Computers & Education 58 (2012) 666–677

Contents lists available at SciVerse ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

# Exploring the characteristics of an optimal design for inquiry-based geography education with Geographic Information Systems

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A R T I C L E I N F O

*Article history:*
Received 21 June 2011
Received in revised form
31 August 2011
Accepted 5 September 2011

*Keywords:*
Secondary education
Geography
GIS
Inquiry-based learning
Deep learning
Design research

A B S T R A C T

Geographic Information Systems (GIS) is a kind of computer software that allows people to work with digital maps in a fast and flexible way. In the past decade, more and more geography teachers have become interested in the possibilities of using GIS in secondary education. However, teaching with GIS is complex, and little is known about how to do so in an optimal way. Therefore, an Educational Design Research study (EDR) was conducted with the aim to explore the characteristics of an optimal design for GIS-supported geographic inquiry projects. In this EDR study, a project was developed via progressive cycles of designing, testing, and evaluating, together with teachers from different schools. This paper summarizes the outcomes of the EDR study, and presents some design principles for GIS-supported inquiry-based geography education. Teachers could use these design principles to design and conduct GIS-supported geographic inquiry projects, and in such a way raise their geography lessons to a higher level.

This paper also shows that although GIS provides many opportunities for enhancing inquiry-based geography projects, it also holds many conditions for its use to be optimal. GIS-supported inquiry-based geography education requires more than providing appropriate software, tasks, and coaching to ensure that students do not get stuck. In order to effectively raise students' geographic thinking to a higher level, the project should offer a considerable amount of guidance: it should include several preparatory and evaluative tasks based on a good domain-specific theory for use in educational settings. In addition, teachers should coach students in structuring, correcting, and expanding their geographic thinking via dialogical teaching.



## 1. Introduction

The media attention given to the geographic knowledge of the general public often reinforces the common view that learning geography is just about learning topographic knowledge (e.g. knowing where Iraq is on a world map) and factual knowledge about the properties of places and regions (e.g. knowing that the main religion in India is Hinduism). However, modern geography is much so more than learning facts. According to Haubrich (1992), geography is "the science which seeks to explain the character of places and the distribution of people, features and events as they occur and develop over the surface of the earth". Different authors stress that it is important to combine knowledge and skills in geography education (Bednarz, 2000; Morgan, 2006; Van der Schee, 2007; Van Westrhenen, 1987). Modern geography should not be seen as a ready-made product that can be handed over from the teacher to the students, but more like an activity that students can engage in. The problems, tasks, and settings of geography education should be meaningful, realistic, and relevant for students. Students should learn how to do geography: they should develop the knowledge, skills, and motivation to engage in geographic inquiry. In this paper, the geographic inquiry process refers to the activities that are carried out by geographers when they study the characteristics and functioning of, or problems in, the world around us. The world around us is characterized by the presence of natural and human phenomena in space and time, and by the relationships between these phenomena. Engaging in geographic inquiry may stimulate progression in one's knowledge, skills, and motivation, but knowledge, skills, and motivation are also a precondition for engaging in geographic inquiry.

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0360-1315/$ – see front matter 
doi:10.1016/j.compedu.2011.09.007

In the past few decades, more significance has been attached to the development of the skills that are required to gain knowledge (Kent, 2006). One of the educational means for achieving this goal is inquiry-based instruction, in which students are expected to develop their own knowledge and skills by engaging in activities 'like researchers do' (Van Joolingen, De Jong, Lazonder, Savelsbergh, & Manlove, 2005). Inquiry-based instruction generally aims to stimulate progression in students' domain knowledge, inquiry skills, and self-regulated learning. Inquiry-based instruction connects to (socio-)constructivist learning theories. According to these learning theories, students learn best in collaborative learning environments in which they work on problems in authentic contexts (Dogru & Kalender, 2007; Guthrie et al., 2004; Hmelo-Sliver, Duncan, & Chinn, 2006; Jonassen, Campbell, & Davidson, 1994; Kim, 2005). Constructivism emphasizes the importance of engaging in minds-on and hands-on inquiry-based activities (Wilson, 1994). Students should be active learners, and teachers should be coaches rather than instructors. Knowledge is not seen as a fixed commodity that can be delivered from teachers to students. Instead, the central idea is that learning processes are most effective when students actively make sense of the subject matter themselves.

New interactive technologies make it easier to design instruction methods based on (socio-) constructivist learning theories (Hill & Solem, 1999; NRC, 1999). One of these technologies is Geographic Information Systems (GIS). From the context of secondary education, GIS can be seen as a type of user-controlled and interactive software for teaching and learning. The software provides tools for working with digital maps. It allows students to visualize, create, manipulate, read, query, summarize, analyse, and present digital geo-data in a fast and flexible way. GIS can be applied in many educational disciplines, such as biology education, history education, and economics education. However, its main field of application is geography education. Many geographers rave about the possibilities of GIS for enhancing secondary geography education (Audet & Abegg, 1996; Audet & Ludwig, 2000; Baker & White, 2003; Bednarz & Audet, 1999; Hall-Wallace & McAuliffe, 2002; Keiper, 1999; Kerski, 2003; Lemberg & Stoltman, 2001; Sinton & Lund, 2007; West, 2003). The book *Learning to Think Spatially* (NRC, 2006) underlines that GIS offers many possibilities for designing instruction methods that are consistent with the ideals of inquiry-based education within authentic contexts. Liu and Zhu (2008) argue that GIS offers possibilities for teaching and learning in connection with (socio-)constructivist ideas. It is not that GIS itself produces learning, but that GIS allows teachers and students to engage in more sophisticated inquiry than would otherwise be possible (Sinton & Lund, 2007). Many of the instruction methods with GIS are very different from traditional instruction methods. In such a way, GIS has the ability to change secondary geography education (Baker & White, 2003; Kerski, 2003; Sinton & Lund, 2007).

## 2. Problem proposition

Inquiry-based teaching with GIS is a new and very complex kind of teaching, and little is known about the characteristics of an optimal design for GIS-supported geographic inquiry projects. After reviewing the literature, Bednarz (2004) concluded that "scant attention has been paid to issues related to pedagogy and GIS". Lam, Lai, and Wong (2009, p.72) argued that in order to support teachers, researchers should "provide more insights on how to make the best use of GIS in geography teaching". So, educational research has not yet provided enough knowledge to help teachers to use GIS. This paper focuses on this issue. The aim is to explore the characteristics of an optimal design for GIS-supported geographic inquiry projects. The design principles presented in this paper can help teachers to design and conduct GIS-supported inquiry-based projects in their schools.

## 3. Research approach

A research approach was followed that falls under the heading of 'Educational Design Research' (Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006b). There is not one single answer to the question: What is Educational Design Research? (Barab & Squire, 2004). Van den Akker, Gravemeijer, McKenney, and Nieveen (2006a) used the term as a common label for a family of related research approaches that treat design as a strategy for developing and refining theories on teaching and learning. This family of research approaches includes 'design research' (Collins, Joseph, & Bielaczyc, 2004; Edelson, 2002; Reeves, Herrington, & Oliver, 2005), 'design-based research' (Dede, 2004), 'developmental research' (Gravemeijer, 1994), and 'design experiments' (Brown, 1992; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Collins, 1990). The emergence of EDR is frequently traced back to the work of Brown (1992) and Collins (1990). Almost two decades ago, Collins and Brown began conducting what they called 'design experiments', because they believed that many of the questions they were interested in could not be answered with experiments in laboratory settings. Since then EDR has grown in popularity and significance (Barab & Squire, 2004). According to Walker (2006), EDR has become more and more accepted in the recent years for two reasons: (1) a growing disappointment with the impact of traditional educational research on educational practice; and (2) a growing need for knowledge about how to design educational modules that are based on new theories of teaching and learning and knowledge about how to design educational modules that use new technologies. Gravemeijer and Cobb (2006, p.46) argued that EDR has the potential to "bridge the gap between theory and practice". Design research has a better change of leading to successful educational innovations.

After reviewing previous works by Cobb et al. (2003), Kelly (2003), the Design-based Research Collective (2003), Reeves et al. (2005), and Van den Akker, Branch, Gustafson, Nieveen, and Plomp (1999), Van den Akker et al. (2006b) formulated a list of five characteristics of EDR. First, EDR has an interventionist nature. Design researchers intervene in the teaching and learning process, and try to reshape it. They thereby work together with teachers. Second, EDR has an iterative nature. The design process is a central component of EDR studies. This process consists of iterative cycles of designing, testing, and evaluating. Third, EDR is process-oriented. It focuses on the understanding of learning processes and the means to stimulate those learning processes. Fourth, EDR is utility-oriented. The knowledge developed in the design process should be useful for the users (teachers, developers of educational materials, developers of national standards, etc.) in real settings. Fifth and finally, EDR is theory-oriented. Educational modules are designed on the basis of theoretical propositions, and the testing of the design of the module contributes to theory building.

According to McKenney, Nieveen, and Van den Akker (2006), the primary output of EDR in the domain of instruction and learning is knowledge in the form of *design principles*, which are heuristic guidelines for the design of educational modules. Design principles aim to help teachers design comparable modules in comparable settings. According to Gravemeijer and Cobb (2006), the primary output of EDR is a *local instruction theory*, which is a situated (hence 'local') empirically-grounded theory of the rationale behind the design. It is a theory about how an educational module works. Local instruction theories contain knowledge about both the process of learning and the means designed to support that learning. They describe how all the elements of the educational module in a classroom setting work together and interact with each other (Gravemeijer & Cobb, 2007). This paper reports about the outcomes of an EDR studied that focused on exploring the characteristics of an optimal design for GIS-supported geographic inquiry projects. The EDR study can be seen as a first stage of research on GIS in secondary education. Later stages may have a more confirmatory character, with the aim to test the effects of GIS-supported inquiry-based geography education on students' learning with a pretest–intervention-posttest approach.

In order to explore the characteristics of an optimal design for GIS-supported geographic inquiry projects, a project was developed in five progressive cycles of designing, testing, and evaluating (Fig. 1). The research team consisted of the first author of this paper and nine geography teachers from six schools from different parts of the Netherlands.

In the design stages, the design of the GIS-supported geographic inquiry project was (re)designed: learning goals were (re)formulated; constructs for use in educational settings were developed or revised; and tasks and coaching strategies were developed or adapted. Also, conjectures were formulated about students' learning processes in relation to the design of the tasks and coaching strategies.

In the test stages, the project was tested in classroom settings, with 4th and 5th grade HAVO (senior general education) and VWO (pre-university education) classes. Students were between 15 and 17 years old. Most of them had no experience with GIS and little experience with conducting geographic inquiry. In total, 375 students participated in the tests. During each test, the teachers conducted the instruction and provided support, with some help from the first author of this paper. Most teachers conducted the project twice. Four types of qualitative data were collected during the tests. First, lessons were videotaped, with a focus on discussions between students, discussions between the teacher and a student, and whole-class discussions. Presentations held by students were also videotaped. Second, field notes were made. All instances in which students got stuck were registered. Third, on-task mini interviews were held with the students in which the students were asked to explain what they were doing, how it was going, why they were doing it, and why they were doing it in that specific way. Fourth, the research plans and reports constructed by the students were collected. Besides the four types of data collecting during the tests, also surveys were conducted among the students right after the tests.

Right after each test, a short evaluative talk was held with the teacher. In the evaluation stages, the design of the GIS-supported geographic inquiry project was evaluated in a systematic way. The data were analysed and interpreted in order to test the conjectures. This was done by the first author of this paper, often together with one or two teachers. The results and interpretations were discussed with the other teachers. Group meetings were held during the design process in which the members of the research team discussed the design of the project. The main point of discussion in these meetings was the question how the design of the project could be improved.

The design process of the GIS-supported geographic inquiry project was guided by four criteria: 'appropriateness', 'legitimacy', 'viability', and 'effectiveness'. *Appropriateness* implies that the topic of the project should be suitable, and that the project should have clear and attainable learning goals. *Legitimacy* implies that educational modules should have a logical and coherent structure, and that they should be based on accepted knowledge about the structure in a domain, and on accepted domain-general and domain-specific teaching and learning theories (McKenney et al., 2006). In the design process, the focus was on the construct for use in educational settings. The tasks and coaching should be based on, among other things, a good domain-specific construct for use in educational settings. Finally, the criteria '*viability*' and '*effectiveness*' were connected to the relationship between the tasks and coaching and the characteristics of students' learning processes. In the design process, the focus was put on the problems that occur when students engage in GIS-supported geographic inquiry. These problems were classified in two ways. First, they were classified into: (1) $\alpha$ problems; and (2) $\beta$ problems. The $\alpha$ *problems* refer to situations in which students get stuck, while the $\beta$ *problems* refer to situations in which the learning processes are less-than-intended, and the learning goals are only partially reached. The $\alpha$ problems threaten the viability of the projects, while the $\beta$ problems threaten the effectiveness of the project. If the teacher is not able to solve the $\alpha$ *problems*, the project has to be aborted, and it does not make sense anymore to talk about the effectiveness of the project. Second, problems are classified into: (1) problems that can be attributed to deficiencies in the design of the tasks and coaching; and (2) problems that can be attributed to student learning difficulties. Student learning difficulties are, in turn, related to insufficient knowledge, skills and/or motivation. So the term 'problem' refers to that which can be observed in the classroom, while the term 'learning difficulty' refers to that which causes problems. Table 1 presents examples of the different types of problems.

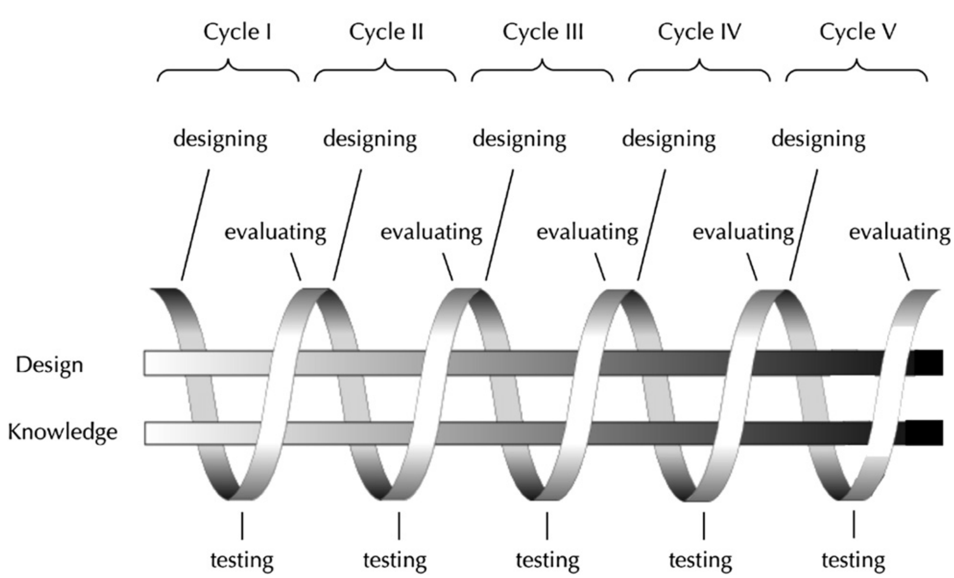


**Fig. 1.** The design process of the GIS-supported geographic inquiry project.

**Table 1**
The different types of problems.

| | $\alpha$ problems | $\beta$ problems |
|---|---|---|
| *Problems that can be attributed to deficiencies in the design of the tasks And coaching* | Students are not able to visualize their data because the step-by-step instruction in the GIS handout contains an omission: one crucial GIS operation is not included in the sequence of GIS operations. | Students overlook a relationship between two GIS map layers because the legends of the map layers contain too many categories. |
| *Problems that can be attributed to student learning difficulties* | Students are not able to visualize their data because they find it difficult to follow the step-by-step instruction in the CIS handout accurately, and rather follow their own way. | Students overlook a relationship between two GIS map layers because they do not expect the relationship, and therefore focus on other information in the map layers. |

The four criteria were mainly used as formative evaluation criteria in the design process of the project. So the design process was not about testing whether a specific design for a project was appropriate, legitimate, viable, and effective. Instead, in the design phase of each cycle, it was explored how the learning goals could be made more concrete, and how the constructs for use in educational settings could be improved. Also, an attempt was made to solve the deficiencies in the design of the tasks and coaching as much as possible, in order to decrease the number of $\alpha$ and $\beta$ problems. Furthermore, it was explored how to prepare students for the inquiry project in order to avoid $\alpha$ and $\beta$ problems related to student learning difficulties; how to support students during the inquiry project so that they are able to overcome such problems; and how to stimulate students to reflect on what they have learned after the inquiry project. In the evaluation stage, the teachers and first author of this paper evaluated together how the changes in the design worked out in practice and how they affected the learning processes, in particular the occurrence of problems. This paper reports only reports those problems that, according to the research team, formed a severe threat to the viability and effectiveness of the project. In other words, it only reports those problems that occurred *too often*.

## 4. The project ‘Services & Customers’

The topic of the GIS-supported geographic inquiry project was ‘Services & Customers’. This topic is a regular part of economic geography in Dutch secondary education. In the project, students investigate the phenomena that influence the size of the market areas of services such as gyms, supermarkets, and primary schools. Market areas are the areas from which services draw their customers. Every gym, supermarket, or primary school has its own market area. It is the area covering the places of residence of the people who travel to use the service.

The final design of the project took 8 h of supervised lessons plus approximately 8 h of students’ own time. The project covers the entire circle of the geographic inquiry process. Students first choose four services and formulate hypotheses about the size of the market areas of these services and the factors that can explain the differences in the sizes. Students then construct surveys. Next, students go to their selected services, and interview 20 customers at each service. They ask, among other things, for the postcodes of the customers. As the students have to explain the differences in the sizes of market areas, they also have to ask additional survey questions that can provide insight into the question why the customers chose to travel to these services (for an example of a student research plan, see Fig. 2). Then, back at school, students enter the geo-data in Excel, and use the Excel file to construct digital maps in GIS (for examples of maps constructed by students, see Fig. 3). These maps enable them to check their hypotheses. Then, students present their finding to the teacher and their classmates, and the teacher organizes an evaluative whole-class discussion on the geographic subject of the project. In this discussion, the teacher and students try to summarize what was learned, and to construct a theory about the phenomena that influence the size of market areas of services in general (see Fig. 4). Finally, students write a report about their project.

Inquiry plan

Main inquiry question
- What are the sizes of the market areas of four gyms in Gorinchem (the Procare, the Living Well, the Fit-4-Less and the Breedveld), and which factors can explain the differences in the size of the market areas?”

Hypotheses
- The Living Well has the largest market area, as the service is very good. So we expect that it attracts people from very far.
- The market areas of the Procare and the Living Well are intermediate in size.
- The Breedveld has the smallest market area, as it is a small gym that is situated in the centre. It is difficult to get there by car.

Data collection strategy
- Survey question 1: What is your age?
- Survey question 2: How often do you visit this gym (per month)?
- Survey question 3: Why do you go to the gym? (A: increase condition; B: gain muscles; C: lose weight; D: for fun)
- Survey question 4: Why did you choose to visit this gym? (A: good service; B: low price; C: short distance; D; other)
- Survey question 5: What transport did you use to go to this gym? (A: car; B: bicycle; C: walking; D: public transport
- Survey question 6: What is your postal code?

**Fig. 2.** Research plan constructed by two students who investigated the market areas of four gyms in Gorinchem.

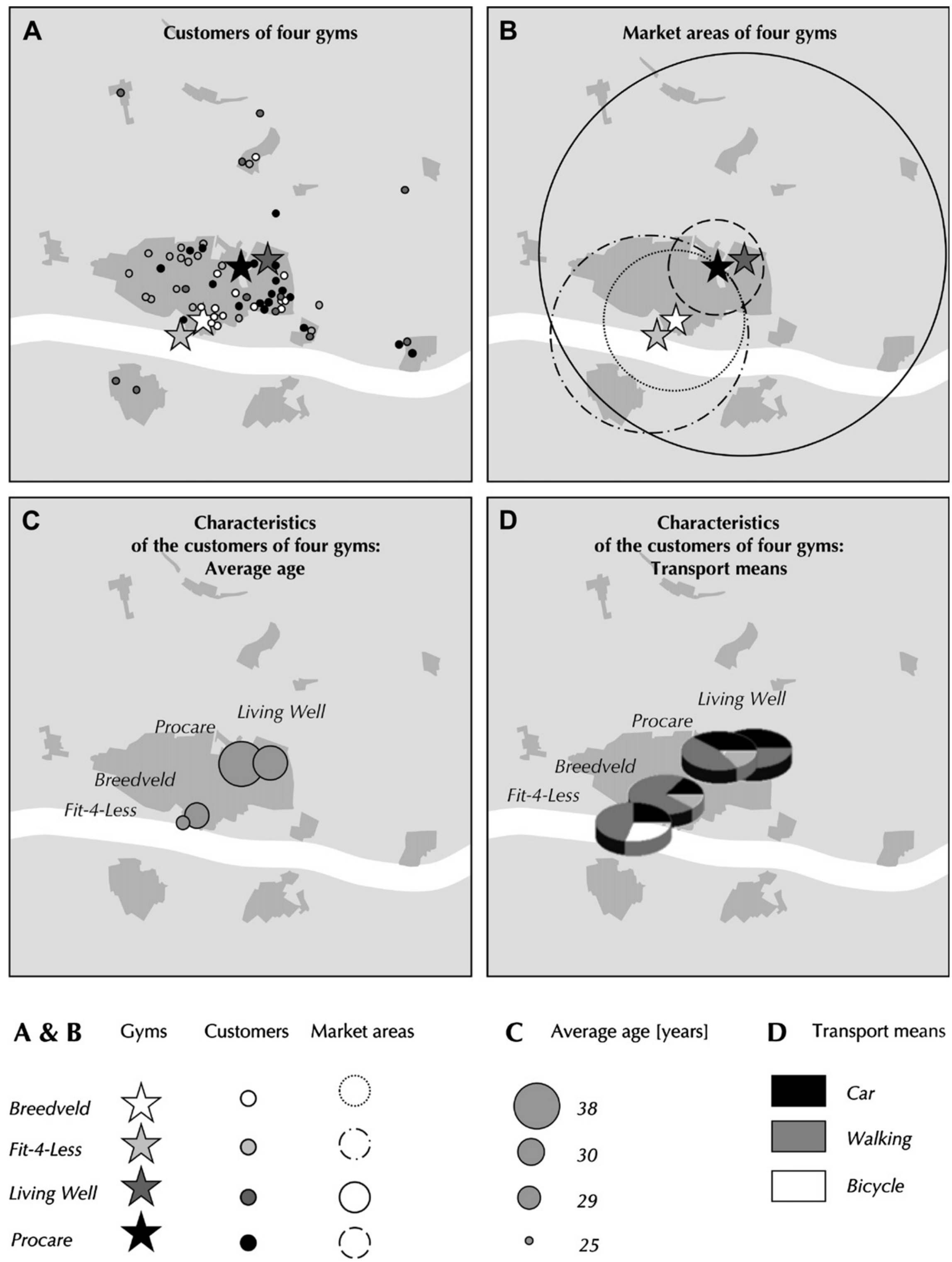


**Fig. 3.** Maps constructed by the two students who investigated the market areas of four gyms in Gorinchem.

## 5. Towards an optimal design

In the course of the design process, the design of the GIS-supported geographic inquiry project improved, and the research team gained knowledge about the characteristics of an optimal design. The entire design process was documented in a 150-page thick, context-rich narrative description of the design activities, test activities, and evaluation activities (Favier, 2011). The decisions made by the research team are substantiated in this document with quantitative and/or qualitative data with interpretations. The next sections summarize the main conclusions of the design process.

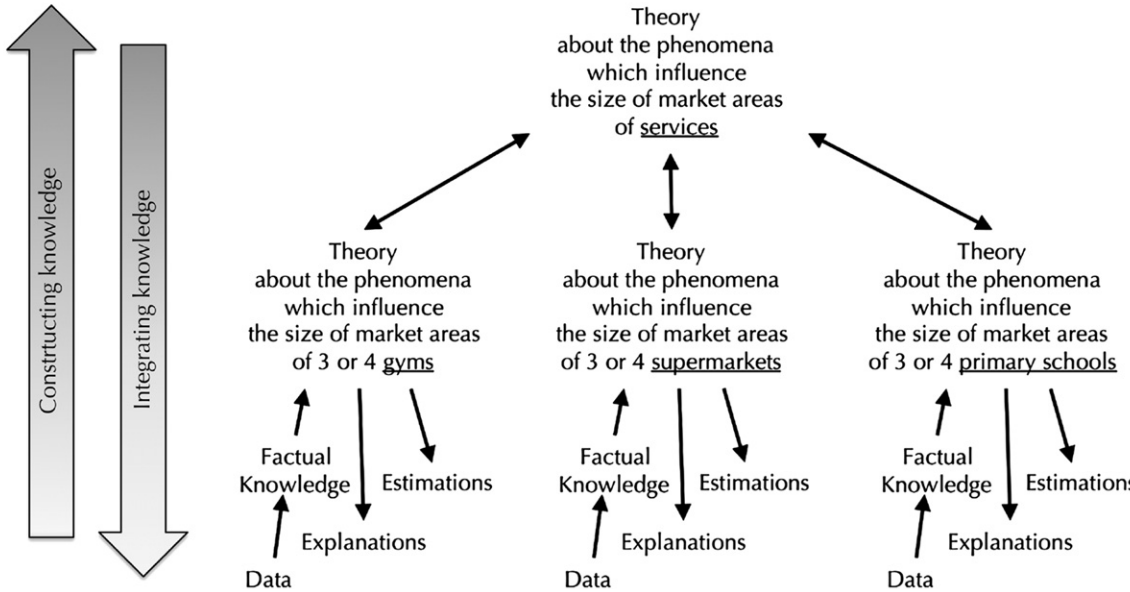


**Fig. 4.** Model for the process in which students develop a theory about the phenomena that influence the size of market areas of services.

### 5.1. The characteristics of an appropriate design

The topic 'Services and Customers' turned out to be very appropriate for a GIS-supported geographic inquiry project, as the distribution of customers and the size of market areas of services is often influenced by a large number of phenomena, and as there are many ways to investigate these relationships. Also, teachers said that they liked the project because it links rather abstract and difficult-to-explain economic-geographic theories to practice.

The learning goals of the GIS-supported geographic inquiry project gradually became more concrete and higher in the course of the design process: they changed to deep geographic learning. Ramsden (1988) correlated deep learning with an internal intention to understand, with a focus on arguments, the structure of knowledge, the relation between theory and practice, and the relation between new knowledge and background knowledge. In the context of the project, deep learning about geographic subjects is seen as follows: students develop a theory about the size of market areas of services that is consistent and practical. In addition, they learn how to construct such a theory, and how to apply the theory to explain their geo-data and other students' geo-data. Students should learn how to think in a structured way about the topic of services and customers. Then, deep learning about geographic inquiry methods is seen as follows: students develop transferable knowledge concerning the characteristics of inquiry strategies which are likely to result in an inquiry with a high domain-specific quality, and they learn to critically evaluate the domain-specific quality of inquiry strategies. The change of the learning goals to deep geographic learning led to discussions in the research team about how to raise students' thinking to a higher level.

### 5.2. The characteristics of a legitimate design

A legitimate design for GIS-supported geographic inquiry projects should be based on, among other things, a good domain-specific construct for use in educational settings. In the course of the design process of the inquiry project 'Services & Customers', the construct became more and more specified. The content part of the construct changed towards a theory expressed in verbal form (a list of generalizations and rules about relationships, see Table 2) and visuo-spatial form (a symbolic representation, see Fig. 5), with a clear distinction between non-spatial relationships (1A–1F) and spatial relationships (2A–2F). The methodological part of the domain-specific construct for use in educational settings changed towards a list of potentially effective inquiry questions and hypotheses, and a list of potentially effective geo-data collection strategies. A distinction was made between spatial questions and non-spatial questions.

In retrospect, the research team concluded that the final construct was consistent and practical. Regarding the consistency, the theory included all relationships that could possibly underly the geo-data, and had a logical structure (i.e. one unit of analysis). Also, the hypotheses, inquiry questions, and geo-data collection strategies were connected to each other, and were connected to the theoretical part of the

**Table 2**
Theory about the size of market areas of services (verbal form).

| *No* | *Generalization* | *Rule* |
|---|---|---|
| 1A | High-quality services generally have a larger market area than low-quality services | The size of market areas (of services) is positively influenced by the quality-level (of those services) |
| 1B | Services that offer good service generally have a larger market area than services that offer bad service | The size of market areas (of services) is positively influenced by the service-level (of those services) |
| 1C | Services with a low price-level generally have a larger market area than services with a high price-level | The size of market areas (of services) is negatively influenced by the price-level (of those services) |
| ID | etc. | etc. |

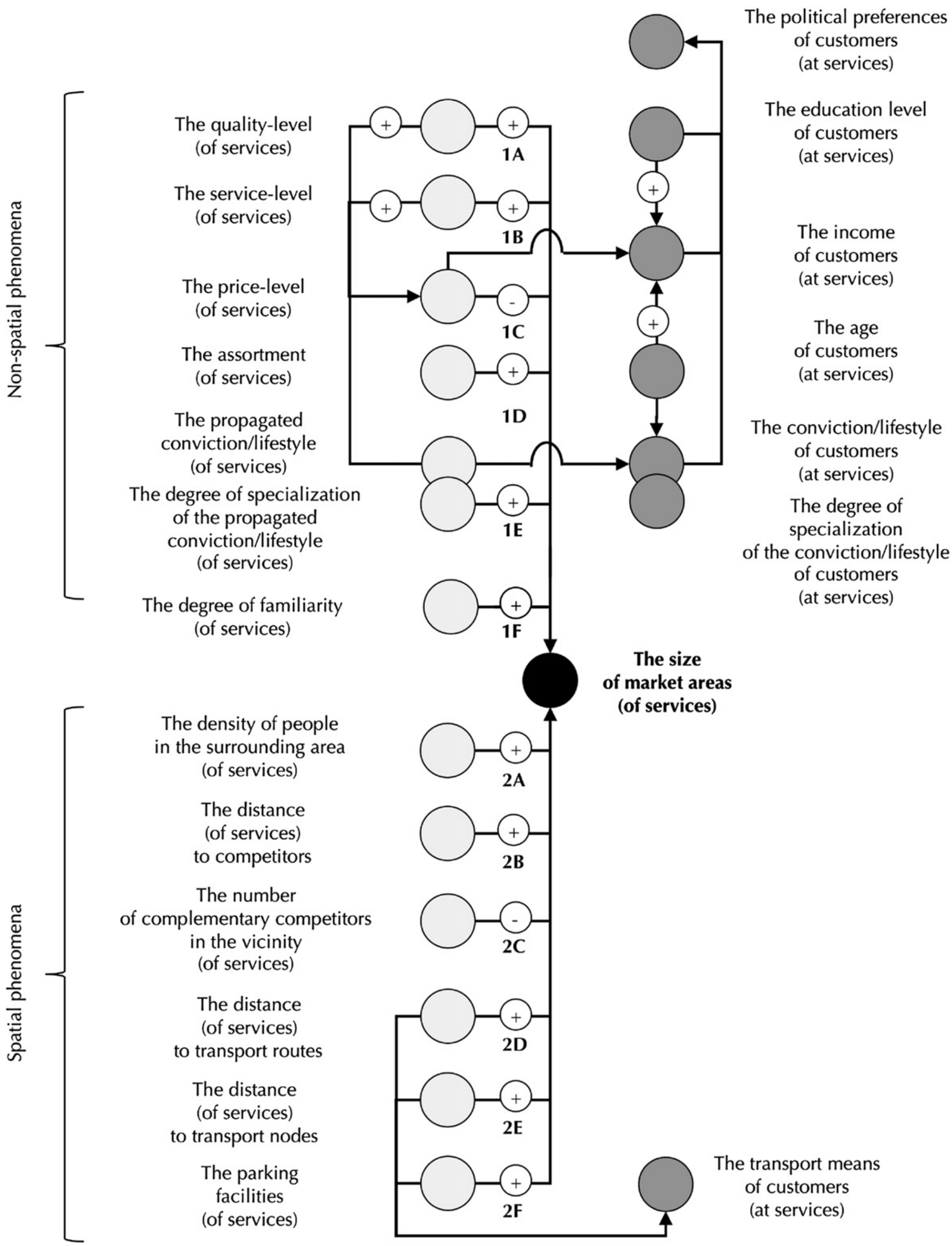


**Fig. 5.** Theory about the size of market areas of services (visuo-spatial form).

construct. Regarding the practicality, the teachers found the theory a useful tool to: (1) design tasks that aim to raise students' geographic thinking to a higher level; (2) to diagnose problems as a result of student learning difficulties when students work on these tasks; and (3) to support students so that they can overcome these problems. It sounds logical that a consistent and practical construct for use in educational settings meets the criteria outlined above. However, this EDR study showed that it should not be assumed that teachers are actually able to develop such constructs easily by themselves. In the EDR study, it took several rounds of designing, testing, and evaluating to develop a good construct.

The methodological part of the domain-specific construct for use in educational settings should consist of a list of potentially effective inquiry questions and hypotheses, and a list of potentially effective geo-data collection strategies. A distinction should be made between spatial questions and non-spatial questions. In this project, spatial questions are questions that are connected to the situation of the services. Also, the hypotheses, the inquiry questions, and the geo-data collection strategies should connect to each other, and should connect to the theory for use in educational settings.

### 5.3. The characteristics of a viable design

During the first cycles of the design process, students often could not perform the tasks as planned when they were working with GIS, and subsequently got stuck. These $\alpha$ problems put a high pressure on the teachers. In the first couple of cycles of the design process, teachers spent almost all their time on supporting students to overcome these problems. Gradually, the research team solved all deficiencies, except for the software-related ones, and learned how to avoid most of the problems as a result of student learning difficulties. As a result, the pressure decreased considerably. By the fifth cycle of the design process, teachers were able to spend half of their time on other things, such as starting one-on-one discussions with students on the geographic content or the domain-specific quality of their inquiry strategy.

So, what was learned from the design process? First, it was discovered that it was useful to let students carry out the whole process from geo-data collection in the field to geo-data entering, manipulating, and aggregating in Excel, and finally geo-data visualizing and analysing in GIS. In this way, students always work with geo-data that is meaningful to them. This makes it easier for them to understand how the GIS operations work. Second, it was learned that the best way to ensure that students visualize all their geo-data without getting stuck was to give them an Excel and GIS handout with a high degree of guidance that consists of step-by-step instructions with worked-out examples. Third, it was learned that the handouts should be absolutely perfect. The tasks should have an appropriate design, and should be free of errors, obscurities, and omissions. Even the smallest and seemingly innocent deficiency is likely to result in students getting stuck. Fourth, it was discovered that it is useful to teach students, in advance, about the difference between map documents and map layers and about the criteria of a proper database table. Some authors (e.g. Johansson, 2006) argue that it is necessary to teach students first *about* GIS before they can engage in learning *with* GIS. However, in this research, it turned out that it was not necessary to teach students extensively about GIS before they started working on their project. Instead, students learn about GIS on the job when they are visualizing and processing their geo-data. Fifth, it was discovered that it was very useful to check whether the geo-data tables in students' Excel files meet the criteria of a proper database table, and to check whether students have entered, manipulated, and aggregated all their geo-data. In doing so, many problems can be avoided in the GIS phase, especially those that are difficult to diagnose and overcome. Sixth, it was discovered that it is essential to instruct students clearly that they should read the handouts carefully and follow them right to the end. In the test stages, many $\alpha$ problems occurred because of careless reading of the step-by-step instructions in the handouts, or because students decided to go their own way and stopped following the handout. Students need to work precisely, otherwise they get stuck. Also, it is essential that teachers provide a lot of structure, give very systematic and precise instruction, and pay attention to all relevant components of the design.

### 5.4. The characteristics of an effective design

The videodata of and products constructed by the students (inquiry plans, presentations, and reports) provided some insight into students' learning processes, and the factors that hampered students' learning. During the data analysis, it turned out that students' learning still was often less-than-intended. As these $\beta$ problems threatened the effectiveness of the project, the research team explored how they could be avoided or overcome. The overall conclusion was, that in order to increase the effectiveness of the project, it is necessary to offer a considerable amount of guidance, otherwise students are likely to conduct an inquiry with a low domain-specific quality, and spend most of their time on superficial details, and do not engage in deep geographic learning. The most important outcomes are discussed below.

One of the most important $\beta$ problems was that students often did not know how to construct inquiry plans because they had little idea of what they were expected to do, and how they could do it. Students had never before carried out a geographic inquiry project in which they had to formulate inquiry questions and hypotheses, formulate a geo-data collection strategy, visualize and process the geo-data in maps, and subsequently answer their inquiry questions. As it was all so new for them, they had to be properly prepared. During the design process, the research team tried out different preparatory tasks. It was discovered that the best way to prepare students is to include a one-hour GIS training session in which students use an Excel file with geo-data of the students of their school in order to construct GIS maps that are similar to the maps they are supposed to construct on the basis of geo-data that is similar to the geo-data they are supposed to collect.

Another important inquiry strategy planning-related $\beta$ problem was that students often constructed inquiry plans with low internal and external validity and a weak spatial perspective. They made illogical selections of services, formulated poor inquiry questions and hypotheses, and/or constructed surveys that contained ill-formulated survey questions or survey questions which were ineffective for testing their hypotheses. Besides this, in their inquiry plans, they included few spatial phenomena, such as the population density in the vicinity of services, the distance of services to competitive services, and the number of complementary competitive services in the vicinity of services. Students were often not aware that the place on earth mattered when they were constructing inquiry plans. In order to avoid these $\beta$ problems, two preparatory assignments were included in the preparation phase. First, an assignment was included in which students learn about the different types of survey questions and the characteristics of correct inquiry questions. Second, an assignment was included in which students investigate maps of the population density, per capita income, and distribution of different kinds of services. Although it was not certain whether these assignments were effective to avoid the $\beta$ problems, they were useful in another way. Teachers often referred back to them later on in the project when students were trying to explain their geo-data.

Another $\beta$ problem was that students rarely reflected on the domain-specific quality of their inquiry strategy by themselves. Including a note in the list of requirements for the presentations and reports that tells them exactly how to reflect helped a little. However, most students still reflected only superficially on the strength of the spatial perspective and the accuracy, reliability, or validity of their inquiry strategy. In the fourth cycle, the teachers engaged in extensive discussions with the students on their inquiry strategy. In order to provide an indication of the effectiveness of these discussions, the discussion sections in the student reports of Cycles III and IV were analysed in more detail. All utterances of reflection were marked and labelled with the help of a coding scheme that contained two dimensions: the type of reflection (17 categories); and the depth of the reflection (3 categories: limited, moderate, and extensive). Then a reflection score was calculated for each type of reflection by counting the utterances of reflection, in which limited reflection counted once, moderate reflection counted twice, and deep reflection counted three times. A comparison of the student reports from the test stages in Cycles III and IV indicated that the discussions resulted in student reports with a higher domain-specific quality: the reflection quality score in Cycle IV was 2½ times higher than in Cycle III. So it can be concluded that it is essential that teachers engage in evaluative discussions with students for the development of transferable inquiry skills.

When students were working with Excel and GIS, it was noticed that they were often more focused on editing the symbology of the map layers than on thinking about the geographic content. Students often spend a considerable amount of time on changing the colours and symbols of the elements in their maps. Teachers should therefore explain that good descriptions and explanations for their geo-data are valued more highly than maps with a perfect layout.

Also, it was noted that students' geographic thinking was often unstructured, incorrect, and limited when they were trying to explain their geo-data. Students often did not make relationships explicit, and frequently used everyday concepts (e.g. "There are more people living there") instead of formal geographic concepts (e.g. "The population density is higher there"). Also, they were often not able to give a correct causal explanation, especially when there were several direct and indirect explanatory factors involved. Next, students often did not explain their geo-data completely and overlooked important factors. Students seemed to overlook spatial factors more frequently than non-spatial factors. For instance, they often ignored the possible influence of differences in the population density and the possible influence of the presence of competitive or complementary competitive services in the vicinity. This shows again that they were often not very aware that the place on earth matters. Another issue was that students were often very focussed on their geo-data. They often tried to find all explanations in their geo-data and did not explore other, non-sampled factors. Also, students' explanations were often not specific enough. Student reports often contained phrases like "It depends on the location", without explaining which properties of the location are important.

One of the other main problems was that students did not know that it is important to choose an appropriate level of analysis and stick to it. Most students changed the level of analysis every now and then. Most students did not realize that, in order to explain the size of the market areas of services, the level of analysis is 'services', and not 'people'. This was a barrier to come to clear reasoning.

Finally, the research team noticed an important difference between analysing maps in atlases and analysing maps in GIS. Atlases contain maps that are constructed with the aim to show relationships. Students can identify relationships at a glance in these maps, without intentionally looking for them. In GIS, however, the extent of the map window, the order of the map layers, and the symbology of the map layers is often far from good for identifying relationships at a glance. Teachers should not hope that students will identify relationships when they are not intentionally looking for them, as this is unlikely to happen. The key to identifying relationships is the generation of a kind of ad hoc and implicit mini-hypotheses. Students need to have a motive. This will drive them to pan and zoom the map, add new map layers, change the order of the map layers, or edit the symbology of the map layers, and check whether a relationship is present or not. Mini-hypotheses may also lead them to apply GIS tools, such as the information tool. However, the fact that students often overlooked relevant factors when they tried to explain their geo-data implies that they did not formulate such mini-hypotheses as often as they should. Furthermore, when students did formulate mini-hypotheses, they often did not use GIS to check them. Instead, they often used their background knowledge about the subject.

In order to help students overcome the geographic thinking-related $\beta$ problems outlined above, and raise students' thinking on the geographic content to a higher level, it was necessary for teachers to engage in discussions with their students. On the basis of the experiences of the design process, we think that that teachers should organize preparatory whole-class discussions at the start of the project, and evaluative whole-class discussions at the end of the project (see Fig. 7) in order to stimulate deeper geographic learning. We also advise teachers to interrupt students now and then when they are working on their inquiry project to talk about the content together. In the preparatory and evaluative whole-class discussions, the teacher and students could construct a theory together. Such whole-class discussions can have different designs. First, they can construct a symbolic representation on the blackboard together. However, this turned out to be a difficult task, for students as well as teachers. Second, the students could fill out a list of generalizations and rules in which the indicators of the direction of the relationships are replaced by 'larger/smaller' and 'positive/negative', or fill out a symbolic representation in which the plus and minus symbols are blanked-out. In both cases, students learn by alternating between knowledge construction (i.e. identifying relationships) and knowledge integration (i.e. using the relationships to explain the size of the market area of individual services), and by alternating between visualizing the theory (i.e. translating generalizations and rules into a symbolic representation) and verbalizing the theory (i.e. translating the symbolic representation into generalizations and rules). During the task, teachers can apply different intervention means to structure, correct, and expand students' geographic thinking: (1) giving feedback; (2) giving hints; (3) instructing; (4) explaining; (5) modelling; and (6) questioning (Van de Pol, Volman, & Beishuizen, 2010). When students' reasoning contains implicit relationships, teachers can stimulate them to make the relationships explicit in the form of generalizations and/or rules by applying interventions such as: "Finish this sentence: the higher A, the … B." The idea of 'dialogical teaching' (Renshaw & Brown, 1998) connects to

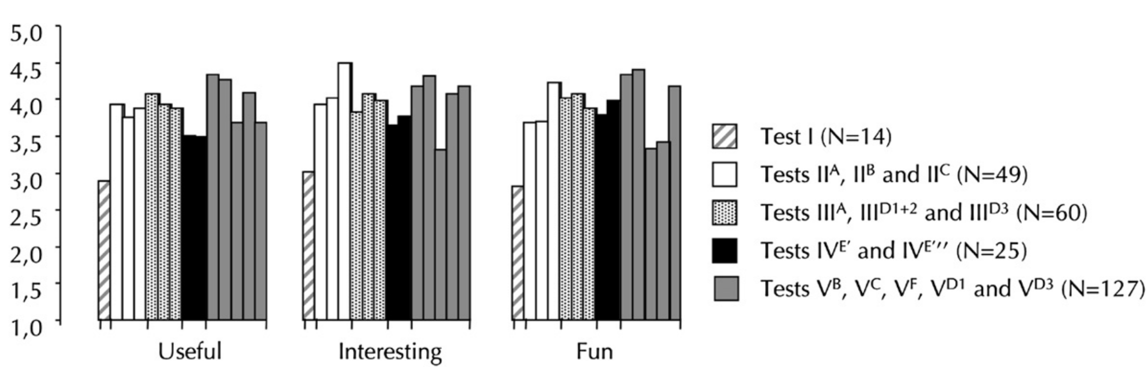


**Fig. 6.** Student opinion about the project.

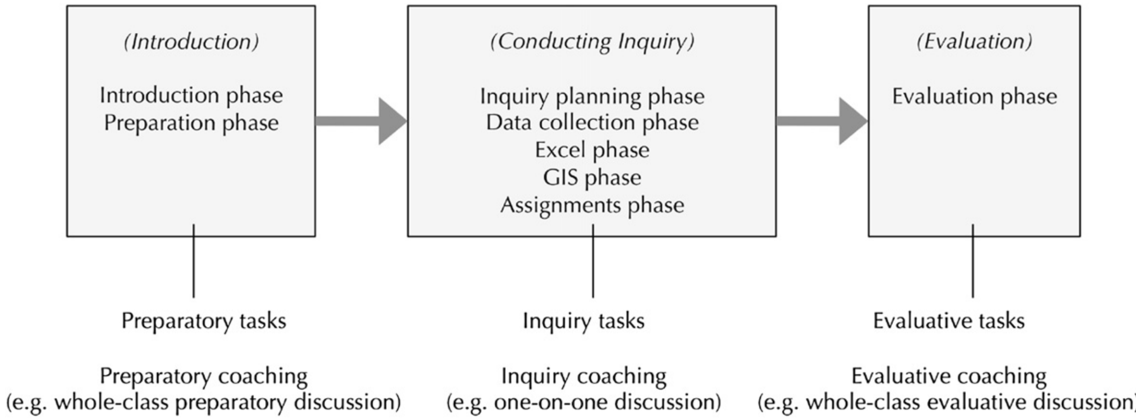


**Fig. 7.** The model for the set-up of GIS-supported geographic inquiry projects.

the kind of teaching outlined above. The importance of discussions for effective learning in geography education is also stressed by the Thinking Through Geography method (Van der Schee, Vankan, & Leat, 2006).

## 6. Evaluation

Besides the videotapes, field notes, mini-interviews, and student products, also a fifth kind of data was collected during the tests. Surveys were conducted among the students immediately after they had received their grades. The surveys contained, among other questions, closed questions about students' opinion of the project. Fig. 6 shows that students' opinion about the project increased considerably between test Cycle I and Cycle II, when the most radical changes were made in the learning goals and set-up of the project. Between these cycles, the project changed from a highly-structured project in which students received standard research questions, to a semi-structured project in which student had to formulate their own inquiry questions, hypotheses, and geo-data collection strategies. The general opinion does not seem to have increased from Cycle II to V, when smaller changes were made in the design of the tasks and coaching strategies. In Cycle V, the items 'useful', 'interesting', and 'fun' scored, respectively, a 4.1, 4.0, and 3.8, on average, on a 1 to 5 scale.

The surveys conducted in Cycle V also contained some open questions, in which students [$N = 127$] were asked to list the positive and negative aspects of the project. This yielded in total 182 positive and 120 negative utterances. The utterances were classified by the first author of this paper. The data showed that students especially liked the project because it was new and different (33 utterances, which is 18 per cent of all positive utterances), and because it allowed them to construct their own maps (22 utterances, which is 12 per cent of all positive utterances). Twenty-eight per cent of the positive utterances were related to the learning process (e.g. "I liked learning how to set up an inquiry by myself"). Regarding the negative aspects of the project, students did not like the strict planning (23 utterances, which is 19 per cent of all negative utterances) and did not like the high workload (19 utterances, which is 16 per cent of all negative utterances). So, in conclusion, students were quit satisfied with the aspects of the project that mattered most for the research team.

At the end of the design process, a survey with closed and open questions was conducted among the teachers [$N = 9$]. The data showed that teachers especially liked the project because it connected the geography of the text books with the geography of the world in which the students live. One teacher noted that: "Students often find it difficult to understand rather abstract theories about market areas and spatial behaviour of customers. This projects makes a connection with the real world, and makes it easier for them to understand such abstract theories."

## 7. Conclusion and discussion

This paper has dealt with innovation at the intersection of technology, pedagogy, and geographic content. In the previous sections, we saw that GIS-supported inquiry-based geography education has the potential to contribute to deep geographic learning in a manner that is different from traditional geography education. This paper therefore underlines the arguments of Baker and White (2003), Kerski (2003), and Sinton and Lund (2007) that GIS has the ability to radically change the way geography is taught in schools, but also underlines their arguments that GIS-supported inquiry-based geography education is a very complex kind of educational innovation issue. Teaching with GIS certainly is a complex kind of teaching. We should therefore raise the following point of discussion: Is it possible to realize optimal GIS-supported inquiry-based geography education, and in such a way raise secondary geography education to a higher level? Yes, we think it is, but that it requires two important actions.

The first action is to provide a proper infrastructure for teachers in terms of software, geo-data, and instruction materials. In this respect, large steps have been made in the Netherlands in the past five years. The most important stimulus to the diffusion of GIS was the development of an Internet portal for secondary education with GIS, called EduGIS (www.edugis.nl). The Internet portal offers a free WebGIS with hundreds of map layers, and several lessons on topics such as spatial planning, water management, and pollution. This WebGIS and the accompanying lessons have been adopted enthusiastically by teachers in the Netherlands, and are integrated in geography books for lower secondary education (Favier, Van der Schee, & Scholten, 2011). However, the WebGIS only offers possibilities to view the digital maps. Especially for the upper levels of secondary education, more tools are required in order to conduct inquiry projects in which students use geo-data collected by themselves in the field, and then visualize and analyse these geo-data in GIS. During the design process, it became clear that professional GIS software is not adapted to the needs of students and teachers, and is too difficult for use in secondary geography education. For this reason, ESRI, which is one of the partners in the EduGIS project, developed an educational GIS software package called

'EduGIS Lokaal' in 2011. The design principles for educational GIS software that were generated during the design process of the GIS-supported geographic inquiry project 'Services & Customers' guided the design of the software package. As well as the improvement of the GIS software and geo-data infrastructure, work should also be done on the instruction materials infrastructure. During the design process, it became clear that the development of good instruction materials for GIS-supported geographic inquiry projects is complex and very time-consuming. It requires many cycles of designing, testing, and evaluating. Therefore, we cannot expect teachers to develop such materials by themselves, and other actors in the field of secondary geography education should help them, or do it for them.

The second action is to train the current and future teacher population. During the design process of the GIS-supported geographic inquiry project 'Services & Customers', it became clear that the teachers found it difficult to coach their students. More teacher training is needed to stimulate the spread and effectiveness of (GIS-supported) inquiry-based geography education. The main line of recent discussions in the literature about what teachers should learn is that teacher training should focus on (Technological) Pedagogical Content Knowledge (e.g. Mitchell, 2011). The experiences of the design process of the GIS-supported geographic inquiry project 'Services & Customers' support the arguments for increased attention to these components of the teacher knowledge basis. The main message of this paper is that teachers should be made aware that stimulating deep geographic learning is a learning goal that is worth pursuing. In traditional education, students often had to listen, for the entire lesson, to a teacher who was telling stories, or to other students who were reading texts. In modern computer education, students now often work on computer assignments for the entire lesson. The most effective form of GIS-supported inquiry-based geography education seems to be a combination of computer tasks and discussions on the geographic content and on geographic inquiry strategies. This implies that teachers should be willing to spend more time on GIS-supported geographic inquiry projects. The statement 'less is more' definitely also applies to teaching with GIS: teaching a few subjects deeply is more worthwhile than teaching a wide range of subjects superficially. It also implies that teachers should be willing to engage more in dialogical teaching with their students, and to construct theoretical knowledge together with their students. This is a difficult task, as it requires teachers to be able to transform their own geographic knowledge, and make it accessible for students.

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