### Table 5-19: The list of primitive key questions (PKQ) (cont.)

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>Example</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1</td>
<td>Question that asks why an entity has a specific property value</td>
<td>“Why does the USA import more than 1 billion barrels of oil from the Middle East?”</td>
<td>Causal explanation</td>
</tr>
<tr>
<td>3-2</td>
<td>Question that asks why a class has a specific property value</td>
<td>“Why are law firms mainly found in Midtown Manhattan?”</td>
<td>Causal explanation</td>
</tr>
<tr>
<td>3-3</td>
<td>(Does not exist)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-4</td>
<td>(Does not exist)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-5</td>
<td>Question that asks why there is a specific relationship between two phenomena</td>
<td>“Why is there a positive relationship between the per capita income (of countries) and the amount of natural resources (in those countries)?”</td>
<td>Interpretation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-1</td>
<td>Question that asks whether it is desirable that an entity has a specific property value</td>
<td>“Is it desirable that the USA imports more than 1 billion barrels of oil from the Middle East?”</td>
<td>Evaluation</td>
</tr>
<tr>
<td>4-2</td>
<td>Question that asks whether it is desirable that a class has a specific property value</td>
<td>“Is it desirable that law firms mainly found in Midtown Manhattan?”</td>
<td>Evaluation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-3</td>
<td>(Does not exist)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-4</td>
<td>(Does not exist)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-5</td>
<td>Question that asks whether it is desirable that there is a specific relationship between two phenomena</td>
<td>“Is it desirable that there is a positive relationship between the per capita income (of countries) and the amount of natural resources (in those countries)?”</td>
<td>(not discussed in this dissertation)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-1</td>
<td>Question that asks how the value of a property of an entity will change in the future</td>
<td>“How will the import of crude oil from the Middle East change in the near future?”</td>
<td>Prediction</td>
</tr>
<tr>
<td>5-2</td>
<td>Question that asks how the value of a property of a class will change in the future</td>
<td>“How will the distribution of law firms in New York change in the future?”</td>
<td>Prediction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-3</td>
<td>(Does not exist)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-4</td>
<td>(Does not exist)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-5</td>
<td>Question that asks how the direction of the correlation, strength of the correlation, and/or direction of the influence of phenomenon upon another phenomenon will change in the future</td>
<td>“How will the direction of the correlation, strength of the correlation, and/or direction of the influence of the amount of natural resources (in countries) and the per capita income (in those countries) change in the future?”</td>
<td>(not discussed in this dissertation)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-1</td>
<td>Question that asks how the value of a property of an entity can be changed</td>
<td>“How can the import of crude oil from the Middle East be reduced?”</td>
<td>Solution to a problem</td>
</tr>
<tr>
<td>6-2</td>
<td>Question that asks how the value of a property of a class can be changed</td>
<td>“How can the distribution of law firms in New York be changed?”</td>
<td>Solution to a problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-3</td>
<td>(Does not exist)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-4</td>
<td>(Does not exist)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-5</td>
<td>Question that asks how the direction of the correlation, strength of the correlation, and/or direction of the influence of phenomenon upon another phenomenon can be changed</td>
<td>“How can the direction of the correlation, strength of the correlation, and/or direction of the influence of the amount of natural resources (in countries) and the per capita income (in those countries) be changed?”</td>
<td>(not discussed in this dissertation)</td>
</tr>
</tbody>
</table>
5.8 Inquiry skills versus inquiry knowledge

In this dissertation, geographic inquiry skills are defined in terms of declarative, procedural, and conditional-strategic knowledge. However, these types of knowledge are defined in a slightly different way from the literature (see Section 2.2). First, declarative knowledge is seen as knowledge that something is the case. Second, procedural knowledge is seen as knowledge about how to perform cognitive or external operations, and why to perform the operations in this specific way. Third, conditional knowledge is seen as knowledge about the conditions under which cognitive or external operations could be applied, and why to apply the operations under these specific conditions. Fourth and finally, strategic knowledge is seen as knowledge about which cognitive or external operations should be applied in order to reach certain aims, and why these operations should be applied, in order to reach these aims. Conditional knowledge and strategic knowledge actually deal with the same thing. However, in conditional knowledge, the operations are central, while, in strategic knowledge, the aims are central.

Note that the declarative knowledge that is part of geographic subject knowledge is different from the declarative knowledge that is part of geographic inquiry skills. For example, knowing that China has 1.3 billion inhabitants, and knowing that a choropleth map is based on attribute data with a number format, are both examples of declarative knowledge. However, the first is part of geographic subject knowledge, while the second is part of geographic inquiry skills.

Declarative, procedural, and conditional-strategic knowledge can have a semantic or episodic form. The previous sections contain descriptions of semantic inquiry knowledge. Episodic knowledge consists of memories about context-bound experiences: declarative episodic knowledge consists of memories that something was the case; procedural episodic knowledge consists of memories about how an operation was performed; conditional episodic knowledge consists of memories about the circumstances under which these operations were performed; and strategic episodic knowledge consists of memories about which operations were performed to reach an aim.

As operations are organized in hierarchies (see Section 5.5.3), the knowledge needed to perform an operation can be described at the level of the operation, or at the level of the sub-operations. See, for example, the knowledge that is needed in order to identify the relationship between the magnitude of the inflow of labour migrants (in provinces) and the wage (in those provinces) in the map about China (see Figure 5-11). In order to be able to identify this relationship, we can say that a student needs to have knowledge about how to perform the operation ‘relating by comparing two generalized distributions’ (Figure 5-13). This is procedural knowledge at the level of the operation. However, we could also say that the student needs to have knowledge about which sub-operations are needed (strategic knowledge at the level of the sub-operations), and knowledge about how to perform these sub-operations (procedural knowledge at the level of the sub-operations), and be able to hold the verbal or visuospatial knowledge about the world around us that forms the input and output of sub-operations temporarily in his or her working memory (declarative knowledge that is part of geographic subject knowledge). Following the definitions outlined above, and the notion that operations are organized in hierarchies, it can be concluded that the term ‘inquiry skills’ can easily be replaced by ‘procedural inquiry knowledge’, when seen at the level of operations, or ‘a
combination of declarative, procedural, and strategic inquiry knowledge, plus declarative subject knowledge’, when seen at the level of sub-operations.

The elaborated model for GIS-supported geographic inquiry can be valuable for teachers who want to support students in their geographic thinking. It may help teachers to identify problems, and to shape support so that students are able to overcome these problems. For example, there can be a number of different reasons to explain why a student is not able to identify the relationship in the map about China. First, it could be that the student does not know that he or she should first generalize the spatial-property distribution in the magnitude of the inflow of seasonal labour migrants and the spatial-property distribution in the wages, then compare the mental maps of the two generalized distributions, then convert the comparison to a generalization, and finally convert the generalization to a rule (lack of strategic knowledge). Second, it could be that the student does not know how to generalize distributions, how to compare two mental maps of generalized distributions, how to convert comparisons to generalizations, and how to convert generalizations to rules (lack of procedural knowledge). Third and finally, it could be that the student is not able to hold the mental map of the generalized distributions, or the comparison, generalization, or β-form rules in his or her working memory. In order to provide contingent support, teachers should be able to diagnose the problem, and shape their interventions accordingly.

The elaborated model also provides some clarity on the nature of skills and strategies. For two reasons, it is better to use the term ‘inquiry knowledge’ than ‘inquiry skills’. First, a skill is not something that people can hold in memory, like an item of semantic or episodic knowledge. Second, it is not correct to say that a skill in applying an operation is equal to the sum of the skills in applying the sub-operations of the operation, as this totally overlooks the importance of declarative and strategic inquiry knowledge, and the importance of the ability to hold the geographic subject knowledge that forms the input and output of the sub-operations temporarily in working memory. For these two reasons, from now on, the term ‘inquiry skill’ is no longer used in this dissertation. In addition, it should be noted that it is not correct to say that people possess a strategy. Instead, it is better to say that people possess strategic knowledge. For this reason, the term ‘strategy’ is from now on only used for a sequence of operations that can be applied in order to reach a specific aim, and not for something that can be present, or not, in human memory.

The elaborated model for GIS-supported geographic inquiry also provides more clarity on the nature of schemas. In this dissertation, schemas are seen as chunks of declarative, procedural, and conditional/strategic knowledge that are needed to perform complex operations. If students possess schemas for complex operations, they will be able to perform the operations without too much effort. It can then be said that the students possess procedural knowledge on the level of the operations. There will be no need to recall individual items of declarative, procedural, and conditional/strategic geographic inquiry knowledge on the level of the sub-operations from long-term memory; no need to hold verbal or visuospatial knowledge about the world around us in working memory; and no need to process these knowledge items consciously.
5.9 The term ‘geographic’ in geographic inquiry

Now we have elaborated the model for GIS-supported geographic inquiry, the question may arise what is so typically geographic about the GIS-supported geographic inquiry? In this dissertation, geographic inquiry is considered to be a generic kind of inquiry that is applied in the domain of geography. There are four characteristics of geographic inquiry that makes it typically geographic. Now follows a short description of these characteristics.

The first characteristic is the geographic focus. Geographers study the characteristics, functioning, and problems of the world around us. They thereby focus on natural phenomena, human phenomena, and relationships between these phenomena at geographic scales, which are scales ranging from the size of a grain of sand to the size of the entire Earth.

The second characteristic is the geospatial reference system. Geographers study geospatially-referenced objects, events, places, lines, regions, and fields. Geographers collect and process geodata and use geodata-based representations. The geospatial reference system is a reference system that is connected to the Earth or a part of the Earth. Notice that a spatial reference system is not necessarily a geospatial reference system. For example, biologists use the body of a person as a reference system when they study that person’s blood vessels. In this case, the specific location of that human body on earth does not matter in their studies. However, biologists do use a geospatial reference system when they engage in ecological research. In this case, the specific location on earth does matter in their studies.

The third characteristic is the spatial perspective. Geographers frequently formulate spatial primitive key questions (see Section 5.7), frequently apply spatial key operations (see Section 5.5), and frequently use spatial key concepts (see Section 5.4.3) when they engage in inquiry. For example, geographers often take the spatial context into account when they study regions. This means that they explain the properties of regions with spatial relationships, which are relationships in which at least one of the properties is connected to a spatial key concept. As questions are the motor behind the geographic inquiry process, stimulating students to formulate spatial primitive key questions is the key to making students’ inquiry more geographic. It should be noted that biologists, physicists, economists, etc. also sometimes formulate spatial key questions. However, geographers do so very frequently.

The fourth and final characteristic is the geographic vocabulary. Geographers have specific terms for specific types of geospatial entities, such as ‘suburb’, ‘floodplain’, and ‘market area’. They also have specific terms for specific properties, such as ‘population density’, ‘Human Development Index’, and ‘climate type’.
6 A student-competency framework

Now that we have learned about the nature of GIS-supported geographic inquiry, we can have a look at the competencies that are key to GIS-supported inquiry-based geography learning for students. Table 6-1 shows the student-competency framework for GIS-supported inquiry-based geography learning that was developed in the theoretical part of the PhD research. The student-competency framework has a matrix structure: the vertical axis shows the six domains of operations in the model for GIS-supported geographic inquiry (see Figure 3-1); the horizontal axis shows the dimensions ‘geographic subject knowledge’, ‘geographic inquiry knowledge’, and ‘geographic inquiry motivation’. Geographic subject knowledge consists of declarative knowledge, while geographic inquiry knowledge consists of declarative, procedural, and strategic knowledge.

6.1 Competencies in Domain A

Questions are the motor behind the geographic inquiry process. In order to study the structure and functioning of the world around us, or to study problems in the world around us, students should be able to formulate good geographic questions. This requires, among other things, declarative inquiry knowledge about the characteristics of good and clear geographic questions, and knowledge about the characteristics of coherent and logical sequences of sub-questions. Students should also know how to formulate good and clear geographic questions (procedural inquiry knowledge). Besides this, they should know which questions are useful to study the characteristics, functioning, or problems of the world around us, and the best way to sequence these questions (strategic inquiry knowledge). Furthermore, they should be aware of the importance of formulating spatial primitive key questions for conducting good geographic inquiry (strategic inquiry knowledge). When students use GIS in open or semi-guided inquiry, they should also know what kind of primitive key questions can be answered with GIS (strategic inquiry knowledge).
Table 6.1: The student-competency framework for GIS-supported inquiry-based geography learning

<table>
<thead>
<tr>
<th>Geogr. subject knowl.</th>
<th>Geogr. inquiry knowl.</th>
<th>Procedural knowledge</th>
<th>Strategic knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong> Asking geographic questions</td>
<td>• geographic questions</td>
<td>• knowledge about the characteristics of good questions&lt;br&gt;• knowledge about the different types of geographic key questions</td>
<td>• knowledge about how to formulate questions</td>
</tr>
<tr>
<td><strong>Ba</strong> Collecting geo-data</td>
<td></td>
<td>• knowledge about how to collect geo-data</td>
<td></td>
</tr>
<tr>
<td><strong>Bb</strong> Collecting external representations</td>
<td>• knowledge about the characteristics of external visuospatial representations about the world around us</td>
<td>• knowledge about how to select external visuospatial representations about the world around us</td>
<td>• knowledge about which external visuospatial representations about the world around us should be selected in order to answer primitive key questions</td>
</tr>
<tr>
<td><strong>C</strong> Visualizing geo-data</td>
<td>• knowledge about the characteristics of geo-data&lt;br&gt;• knowledge about the characteristics of external visuospatial representations about the world around us&lt;br&gt;• knowledge about the relationship between geo-data and external visuospatial representations about the world around us</td>
<td>• knowledge about how to apply (analogue and computer-supported) geo-data visualization operations</td>
<td>• knowledge about which (analogue and computer-supported) geo-data visualization operations should be applied in order to construct external representations which show the answers to primitive key questions</td>
</tr>
<tr>
<td><strong>Da</strong> Cognitive knowledge processing</td>
<td>• geographic definitions</td>
<td>• knowledge about how to apply cognitive knowledge processing operations</td>
<td>• knowledge about which cognitive knowledge processing operations should be applied in order to answer primitive key questions</td>
</tr>
<tr>
<td><strong>Db</strong> External geo-data processing</td>
<td>• geographic definitions&lt;br&gt;• knowledge about the characteristics of geo-data&lt;br&gt;• knowledge about the characteristics of external visuospatial representations about the world around us&lt;br&gt;• knowledge about which geo-data manipulation, reading, querying, summarizing, analysis, and creation (via exporting) operations should be applied in order to answer primitive key questions</td>
<td>• knowledge about how to apply (analogue and computer-supported) geo-data manipulation, reading, querying, summarizing, analysis, and creation operations</td>
<td></td>
</tr>
<tr>
<td><strong>E</strong> Answering geographic questions</td>
<td>• answers to geographic questions&lt;br&gt;• knowledge about the characteristics of good answers to geographic questions</td>
<td>• knowledge about how to organize knowledge into answers to geographic questions</td>
<td>• knowledge about which knowledge should be organized in order to answer geographic questions</td>
</tr>
<tr>
<td><strong>F</strong> Presenting the results of inquiry</td>
<td>• knowledge about the characteristics of a good presentation or report</td>
<td>• knowledge about how to construct a good presentation or report</td>
<td>• knowledge about the elements which should be included in a presentation or report</td>
</tr>
</tbody>
</table>

Notes: The motivation dimension is not included in the table in order to save space.
The inquiry project described in the Preface is used to illustrate the knowledge that students need in the different domains. The student, Myrthe, wanted to investigate 'something that has to do with playgrounds'. By herself, she formulated the question: “Is the distribution of playgrounds fair?” This is a good question for geographic inquiry on this topic. Myrthe was aware that this was an evaluative question (presence of declarative knowledge). With a little support from the teacher, Myrthe decided to compare two neighbourhoods. After some thinking, Myrthe formulated three sub-questions: (I) “Why are there so many playgrounds in the Schildersbuurt neighbourhood?”; (II) “Where do children play in the Schildersbuurt neighbourhood and the Bezuidenhout neighbourhood?”; and (III) “Are there enough playgrounds?” Although these questions are good geographic questions in themselves (presence of declarative inquiry knowledge), they are not very relevant for answering the main question, and do not show a logical order (absence of strategic inquiry knowledge). Furthermore, the third sub-question might be difficult to answer and is therefore not very viable. It would have been better if Myrthe had formulated sub-questions such as: “What are the differences in the number of playgrounds per child between the Schildersbuurt and the Bezuidenhout neighbourhoods?”; and “Which factors can explain these differences?” She could have answered the first question by selecting the playgrounds and selecting the children in the two neighbourhoods, opening the attribute table, and reading the total number of selected elements. However, Myrthe was probably not aware that such questions could be answered with GIS (absence of strategic inquiry knowledge).

6.2 Competencies in Domain B

Domain B is about acquiring geographic resources. The domain consists of three sub-domains: (Ba) acquiring geodata; (Bb) acquiring sources of geographic information about the world around us; and (Bc) acquiring other geographic resources.

Sub-domain Ba is about acquiring geodata. Geodata can be collected in the field by conducting surveys, taking photos, or carrying out simple measurements. Geodata can also be downloaded from a geoportal (a website that allows the user to download thematic geodata per neighbourhood, municipality, province, or country) or be constructed by digitizing external representations. In order to acquire geodata in the right way, students should have some knowledge about the characteristics of geodata in general. This is general declarative inquiry knowledge in Domain Ba.

Domain Bb is about acquiring sources of geographic information: selecting a map in an atlas; searching for a map layer in a WebGIS; searching the Internet for a specific article or policy report; etc. In order to acquire the right geodata-based external representation, students should have declarative knowledge about the characteristics of geodata-based external representations. This includes knowledge about the different map types, the characteristics of maps in general (scale, coordinate system, projection), and the name and function of map elements (title, legend, scale bar, etc.). This is the general declarative knowledge in Domain Bb.

Besides this general declarative knowledge, there is also specific declarative knowledge. This includes knowledge about the location of a specific source of information, for example, knowledge about the page in the atlas where a specific map can be found, knowledge about where specific geodata can be found on a geoportal, and knowledge about the directory on the computer where a specific digital map layer can be found. It also includes knowledge about the
content at meta-level of available sources of geographic information. What does the map show? What information does the website provide? What is the content of the data file?

The procedural knowledge in Domain Ba consists of knowledge about how to collect geodata in the field. This knowledge includes, for example, knowledge about how to formulate good survey questions, and knowledge about how to measure the air temperature with a thermometer in the right way. The criteria ‘accuracy’ and ‘reliability’ are connected to this knowledge. Students should also know how to select, or search for, geodata-based external representations about the world around us. This includes, for example, knowledge about how to use the index in an atlas to find a map, how to find geodata in a geoportal and download this geodata, and how to search the computer for a digital map layer and how to add this map layer in GIS. This is procedural knowledge in Domain Bb.

The strategic knowledge in Domain Ba consists of knowledge about which geodata should be collected to answer specific primitive key questions. It is knowledge about which geodata are needed to answer a question, and knowledge about which is the best method to collect geodata required. This connects to the criterion ‘validity’. The strategic knowledge in Domain Bb consists of knowledge about which sources of geographic information could be useful in order to answer a primitive key question.

In the inquiry project described in the Preface, Myrthe constructed maps of the distribution of playgrounds and the distribution of children in The Hague by herself. She searched the database for useful map layers and added these map layers in ArcGIS. This shows that she possessed the required procedural and strategic knowledge. She could have used the geoportal of the Municipality of The Hague too. This geoportal contained some interesting geodata for inquiry on the topic ‘playgrounds’, such as geodata about the average size of gardens per inhabitant, the density of children, and participation in sports clubs per sub-neighbourhood. Myrthe did not use this geodata, probably because she was not aware that this geodata was available (insufficient specific declarative knowledge).

6.3 Competencies in Domain C

The declarative knowledge in Domain C, ‘visualizing geodata’, consists of the same declarative knowledge as in Domain B, supplemented with knowledge about the relationship between the characteristics of geodata and the characteristics of geodata-based external representations about the world around us. The latter includes knowledge about the connection between the format of attribute geodata and the different types of symbology. It includes, for example, knowledge that quantities map layers are based on attribute geodata with a ratio scale and a number format and that categories map layers are based on geodata with a nominal scale and a text format. It also includes knowledge about the characteristics of a geodata table in an Excel file that can be used to construct GIS maps. The structure of such a file should meet the criteria of a proper database table, otherwise it cannot be used in GIS. Besides this general knowledge, the declarative knowledge also consists of more specific knowledge. This includes, for example, knowledge about whether a specific geodata table in an Excel file meets the criteria of proper database table.

The procedural knowledge in Domain C consists of knowledge about how to apply analogue or computer-supported geodata visualization operations. This includes, for example, knowledge
about how to enter geodata in Excel, how to construct point map layers on the basis of an Excel file with XY geodata, and how to join an Excel file with geocodes to a map layer in GIS. It also includes knowledge about how to change the cartographic display (the extent, scale, and projection of the map; the order of the map layers; and the symbology, labelling, and transparency of each map layer). This is, for example, knowledge about how to construct graduated symbols quantities map layers or graduated colours quantities map layers.

Strategic geodata visualization knowledge consists of knowledge about which geodata visualization operations should be performed in order to construct geodata-based external representations that show the answers to specific kinds of primitive key questions. It includes, for example, knowledge that one needs to use the display XY geodata tool or the join tool to visualize geodata tables in Excel files. It also includes knowledge about what kind of symbology is best to show the answer to a specific kind of primitive key question, for example, whether the geodata should be visualized in a graduated symbols quantities map layer, or in a graduated colours quantities map layer.

In the inquiry project described in the Preface, Myrthe constructed a GIS map that showed the differences in the distribution of playgrounds and children between two neighbourhoods in The Hague. She first selected the Schildersbuurt neighbourhood, then selected the playgrounds and children in that neighbourhood, and finally created new map layers that showed the selected elements only. Myrthe repeated the procedure for the Bezuidenhout neighbourhood. Next, she changed the symbology of the map layers in such a way that the differences between the two neighbourhoods became more pronounced (see Figure 0-1). This shows that she possessed the necessary procedural and strategic knowledge in Domain C.

### 6.4 Competencies in Domain D

Domain D is subdivided into: (Domain Da) the cognitive developing and processing of knowledge about the world around us in human memory; and (Domain Db) the external processing of geodata. We will first focus on Domain Da.

Geographic subject knowledge consists of (integrated) mental representations about the world around us, and (integrated) bodies of verbal knowledge about the world around us, while declarative inquiry knowledge consists of knowledge about the meaning of geographic definitions (see Section 5.4). The procedural inquiry knowledge consists of knowledge about how to perform the different cognitive knowledge developing and processing operations (see Section 5.5): how to perceive and assign meaning to stimuli; how to construct knowledge; how to translate knowledge, how to integrate knowledge; how to memorize knowledge; and how to recall knowledge. The strategic inquiry knowledge consists of knowledge about which cognitive knowledge developing and processing operations should be applied in order to answer a primitive key question. Myrthe’s first sub-question, “Why are there so many playgrounds in the Schildersbuurt neighbourhood?”, is an example of an explanatory primitive key question. Myrthe answered the sub-question by integrating several facts about the characteristics of the Schildersbuurt neighbourhood and several rules. However, she did not make the rules explicit. Instead, she just argued: “The Schildersbuurt neighbourhood has a lot of playgrounds because the population density is very high (lots of 4-storey flats), and there are many children, especially because there are many Turkish and Moroccan people living there. In addition, most houses have no garden, so children have to go to the playgrounds if they want
to play” Myrthe’s second question, “Where do children play in the Schildersbuurt neighbourhood?”, is an example of a descriptive primitive key question. Myrthe answered this question with the help of her maps. By applying operations such as ‘describing patterns’ and ‘describing the situation in space’, she discovered that the playgrounds are more or less evenly distributed over the Schildersbuurt neighbourhood, and that most playgrounds are situated in squares. This showed that Myrthe possessed the necessary declarative, procedural, and strategic knowledge in Domain Da to answer her inquiry questions.

Domain Db refers to the external processing of geodata with analogue or computer-supported techniques. The declarative inquiry knowledge consists of knowledge about the characteristics of geodata and geodata-based external representations about the world around us, and knowledge about the meaning of geographic definitions. This knowledge is also part of, respectively, the declarative inquiry knowledge in Domain C, and Domain Da. The procedural inquiry knowledge is knowledge about how to apply external geodata processing operations (see Section 5.6). It is, for example, knowledge about how to fill out the menus of GIS tools in a correct way. Strategic geodata processing knowledge consists of knowledge about which GIS tools should be applied in order to answer primitive key questions. In the inquiry project described in the Preface, Myrthe constructed a map that showed the answers to her inquiry questions. She could have answered her inquiry questions in a more quantitative way too, by selecting the children and playgrounds in each of the two neighbourhoods (with the select-by-situation tool), opening the attribute tables of the map layers, and reading the number of selected playgrounds and the number of selected children. However, she did not do so, possibly because she didn’t know how to apply these GIS tools (insufficient procedural inquiry knowledge in Domain Db), or because she didn’t know which GIS tools to apply, and in which order to apply these tools (insufficient strategic inquiry knowledge in Domain Db).

6.5 Competencies in Domain E

Domain E is about organizing answers to primitive key questions in an answer to a main question. This requires students to weight the importance of different knowledge. Although Myrthe’s sub-questions are not very relevant for answering her main inquiry question “Is the distribution of playgrounds fair?”, Mythe was able to answer her question. In her report, she argued “There are much more playgrounds in the neighbourhood ‘Schildersbuurt’ than in the neighbourhood ‘Bezuidenhout’. But still we can see that the distribution is fair. This is because there are also much more children in the neighbourhood ‘Schildersbuurt’.

6.6 Competencies in Domain F

Finally, Domain F is about presenting the results of geographic inquiry. It is about constructing good layouts, constructing good presentations, and writing good reports.
7 A teacher-competency framework

This chapter presents the teacher-competency framework for GIS-supported inquiry-based geography teaching that was developed in the theoretical part of the PhD research. The framework is based on the TPCK framework (see Section 2.3). The original TPCK framework was: (1) specified for inquiry-based teaching; (2) elaborated in the sense that the knowledge in the seven components was described in terms of declarative, procedural, and strategic knowledge; (3) expanded by adding a motivation dimension; and (4) specified for the discipline of geography.

This dissertation focuses on inquiry-based education in which students actively work on the computer. The technology is therefore part of the learning goals and learning output, although this is not always made explicit. Teachers should have enough knowledge to design good inquiry projects, and to coach students in an optimal way when the inquiry projects are conducted in classroom settings. Figure 7-1 explains the meaning of the knowledge in the different components of the TPCK framework when the framework is specified for inquiry-based teaching.

Figure 7-1: The TPCK framework, specified for inquiry-based teaching

<table>
<thead>
<tr>
<th>TK</th>
<th>Technological Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>PK</td>
<td>Pedagogical Knowledge</td>
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<tr>
<td>CK</td>
<td>Content Knowledge</td>
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<tr>
<td>TPK</td>
<td>Technological Pedagogical Knowledge</td>
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<tr>
<td>TCK</td>
<td>Technological Content Knowledge</td>
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<tr>
<td>PCK</td>
<td>Pedagogical Content Knowledge</td>
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<tr>
<td>TPCK</td>
<td>Technological Pedagogical Content Knowledge</td>
</tr>
</tbody>
</table>
Knowledge in the **TK component** refers to the knowledge that is needed for engaging in technology-supported domain-general inquiry. For example, when a teacher constructs a database of students’ marks in Excel, this can be seen as engaging in technology-supported domain-general inquiry. The knowledge in the TK component then consists of knowledge about the characteristics of a consistent database (declarative knowledge); knowledge about how to enter formulas in Excel (procedural knowledge); and knowledge about which formula should be used to calculate average scores per student (strategic knowledge).

Knowledge in the **PK component** refers to the knowledge that is needed for teaching in general. It is, for example, knowledge about the factors that influence students’ motivation to do their homework (declarative knowledge); knowledge about how to motivate students to do their homework (procedural knowledge); and knowledge about which interventions are effective in particular circumstances (strategic knowledge).

Then, knowledge in the **CK component** refers to the knowledge that is needed for engaging in inquiry in a specific domain. Geography teachers should be geographically literate themselves. First, they should have sufficient geographic subject knowledge. For example, they should understand Ullman’s interaction law, which says that flows of people only occur when the conditions of complementarity, transferability, and absence of intervening opportunities are met. This is declarative knowledge. In addition, teachers should have sufficient geographic inquiry knowledge. They should know, for example, how professional geographers evaluate the suitability of sites for new supermarkets. They should be able to conduct such inquiry projects, and perhaps use Ullman’s interaction law to select the best site. This geographic inquiry knowledge consists of declarative, procedural, and strategic knowledge (see also Section 5.9 and Chapter 6).

Knowledge in the **TPK component** refers to the knowledge that is needed to engage in technology-supported inquiry-based teaching that is not connected to a specific domain. An example of such domain-general inquiry teaching is teaching students to construct graphs in Excel. In this dissertation, the TPK component is subdivided into three sub-components. The first sub-component is called ‘learning goals for technology-supported inquiry knowledge’. Teachers should have knowledge about the characteristics of appropriate learning goals for technology-supported inquiry. Learning goals should be concrete. Also, they should be within the zone of proximal development of students: high but attainable. The second sub-component is ‘technology-supported inquiry knowledge for use in educational settings’. The declarative knowledge in this sub-component consists of technological knowledge that is structured and transformed so that it becomes accessible for students. It is, for example, a technological construct for use in educational settings about how formulas work in Excel. The procedural knowledge in this sub-component consists of knowledge about how to structure and transform technological knowledge into such technological constructs for use in educational settings, and the strategic knowledge consists of knowledge about which constructs should be used to reach a specific learning goal. The third and final sub-component of the TPK component is called ‘technology-supported inquiry tasks, coaching, and student learning processes’. The declarative knowledge in this sub-component consists of knowledge about the characteristics of student learning processes in relation to the design of technology-supported domain-general inquiry tasks, and in relation to the design of coaching that accompanies these tasks. This includes knowledge about the nature of problems that can occur as a result of technological learning difficulties. It is, for example, knowledge that students often copy cells with formulas in Excel.
without changing the references. Learning difficulties, in turn, are related to insufficient geographic subject knowledge, geographic inquiry knowledge, and/or geographic inquiry motivation in one or more domains of the student-competency framework. The procedural knowledge in the sub-component ‘technology-supported inquiry tasks, coaching, and student learning processes’ refers to knowledge about how to design technology-supported domain-general inquiry tasks, and how to shape coaching interventions when students work on these tasks. This includes knowledge about how to prepare students in order to avoid problems caused by technological learning difficulties before the inquiry project; how to support students in order to ensure that they can overcome such problems during the inquiry project; and how to stimulate students to reflect on what was learned after the inquiry project. Finally, the strategic knowledge in this sub-component refers to the knowledge about what kind of technology-supported domain-general inquiry tasks are suitable in a specific situation, and what kind of coaching interventions should be applied in a specific situation.

Knowledge in the TCK component refers to the knowledge that is needed to engage in technology-supported inquiry in a domain. GIS is often used in geographic inquiry. Geography teachers should know how to use GIS to answer geographic questions. For example, they should know how to use GIS to evaluate the suitability of sites for new supermarkets. In order to do so, teachers should have a knowledge about the characteristics of geodata and geodata-based external representations about the world around us, and knowledge about the structure of GIS (declarative knowledge). Also, they should know how to apply GIS operations (procedural knowledge), and know which sequences of operations should be applied in order to evaluate the suitability of sites (strategic knowledge).

Knowledge in the PCK component refers to the knowledge that is needed for inquiry-based teaching within a domain. This component is also subdivided into three sub-components. The first sub-component is called ‘learning goals for domain-specific subject knowledge and domain-specific inquiry knowledge’. This sub-component refers to learning goals for the relevant subjects and relevant inquiry methods in a domain. The second sub-component is ‘domain-specific subject knowledge and domain-specific inquiry knowledge for use in educational settings’. The declarative knowledge in this sub-component consists of knowledge about the relevant subjects and relevant inquiry methods in a domain that is structured and transformed so that it becomes accessible for students. It is, for example, a construct for use in educational settings about Ullman’s interaction law, or a construct for use in educational settings about appropriate inquiry questions for student inquiry projects in which students evaluate the suitability of sites for new supermarkets. Other kinds of domain-specific constructs for use in educational settings are theories expressed in symbolic representations and in formal geographic language (see Figure 5-7, Table 5-14, and Table 5-13), and models of operations (for examples, see Figure 5-10, Figure 5-12, and Figure 5-13). The procedural knowledge consists of knowledge about how to structure and transform domain-specific knowledge to domain-specific constructs for use in educational settings. This includes knowledge about how to develop theories in the form of symbolic representations or in the form of list of generalizations and rules. It also includes knowledge about how to analyse an operation and subdivide it into series of sub-operations and identify the in-between products, which are the input and output of the sub-operations. The strategic knowledge consists of knowledge about which construct for use in educational settings is suitable for a specific learning goal. The third sub-component of the PCK component is called ‘domain-specific inquiry tasks, coaching, and student learning processes’. The declarative knowledge in this sub-component consists of
knowledge about how students learn in relation to the design of domain-specific inquiry tasks, and in relation to the design of coaching that accompanies these tasks. This includes knowledge about the nature of problems that can occur as a result of domain-specific learning difficulties. It is for example knowledge about problems caused by the learning difficulty that students often find it difficult to understand the meaning of the concepts ‘range’ and ‘market area’. The procedural knowledge in this sub-component refers to knowledge about how to design domain-specific inquiry tasks, and how to coach students when these tasks are conducted in classroom settings. Again, we can say that teachers should know how to prepare students in order to avoid problems caused by domain-specific learning difficulties, how to support students in order to ensure that they can overcome such problems, and how to stimulate students to reflect on what was learned from the inquiry project. Finally, the strategic knowledge in this sub-component refers to the knowledge about what kind of domain-specific inquiry tasks are suitable in a specific situation, and what kind of preparation, support, and reflection interventions should be applied in a specific situation.

Knowledge in the TPCK component refers to the knowledge that is needed for technology-supported inquiry-based teaching in a domain. It is for example knowledge about how to design an geographic inquiry project in which students use GIS to learn about the phenomena that influence the suitability of sites for new supermarkets. This component can also be subdivided into three sub-components. The first sub-component is ‘learning goals for technology-supported domain-specific inquiry knowledge’. This sub-component refers to learning goals for the relevant technology-supported inquiry methods in a domain. The second sub-component is ‘technology-supported domain-specific inquiry knowledge for use in educational settings’. The declarative knowledge in the second sub-component refers to technology-supported inquiry methods knowledge that is structured and transformed so that it becomes accessible for students. It is, for example, a construct for use in educational settings about data collection strategies that students can use to investigate the suitability of sites for new supermarkets with GIS. The procedural and strategic knowledge consists of, respectively, knowledge about how to develop such constructs and knowledge about what kind of constructs are suitable in specific situations. The third sub-component is called ‘technology-supported domain-specific inquiry tasks, coaching and student learning processes’. The declarative knowledge in this sub-component consists of knowledge about the characteristics of students’ learning processes in relation to the design of technology-supported domain-specific inquiry tasks, and in relation to the coaching provided by the teacher. This includes knowledge about the nature of problems as a result of learning difficulties that occur when students work on technology-supported domain-specific inquiry tasks. It is, for example, knowledge that students rarely switch irrelevant map layers off when they work with GIS. This obstructs the clarity of the Map View, and makes it more difficult for them to identify relationships. The procedural and strategic knowledge can be described in the same way as the procedural and strategic knowledge in the third sub-component of the TPK and PCK components.

In summary, we have seen that, in this dissertation, the TPK, PCK, and TPCK components are subdivided into three sub-components: (I) learning goals; (II) knowledge for use in educational settings; and (III) inquiry tasks, coaching, and student learning processes. This is because these components are at the interplay of the PK component, which has two sub-components, and the TK and CK components, which have one sub-component (Figure 7-2).
Figure 7-2: The sub-components of the TPCK framework, specified for inquiry-based teaching

**Sub-component I**
- **PK-I**: domain-general learning goals
- **TPK-I**: learning goals for technology-supported inquiry knowledge
- **PCK-I**: learning goals for domain-specific subject knowledge and domain-specific inquiry knowledge
- **TPCK-I**: learning goals for technology-supported domain-specific inquiry knowledge

**Sub-component II**
- **TK-II**: technology-supported domain-general inquiry knowledge
- **CK-II**: domain-specific subject knowledge and domain-specific inquiry knowledge
- **TPK-II**: technology-supported inquiry knowledge for use in educational settings
- **TCK-II**: technology-supported domain-specific inquiry knowledge
- **PCK-II**: domain-specific subject knowledge for use in educational settings, and domain-specific inquiry knowledge for use in educational settings
- **TPCK-II**: technology-supported domain-specific inquiry knowledge for use in educational settings

**Sub-component III**
- **PK-III**: domain-general tasks, coaching, and student learning processes
- **TPK-III**: technology-supported inquiry tasks, coaching, and student learning processes
- **PCK-III**: domain-specific inquiry tasks, coaching, and student learning processes
- **TPCK-III**: technology-supported domain-specific inquiry tasks, coaching, and student learning processes
The question is: What is the difference between the elaborated framework and Shulman’s (1986) PCK framework and Mishra & Koehler’s (2006) TPCK framework outlined in Section 2.2? First, the framework presented in this dissertation includes the static kind of knowledge (Shulman, 1986), as well as the dynamic kind of knowledge (Mason, 1999). Second, the framework presented in this dissertation is more elaborated and shows a high degree of structure. The knowledge in the TPK and TPCK components is subdivided into the same way as the knowledge in the knowledge in the PCK component. The first sub-component, ‘learning goals’, is not distinguished by Shulman (1986). The second sub-component, ‘knowledge for use in educational settings’, is comparable with the sub-component ‘domain knowledge that is transformed so that it becomes accessible for students’ in Shulman’s (1986) PCK framework. The third sub-component of the TPK, PCK, and TPCK components refers to the characteristics of students’ learning processes in relation to the design of inquiry tasks, and in relation to the design of coaching. This is somewhat broader than the sub-component ‘knowledge about common student preconceptions and common student learning difficulties’ in Shulman’s (1986) PCK framework.

In order to teach geography successfully with GIS, teachers should have declarative, procedural, and strategic knowledge in every component of the TPCK framework. The components that contain a ‘C’ should then be specified: CK then becomes Geo-CK; TCK then becomes GIS-TCK; PCK then becomes Geo-PCK; and TPCK then becomes GIS-TPCK (Figure 7-3).

The TPCK framework focuses on knowledge only. However, motivation also plays an important role in designing technology-supported geographic inquiry projects, and in coaching students when they engage in technology-supported inquiry. For example, regarding the second sub-component of the PCK component, teachers should not only have domain-specific constructs for use in educational settings in their minds (declarative knowledge), know how to develop such constructs (procedural knowledge), and know what kind of constructs are suitable for specific learning goals (strategic knowledge) but should also be willing to develop such constructs (motivation). Regarding the third sub-component, teachers should not only know which problems as a result of learning difficulties occur frequently when students work on domain-specific inquiry tasks (declarative knowledge), know how to support students so that they can overcome these problems (procedural knowledge), and know what kind of support interventions should be applied in order to overcome these problems (strategic knowledge), but should also be willing to spend considerable time on supporting students (motivation). The same applies to the other components in the TPCK framework. For this reason, the TPCK framework was expanded with a motivation dimension, and an ‘M’ was added to every component (Figure 7-3).
Chapter 7: A teacher-competency framework

Figure 7-3: The TPCK framework, expanded with a motivation dimension and specified for GIS-supported inquiry-based teaching

- **Technological Knowledge & Motivation**
  - the knowledge and motivation that is needed for engaging in technology-supported domain-general inquiry
    - technology-supported inquiry knowledge

- **Pedagogical Knowledge & Motivation**
  - the knowledge and motivation that is needed for teaching in general
    - domain-general learning goals
    - domain-general tasks, coaching, and student learning processes

- **Content Knowledge & Motivation**
  - the knowledge and motivation that is needed for engaging in domain-specific inquiry
    - domain-specific subject knowledge and domain-specific inquiry knowledge

- **Technological Pedagogical Knowledge & Motivation**
  - the knowledge and motivation that is needed for technology-supported domain-general inquiry-based teaching
    - learning goals for technology-supported inquiry knowledge
    - technology-supported inquiry knowledge for use in educational settings
    - technology-supported inquiry tasks, coaching, and student learning processes

- **Technological Content Knowledge & Motivation**
  - the knowledge and motivation that is needed for engaging in technological-supported domain-specific inquiry
    - technology-supported domain-specific inquiry knowledge

- **Pedagogical Content Knowledge & Motivation**
  - the knowledge and motivation that is needed for domain-specific inquiry-based teaching
    - learning goals for domain-specific subject knowledge and domain-specific inquiry knowledge
    - domain-specific subject knowledge for use in educational settings, and domain-specific inquiry knowledge for use in educational settings
    - domain-specific inquiry tasks, coaching, and student learning processes

- **Technological Pedagogical Content Knowledge**
  - the knowledge and motivation that is needed for technology-supported domain-specific inquiry teaching
    - learning goals for domain-specific technological inquiry
    - domain-specific technological inquiry knowledge for use in educational settings
    - technology-supported domain-specific inquiry tasks, coaching, and student learning processes
Similar to the student-competency framework, we can say that teachers need to have knowledge and motivation in the different components of the teacher-competency framework in order to design and conduct GIS-supported geographic inquiry projects, but that engaging in GIS-supported inquiry-based geography teaching also results in progression in knowledge and motivation in the different components of the teacher-competency framework. A large-scale study by Kirschner and Davis (2003) suggested the need for a considerable deepening of teachers’ understanding and application of ICT before progress can be made in developing knowledge about how to teach with ICT. This implies that teachers need to have TCK before they can develop TPCK. It seems logical to suggest that such prerequisites also apply for the other components in the TPCK framework, and not only for the declarative, procedural, and strategic knowledge dimensions, but also for the motivation dimension. This means that knowledge and motivation in the single components (CK&M, TK&M, and PK&M) is a prerequisite for progression in knowledge and motivation in the double components (PCK&M, TCK&M, and TPK&M). In turn, knowledge and motivation in the double components are a prerequisite for progression in knowledge and motivation in the triple component (TPCK&M).
8 Summary and Discussion

8.1 Summary

This section summarizes the three main outputs of the theoretical part of the PhD research: (1) the model for GIS-supported geographic inquiry; (2) the student-competency framework for GIS-supported inquiry-based geography learning; and (3) the teacher-competency framework for GIS-supported inquiry-based geography teaching.

8.1.1 The model for GIS-supported geographic inquiry

The geographic inquiry process can be seen as a cyclical process for studying the characteristics, functioning, or problems of the world around us in a geographic way. The process consists of six domains of operations (A to F in Figure 8-1). Engaging in inquiry may stimulate progression in one’s geographic subject knowledge, geographic inquiry knowledge, and geographic inquiry motivation, but geographic subject knowledge, geographic inquiry knowledge, and geographic inquiry motivation are also a prerequisite for engaging in geographic inquiry. So geographic literacy and geographic drive are an input as well as output of (GIS-supported) inquiry-based geography education.

Figure 8-1: The model for GIS-supported geographic inquiry

Notes: I = internal operations; E = (largely) external operations.
The first domain (A in Figure 8-1) refers to asking geographic questions. Questions are the motor behind the geographic inquiry process. The five key questions of geography are: (1) descriptive questions; (2) explanatory questions; (3) predictive questions; (4) evaluative questions; and (5) problem solving questions. The question is: What is so typically geographic about these questions? Geographers frequently formulate questions about the properties of (classes of) georeferenced objects and events or geospatial entities such as places and regions. If these questions are connected to spatial key concepts, such as location (“Where is the supermarket located?”), situation in space (“Where is the supermarket situated in respect to other supermarkets?”), situation in a spatial network (“How is the accessibility of the supermarket by car?”) and spatial distribution (“What is the distribution of customers of the supermarket?”), these questions can be seen as typically geographic. Questions can often be subdivided into sub-questions. Primitive questions are questions that cannot be subdivided any further.

The second domain (B in Figure 8-1) refers to collecting geodata and collecting external representations about the world around us. Collecting geodata in the field is often seen as an important and intrinsic part of doing geography. Nowadays, geodata are also offered by governmental institutes (e.g. the National Census offices) via web-based geodata portals. Geographers frequently use geospatial external representations, such as maps, when they study or communicate about the world around us.

The third domain (C in Figure 8-1) refers to visualizing geodata in external representations about the world around us. This can be done with analogue techniques (pen and paper) or with computer techniques (GIS). The latter are often much faster, flexible and accurate.

The fourth domain (D in Figure 8-1) consists of two sub-domains. The first sub-domain refers to the cognitive developing and processing of knowledge about the world around us in human memory. There are seven main categories of cognitive information developing and processing operations: (1) perceiving stimuli; (2) assigning meaning to stimuli; (3) constructing knowledge; (4) integrating knowledge; (5) translating knowledge; (6) memorizing knowledge; and (7) recalling knowledge. These operations can be performed on auditive or visual stimuli from the world around us or auditive or visual stimuli from external representations about the world around us, or (integrated) knowledge about the world around us. They result in new or adapted (integrated) knowledge about the world around us. There are two main types of knowledge about the world around us: mental representations about the world around us; and verbal knowledge about the world around us. Five types of primitive bodies of verbal knowledge can be distinguished: (1) facts, which are bodies of verbal knowledge about the properties of entities; (2) generalizations, which are bodies of verbal knowledge about the properties of classes; (3) hierarchic definitions, which are bodies of verbal knowledge about the position of entities and classes in hierarchies; (4) taxonomic definitions, which are bodies of verbal knowledge about the position of entities and classes in taxonomies; and (5) rules, which are bodies of verbal knowledge about relationships between phenomena. These primitive bodies of verbal knowledge are the smallest pieces of knowledge about the world around us. They cannot be further subdivided. Primitive bodies of verbal knowledge about the world around us can be combined in combined knowledge, or integrated in comparisons, interpretations, causal explanations, causal descriptions, predictions, evaluations, solutions to problems, or estimations. The structure of (combined/integrated) bodies of verbal knowledge about the world around us can have a specific format (see Section 5.4). This can be seen as the geographic