magnitude of car traffic, the magnitude of bicycle traffic, etc.) or of the same phenomena at different moments in time (e.g. the air temperature in the morning and the air temperature in the morning), they often produced map layers with different class boundaries and different colour schemes. This made it hard for them to compare the map layers. For this reason, we first let the students change the symbology manually and presented some questions about individual map layers. We then asked them to load a prepared legend file and apply it on the map layers. After they constructed maps with the same symbology, we presented some questions about differences between the map layers.

5.3. Technical limitations

Technical limitations, though seemingly insignificant, may cause a lot of problems. For example, the first pilot with the traffic student research project almost turned into a complete disaster because the join functionality in *ArcGIS* did not work. For some reason it was impossible to join the traffic data to the map layer of the roads. It took us almost one hour to find out that the name of the table with the traffic data was the cause of this problem: it contained a space, and tables with spaces in its name cannot be joined successfully to a map layer.

In the test rounds, we made inventories of technical limitations. We subsequently designed ways to evade these limitations, especially via the prepared spreadsheets. Still, there are some problems that often occur but cannot be evaded. For example, *ArcGIS* does not allow the user to load a table if the table is still open in the spreadsheet program. Although the instruction materials explicitly told the students to close the table in the spreadsheet program first, many did not do so and subsequently could not load the table into *ArcGIS*. For teachers, it is essential to know how to solve this kind of problems. We therefore constructed a list of common problems and incorporated this list in the teacher handouts.

Summarising, we identify the following characteristics of feasible and potentially rich (regarding the development of geographic knowledge, geographic thinking skills and geographic research skills) approaches to combining quantitative data acquisition in fieldwork with data visualisation, manipulation and analysis in GIS:

(1) A good theme and a clear and simple geographic framework.
(2) Complementary data acquisition by students and combination of the data files to one large database.
(3) Facilitation of data entry, preparation, manipulation, transformation and combination with prepared spreadsheets, online entry forms and an exchange directory.
(4) Facilitation of data visualisation with prepared legend files, especially when students have to compare different map layers.
(5) Waterproof instruction materials.
(6) A good teacher handout that contains information about how to solve frequently occurring problems.

6. Discussion

So far our design of the student research projects with GIS has not been tested at other schools nor have the learning outcomes of the projects been evaluated. Nevertheless, we think the first step is worthwhile. The foundation of the building for learning geography by combining fieldwork with GIS has been constructed. We expect that doing research projects with GIS stimulates students' research skills: asking good geographical research questions, skills in choosing data acquisition methods, skills in collecting data, skills in manipulating, visualising and analysing data, and skills in reporting and presenting. The most important question is how to organise discussions that enhance the transferability of general and domain-specific knowledge and skills in a way that students are able to formulate research strategies for investigating similar problems. A lot of teaching focuses on drilling concepts and strategies – even research strategies – and not on reflective power (Alexander & Murphy, 1999). We think that projects in which students investigate real world problems combining fieldwork with GIS can have a great impact on students' learning. It is important that students are the owners of a problem, that they work together with other students and teachers in a community of learners and that broad time for reflection is included (Beishuizen, 2004).

Last but not least, we think that it is very important to get more information about the process of knowledge construction by students. Regarding the learning of geographic thinking skills, we expect that higher order geographic thinking operations are predominantly applied in the assignment phase and discussion phase:

(1) In the data acquisition phase, students gain lower order (factual) geographic knowledge about the specific features of objects (stores, road sections), places (places where temperature measurements are carried out) and regions (neighbourhoods) they sampled. They gain knowledge about the phenomena they sampled, and, more importantly, knowledge about other features of these specific objects, places and regions. For example, students gain knowledge about the average size of the stores, the tidiness of the neighbourhoods, the safety conditions at the road sections and the type of vegetation at the places where temperature measurements are carried out.
(2) In the data visualisation phase, students construct knowledge about the features of objects, places and regions sampled by other students. Maybe they also construct knowledge about higher order geographic concepts like spatial pattern and spatial relationship. Questions about the causes of differences in feature values and causes of spatial patterns and associations may pop-up in their minds.
(3) In the assignment phase, students are presented questions that mainly ask for descriptions of patterns and relationships, and the causes for high and low values of specific objects, places or regions. In this way, students construct bodies of higher order (conceptual) geographic knowledge and outline the connection between different bodies of knowledge.
(4) The discussion phase is the moment when everything comes together. This phase is therefore very important for the learning process. In the discussion, the teacher can combine a thematic and a regional/individual approach. By choosing for a thematic approach, he or she can ask students to make descriptions of and give explanations for spatial patterns, spatial gradients and spatial associations. The teacher could then switch to a regional/individual approach, thereby asking students to make descriptions of the features of individual objects, places and regions. The teacher could also ask which objects, places or regions fit the rule and which form an exception to the rule, regarding the value of a feature. In the discussion, the teacher could make use of fact that every student pair has at least visited one object, place or region, and therefore has knowledge about the specific features of this unit. Therefore, students can learn from each other.

The next phase of the study will attend the question how instruction materials and teachers can maximise students' learning of geography by combining fieldwork with GIS focusing on reflection and higher order thinking skills.

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