describing the characteristics and functioning of the world around us. From now on, the term ‘key concept’ will only be used for this kind of concept.

The lists of key thinking skills also show many differences. Most of them contain predominantly cognitive operations that can be applied to construct new bodies of verbal knowledge about the world around us (e.g. ‘describing conditions’, ‘describing patterns’, ‘regionalizing’, ‘comparing’, and ‘aggregating’), but there are large differences in the thinking skills that are distinguished. Some lists include operations that should actually be seen as activities, as they involve a combination of external operations and cognitive operations (e.g. ‘way finding’ and ‘sketch mapping’). Jo’s (2007) list contains operations that should actually be seen as possessing subject knowledge (e.g. ‘comprehending spatial hierarchies’ and ‘comprehending frames of spatial references’). Among the most consistent lists is that of Gersmehl and Gersmehl (2006). This list almost exclusively contains operations that can be applied to construct new bodies of verbal knowledge about the world around us. Interestingly, none of the lists includes mental representation transformation operations such as ‘performing mental rotations’ and ‘performing mental displacements’, which can be seen as typical spatial thinking skills.

Lists of key concepts and lists of thinking skills are often used to shape the geography curricula. For example, the UK National Geography Standards are based on the QCA key concepts. The six geographic thinking skills distinguished by Ankoné and Van der Vaart (2007, p.48) are an important component of the Dutch National Geography Standards.

It is clear that the literature shows a lack of consensus about which concepts and which thinking skills are key to geography. Golledge, Marsh, and Battersby (2008, p.89) argued that: “What apparently is needed to improve our understanding of geospatial concepts is more intensive investigation of the nature of spatial knowledge in general, and knowledge about the world around us in particular”; and that “understanding the nature of geospatial thinking […] is still much of a terra incognita”. Another problem is that the list of concepts and thinking skills do not form a consistent whole: it is not clear how the operations can be applied on the world around us, on external representations about the world around us, or on knowledge about the world around us in human memory; and it is not clear how these operations can result in new or adapted knowledge. Gersmehl and Gersmehl (2006, p.6) argued that: “Despite years of effort in writing educational standards, the discipline of geography has not yet produced a coherent list of spatial thinking skills.”

2.1.6 Human cognition

In order to construct a model for GIS-supported geographic inquiry, it is also necessary to know something about how knowledge is processed in human memory in general. This sub-section discusses the literature about human cognition that can be useful to construct a model for GIS-supported geographic inquiry.

According to accepted cognitive theories, the human memory is divided into the sensory memory, the working memory, and the long-term memory. The sensory memory is directly linked to a person’s senses. It captures incoming stimuli, for example, spoken texts that are heard by the ears and written texts, photos, or maps which are seen through a person’s eyes. These perceived stimuli are usually held only for a fraction of a second in sensory memory. When people focus attention on these stimuli and assign meaning to them, they enter working
memory and the stimuli become knowledge. This process has internal and external aspects: the characteristics of the stimuli and the characteristics of the person who perceives the stimuli determine how the knowledge is constructed. Working memory is seen as a system that allows someone to hold or temporarily store knowledge, and to perform operations on this knowledge (Baddeley & Hitch, 1974; Daneman & Carpenter, 1980; Miyake & Shah, 1999). The working memory is used to perform cognitive tasks. Most tasks require the involvement of both the storage component and the processing component. The working memory is assumed to have limited resources that must be shared between maintaining knowledge (the storage part of the task) and processing knowledge (the processing part of the task). Working memory is capable of storing only about seven items at the same time when there is no demand on the processing component (Miller, 1956). When working memory is also used to process knowledge, humans are probably only able to store two or three items of knowledge simultaneously (Sweller, Van Merriënboer, & Paas, 1998). The load imposed by holding and cognitive processing of knowledge in working memory is called the cognitive load. Students’ capacity for holding and cognitive processing of knowledge is limited. If the cognitive demands (the intended cognitive processing) exceed the cognitive capacity, students face a cognitive overload. Duff and Logie (2001) argue that the processing component is not the critical factor for performing a task well. Instead, the effectiveness of the knowledge processing depends on how tight the system of holding or temporarily storing and processing of this knowledge is. A tight system leaves little need to maintain attention on knowledge. It also leaves little need to rehearse operations, as the results of an operation are not lost from the temporary store (Barrouillet, Bernadin, & Camos, 2004; Conlin, Gathercole, & Adams, 2005; Friedman & Miyake, 2004; Lépine, Barrouillet, & Camos, 2005). Knowledge can be memorized and stored in long-term memory. This system has a virtually unlimited capacity for storing knowledge. When people recall knowledge that has been stored long ago, it enters working memory again. Prior knowledge (in long-term memory) and expectations determine how people make sense of perceived stimuli in sensory memory (Olson & Bialystok, 1983). In short: people often see what they expect to see. MacEachren (1995) showed that researchers are more likely to interpret visual evidence that supports their beliefs than to interpret visual knowledge that contrasts with their beliefs. Furthermore, the questions that people ask themselves determine the processing of knowledge in human memory.

The question is: What form has knowledge in working memory and long-term memory? According to schema theory (Anderson, 1977), knowledge is stored in long-term memory in the form of schemas. A schema categorizes knowledge according to the manner in which they will be used. When reading a text, people can derive knowledge from the text because they have schemas that allow them to categorize letters, words and combinations of words. When reading a map, people can derive meaning from the map because they have schemas that allow them to identify the categorized symbols and derive meaning to those symbols.

Knowledge can be processed either automatically or consciously (Schneider & Schriffin, 1977). Conscious processing occurs when people have not yet developed schemas. It takes place in working memory. Practice results in the development of schemas and an increase of automaticity. With sufficient practice, sequences of operations can be carried out with minimal effort, and therefore minimal cognitive load. Experienced problem solvers in a specific domain can hold more knowledge because a schema counts as one element. So the more elaborate a schema, the more knowledge can be held in working memory. Automatization of operations can therefore free working memory for other activities (Sweller et al., 1998).
According to Paivio’s (1971) dual coding model, knowledge in long-term memory can have a visuospatial form or a verbal form. This assumption has been supported by considerable evidence. Baddeley and Hitch’s (1974) working memory model is based on the assumption that there are two channels for processing incoming stimuli: one for processing incoming visual stimuli (written texts, photos, maps, cross-sections, graphs, schematic drawings, etc.); and one for processing incoming auditory stimuli (spoken texts, sounds, etc.). The visual and auditory stimuli can be seen as sources of information, which can become, respectively, visuospatial knowledge and verbal knowledge when meaning is assigned to them. This process is guided by the visuospatial and verbal knowledge in working memory and long-term memory, and by the questions people ask themselves.

Baddeley and Hitch’s (1974) model of working memory distinguishes two components for holding knowledge: one for holding verbal knowledge; and one for holding visuospatial knowledge. The first component is called the phonological loop; the second is called the visuospatial sketchpad. Besides these two components, the model also distinguishes an attentional controller or central executive that directs the holding and processing of the knowledge. It also directs the translating of verbal knowledge into visuospatial knowledge and the translating of visuospatial knowledge into verbal knowledge. The processing of incoming stimuli in human memory is not a solitary one-way process. Instead, it is part of a perceptual cycle (Neisser, 1976) or the empirical cycle (Van Eijck, 1984).

All literature discussed in this section was used to construct the model for GIS-supported geographic inquiry. Now that we have had a look at this literature, we are ready to have a look at the literature that was used to construct a student-competency framework for GIS-supported inquiry-based geography learning. This literature is discussed in the next section.

2.2 Literature for constructing a student-competency framework

This section reviews the literature that can be useful for constructing a student-competency framework for GIS-supported inquiry-based geography learning.

The term ‘competency’ is a bit fuzzy (Delamare le Deist & Winterton, 2005). The literature shows a wide range of explanations of the term. On the basis of an extensive literature review, Van Merriënboer, Klik, and Hendriks (2002) concluded that the term ‘competency’ is best defined as “The ability to act adequately on the basis of a coherent structure of knowledge, skills, (professional) attitudes and personal characteristics”. In this dissertation, the focus is on the knowledge, skills, and motivation components (see the definition of geographic literacy and geographic drive in Section 1.1.1).

Competencies can also be described in terms of declarative knowledge, procedural knowledge, and conditional knowledge (Paris, Lipson, & Wixon, 1983). According to Paris et al., declarative knowledge is “knowing that” or “knowing about”. Procedural knowledge is “knowing how to”. Finally, conditional knowledge, is “knowing when and why”. Other authors define conditional knowledge in a slightly different way. For example, Ruddell (1994, p.417) defines conditional knowledge as “the ability to apply various operations strategically”. Woolfolk (1998) defines conditional knowledge as follows: “Conditional knowledge addresses when and why to use declarative and procedural knowledge.”
Competencies can be systematically arranged in what are called competency frameworks (Schubert & Uphues, 2009). Student-competency frameworks should describe the relevant competencies in such a way that they can be turned to tasks and measured in tests. In Chapter 6, the model for GIS-supported geographic inquiry and the three types of knowledge distinguished by Paris et al. (1983) are used to construct a student-competency framework for GIS-supported inquiry-based geography learning. The next section describes the literature that was used to construct the teacher-competency framework for GIS-supported inquiry-based geography teaching.

2.3 Literature for constructing a teacher-competency framework

This section reviews the literature that can be useful for constructing a teacher-competency framework for GIS-supported inquiry-based geography teaching. One of the barriers to the diffusion of GIS in secondary geography education is teachers’ limited knowledge about how to teach geography with GIS. The question is: What knowledge do geography teachers need in order to be able to teach successfully with GIS? In the past two decades, the concept ‘PCK’ has become an accepted framework to describe the knowledge that teachers use and need to teach specific domain knowledge (Berry, Loughran, & Van Driel, 2008). First, teachers need to have general Pedagogical Knowledge (PK). This includes, among other things, “knowledge about the processes and practices or methods of teaching and learning and how it encompasses, among other things, overall educational purposes, values and aims” (Mishra & Koehler, 2006, p.1025). This is a domain-general kind of knowledge. Second, teachers need to have disciplinary knowledge, also called Content Knowledge (CK). Every discipline has its own core of central ideas, concepts, and methods that teachers need to be fluent with if they wish to teach their students. However, just adding PK and CK together does not make a teacher. Teachers need to know how to teach the specific subject knowledge and specific inquiry methods knowledge of a domain. Shulman (1986) introduced the term ‘Pedagogical Content Knowledge’, abbreviated to PCK, to refer to the knowledge that exists at the intersection of PK and CK (Figure 2-4). There is now a shared understanding in the educational research literature that teachers’ PCK is an important determinant of the quality of instruction, and thus an important determinant of the learning outcomes of instruction (Baumert, Kunter, Blum, Brunner, & Voss et al., 2010). Teachers need to have sufficient PCK in order to be able to select or design good representations for the subject matter to be taught, select or design appropriate tasks, diagnose student learning difficulties, and facilitate effective whole-class discussions (Ball, Lubienski, & Mewborn, 2001).
According to Shulman (1986), teachers’ knowledge in the PCK component consists of two sub-components. The first sub-component is ‘domain knowledge that is transformed so that it becomes accessible for students’; the second subcomponent is ‘knowledge about common student preconceptions and common student learning difficulties’.

Although the PCK framework has become an accepted framework since its introduction by Shulman, educational researchers conceptualize PCK in different ways (Van Driel & Berry, 2010). Almost all educational researchers adopted the two key elements of PCK identified by Shulman (1986), but some include more components in the definition. Lee and Luft (2008) and Park and Oliver (2007) have presented overviews of the definitions and use of the concept of PCK in the literature. Mason (1999) emphasized the dynamic nature of PCK. Rather than representing PCK as a fixed and static knowledge that teachers may have or not have, he perceived PCK to be the ability to combine knowledge and skills in a domain with teaching. The static kind of PCK is needed to conduct existing educational modules, while the dynamic kind is needed to design new educational modules.

Successful teaching with technology requires the teacher not only to have PK, CK, and PCK, but also general technological knowledge (TK) and knowledge about how to teach with technology in general (TPK). TK includes knowledge about how to use standard software tools such as word processing software, spreadsheet software, file management software and the Internet, and knowledge about how to install software on the computer. TPK includes knowledge about how to teach with such software tools. Some technology-supported methods are typical for a certain domain. In order to teach a subject, teachers should have knowledge about how the technology could be used to gain subject knowledge in that domain (TCK). Teachers should also have knowledge about how to use the technology in their lessons so that it stimulates progression in students’ knowledge and skills in that domain. The latter kind of knowledge is knowledge at the intersection of technological knowledge, disciplinary knowledge, and pedagogical knowledge (Figure 2-5), and is called ‘Technological Pedagogical Content Knowledge (TPCK)’ (Mishra & Koehler, 2006). This knowledge is different from the knowledge about a disciplinary expert, a technology expert, or an expert in pedagogy. The authors of the TPCK framework emphasized that TPCK is very context-bound: it varies, among other things, per student (depending on the grade level, background knowledge, learning style, etc.).

Source: Shulman (1986).
It must be noted that the teacher knowledge base should not be seen as a collection of individual bodies of PK, CK, TK, TPK, TCK, PCK, and TPCK. Instead, it is a consistent whole of semantic knowledge and episodic knowledge. Teachers develop their knowledge base by reflecting on their experiences from teaching practice, and linking it with semantic input. The TPCK framework only offers a possibility to describe the teacher knowledge base in a systematic way.

The TPCK framework can be specified for different disciplines. In Chapter 7, the framework is specified for the discipline of geography.

### 2.4 Literature for designing and conducting GIS-supported geographic inquiry projects

This section discusses some other educational literature that can be useful for designing and conducting GIS-supported geographic inquiry projects that aim to stimulate progression in students’ geographic literacy and geographic drive. In this dissertation, we are interested in the question how teachers can bring about a shift in students’ thinking from everyday reasoning to more formal geographic reasoning. Section 2.4.1 discusses the relevant literature on this topic. We are also interested in the question how teachers can create an environment in which deep geographic learning is possible. Deep learning focuses on understanding rather than remembering. Some of the literature about deep learning is discussed in Section 2.4.2. An important aspect of inquiry-based geography education is that students develop their own knowledge about the functioning of the geographic system in the form of a theory. In secondary science education, such theories are often called ‘models’, and the activity in which students construct operation models is called ‘modelling’. Section 2.4.3 gives some more information about modelling. Finally, it is also useful to have a look at some literature about scaffolding (see Section 2.4.4), as the literature about scaffolding may provide a framework for analysing and shaping coaching interventions in the classroom.
2.4.1 Everyday reasoning and scientific reasoning

Vygotsky (1987) argued that learning within a discipline does not simply imply that scientific reasoning (using scientific concepts, cultural language, and higher mental functions) replaces students’ everyday reasoning (using everyday concepts, spontaneous language, and elementary mental functions). Scientific concepts presented to children in general and abstract terms without connection to their concrete, empirical, and personal experience often remain empty. On the other hand, everyday concepts remain limited in their application and generality without being connected to more systematized concepts (Renshaw & Brown, 2007). Although it is difficult to specify the distinction between the terms ‘everyday’ and ‘scientific’ (Zach, 1999), there is evidence (e.g. Lampert, 1990; Tharp & Gallimore, 1988) that progress in students’ understanding involves the integration of students’ everyday experiences with scientific concepts, cultural language, and higher mental functions. Thus, the education of children requires the creation of social contexts of thinking, where everyday and scientific reasoning is brought together (Kozulin, 1990). According to Vygotsky, the relationship between ‘talking’ and ‘thinking’ is fundamental to the development of a scientific way of reasoning. Vygotsky argued that understanding emerges through social interaction and dialogue. Of particular significance is the process of intertwining everyday reasoning and scientific reasoning (John-Steiner, Wardekker, & Mahn, 1998). Intertwining is regarded as a dynamic and interactive process that occurs as students and teachers engage in a classroom talk. In such discussions, everyday concepts and scientific concepts are brought together, the spontaneous and the cultural languages are connected and the elementary mental functions and higher mental functions are linked.

In the practical part of the PhD research, it was explored how teachers could engage in one-on-one discussions and whole-class discussions with students in order to bring about a shift from everyday reasoning to more formal geographic reasoning.

2.4.2 Retention and transfer

Two of the most important educational goals are to promote retention and to promote transfer (Mayer, 2002). Retention is the process that results in the ability to store knowledge and procedures in long-term memory, so it will be available later in the same way as it was presented during the learning. Transfer is the process that results in the ability to use knowledge and skills learned in particular contexts to solve problems and answer questions in new and unfamiliar contexts. In short, retention requires students to remember the knowledge and procedures, whereas transfer requires students to remember and to make sense of the knowledge and procedures (Mayer, 2002). Transfer is often differentiated into near transfer and far transfer. Near transfer is the transfer of what has been learned to tasks and settings that resemble the original learning situations. Far transfer is the transfer of what has been learned to tasks and settings that have little similarity with the original learning tasks and settings. Several studies have shown that near transfer is more likely to occur than far transfer, especially when the similarities are rather apparent (Detterman, 1993). Salomon and Perkins (1989) argued that there are two roads to transfer. The low road to transfer refers to the spontaneous and automatic application of skills with little need for reflective thinking. Following the low road, students can develop transferable knowledge and skills by applying the knowledge and practising the skills extensively in various contexts (Dienes & Berry, 1997). The high road to transfer occurs by
mindfull abstraction of knowledge and skills from the context in which they were learned and by application of this knowledge and skills in a new context. There are two kinds of high road transfer: backward and forward transfer (Salomon & Perkins, 1989). Backward-reaching high-road transfer refers to the process in which learned knowledge or skills are deliberately retrieved during the application, while forward-reaching high-road transfer refers to the process in which knowledge or skills are prepared for later spontaneous use in other contexts during the learning. Transferable knowledge and skills are needed for successful problem-solving (Mayer, 2002).

The kind of learning which results in retention is often called rote learning or surface learning while the kind of learning which results in transferable knowledge and skills is often called meaningful learning or deep learning (Mayer, 1999). In deep learning, the student searches actively for meaning and tries to relate it to prior knowledge, experience, and learning, in this way transforming the knowledge gained. Students are aiming towards understanding. Surface learning on the other hand renders the students more passive. Students are mainly aiming to memorize material and to reproduce it accurately at a later stage. There is little attempt to relate it to prior knowledge, experience, or learning, and to transform the knowledge so that it becomes operational (Marton & Säljö, 1976). Mayer (1999) argues that the focus on meaningful learning is consistent with constructivism. In meaningful learning, students make sense of their experiences by engaging in active cognitive processing. In contrast, a focus on rote learning is consistent with a traditional view of learning in which student acquire knowledge by adding new knowledge in their long term-memory.

In the practical part of the PhD study, it was explored what kind of low road, forward reaching high-road and backward-reaching high-road strategies are useful in GIS-supported inquiry-based geography education, and how to shape these strategies in order to stimulate the development of transferable knowledge and skills.

2.4.3 Modelling

Modelling is a form of active, generative learning in which knowledge construction about the functioning of a system is supported by creating external operational models of that system (Forrester, 1994). Löhner (2005) described the modelling process as a cyclic iterative process in which the external model is constantly refined. Students create an external model by translating internal ideas about the components and the relationships between those components to an external model. By investigating the external model, the students may create new internal ideas. The cycles of revisions may lead to increased quality of the internal ideas and increased quality of the external model. Constructing operational computer models (which can be run by the user) does not fall within the scope of geography education. However, constructing symbolic representations of geographic theories can be an interesting and potentially effective way to stimulate progression in students’ knowledge about the functioning of the world around us. Within the context of secondary geography education, modelling can be seen as a progressive iterative process in which students develop symbolic representations of geographic theories by translating their verbal knowledge about the functioning of the world around us (rules), and investigate the symbolic representation to develop verbal knowledge about the functioning of the world around us (rules). In the course of this progressive iterative process, the quality of the symbolic representation, and the quality of the verbal knowledge improves.
In the practical part of the PhD study, it was explored how teachers can design geographic modelling tasks.

### 2.4.4 Scaffolding

*Scaffolding* is an important and frequently studied concept in educational science. However, there is a lot of debate about its conceptualization, appearance, and effectiveness. After a review of the relevant literature, Van de Pol, Volman, and Beishuizen (2010) conclude that scaffolding is generally seen as support given by a teacher to a student when performing a task that the student might otherwise not be able to accomplish. This support should meet three criteria. First, the support interventions should be contingent. It should be responsive and tailored to the current level of the student’s ability. In order to provide contingent support, the teacher should first diagnose the problem. So offering support is a cyclical and iterative process in which teaching processes and learning processes interact with each other. Second, the support should fade in time. Third and finally, there should be a gradual transfer of responsibility to the learner. A distinction is often made between how the support takes place and what is supported. So teacher interventions can be classified along the dimensions ‘intervention means’ and ‘intervention intentions’. Van de Pol et al. (2010) presented a framework for analysing and shaping teacher interventions in the classroom, based upon the intervention means proposed by Tharp and Gallimore (1988) and the intervention intentions proposed by Wood, Bruner, and Ross (1976). The framework shows that different means can be used to achieve different goals. The main categories of intervention means are: (1) giving feedback; (2) giving hints; (3) instructing; (4) explaining; (5) modelling; and (6) questioning. The intervention intentions are: (A) simplification of the task approach; (B) presentation and discussion of general principles; (C) simplification of subject matter; (D) recruitment of students’ interest in the task; and (E) frustration control. It seems as if intentions A and B aim to stimulate progression in students’ skills, and that intention C aims to stimulate the development of students’ knowledge. Intentions D and E focus on students’ motivation.

The application of teacher interventions does not automatically imply the occurrence of scaffolding. For scaffolding to occur, the teacher must apply these strategies contingently and the strategies should fade over time with, as a result, increased student responsibility for the task concerned.

In the practical part of this dissertation, it is explored how Van de Pol et al.’s (2010) framework could be used to design support interventions when students engage in GIS-supported inquiry-based geography learning, and to analyse the support afterwards.
3 A model for GIS-supported geographic inquiry (main outlines)

It is clear from the previous sections that the current literature does not provide a consistent model for GIS-supported geographic inquiry. However, the literature does provide many useful building blocks for constructing such a model. In the theoretical part of the PhD research, a model for GIS-supported geographic inquiry was constructed on the basis of this literature. This model is an adaptation of the model in the US National Geography Standards (National Education Standards Project, 1994, p. 42). First, a distinction was made between: (1) the world around us; (2) geodata; (3) external sources of information about the world around us; and (4) the perceived world around us (in human memory). These are the four cornerstones of the GIS-supported geographic inquiry. Geodata (cornerstone 2) and external sources of information about the world around us (cornerstone 3) can both be seen as geographic resources. Second, a distinction was made between external processing of data with analogue techniques or computer techniques on the one hand, and cognitive developing and processing of geographic knowledge in human memory on the other hand. Third and finally, the activity ‘presenting the result of inquiry’ was added to the model. Following these three changes, the new model for the geographic inquiry process consists of operations in six domains: (A) asking questions; (B) acquiring geographic resources; (C) visualizing geodata; (D) cognitive processing of knowledge about the world around us, and external processing of geodata; (E) answering geographic questions; and (F) presenting the results of geographic inquiry (Figure 3-1).

Figure 3-1: The model for GIS-supported geographic inquiry

Notes: I = internal operations; E = (largely) external operations.
In practice, a cycle of geographic inquiry does not always include operations in all six domains. The external operations in the domains ‘acquiring geographic resources’, visualizing geodata’, ‘external processing of geodata’, and ‘presenting the results of geographic inquiry’ are sometimes skipped. However, a cycle of geographic inquiry always includes internal operations in the domains ‘asking geographic questions’, ‘cognitive developing and processing of knowledge’, and ‘answering geographic questions’. An entire inquiry project can be seen as one cycle of geographic inquiry. However, within this inquiry project, several mini-cycles of geographic inquiry may occur. Such mini-cycles can be very short (e.g. several seconds).

The four cornerstones and the six domains of operations are visualized in Figure 3-2. The figure also contains three other domains of operations that are important in doing geography, but which fall beyond the scope of geographic inquiry: (Domain X): developing and processing feelings about the world around us; (Domain Y) communicating about the world around us; and (Domain Z) changing the world around us.

**Figure 3-2: The cornerstones of GIS-supported geographic inquiry**

**Notes:** I = internal operation; E = (largely) external operation.
Any attempt to define the nature of GIS-supported geographic inquiry should at least imply the acceptance of the following assumptions about the different cornerstones and different domains of operations of doing geography:

**Assumption 1:** The world around us (Cornerstone 1) is the world in which we live. It is characterised by the presence of natural and human phenomena within time and space, and by relationships between these phenomena (see the second and fourth component of Harvey’s definition of geographic understanding, Section 2.1.1).

**Assumption 2:** Geodata (Cornerstone 2) are data about the world around us with one or more geospatial references. Geodata describe the properties of objects, events, and other entities, and data about the values of fields.

**Assumption 3:** External sources of information about the world around us (Cornerstone 3) can be used by people to construct knowledge about the world around us. There are two types of external sources of information about the world around us (Figure 3-3). The first type are geodata-based external representations about the world around us. Examples are: 3D models; maps; cross-sections; and charts. Geographers frequently use maps when they study the characteristics, functioning, or problems of the world around us (see the first component of Harvey’s definition of geographic understanding, Section 2.1.1). The second type are non-geodata-based external representations about the world around us. Examples are: spoken texts; written texts; photos; and videos. When these representations are connected to a location, they can be seen as geodata in itself.

**Assumption 4:** People can have feelings about the world around us, and can store and hold knowledge about the world around us in their memories. Together, the knowledge and feelings form the ‘perceived world around us’ (Cornerstone 4).

**Assumption 5:** People ask questions when they study the characteristics, functioning, and problems of the world around us (Domain A). These questions are the driving forces behind the geographic inquiry process. The formulation of questions is often triggered by a knowledge deficit or knowledge conflict (Logtenberg, Van Boxtel, Van Drie, & Hout-Wolters, 2011), hence the arrow from Domain F (‘presenting the results of geographic inquiry’) to domain A (‘asking questions about the world around us’).

**Assumption 6-1:** People can collect geodata in the field, for example, by performing measurements or conducting surveys. As humans are part of the world around us, data about people’s feelings or knowledge or data about people’s actions can also be seen as geodata. People can also construct data on the basis of external representations about the world around us, for example, by digitizing analogue maps (Domain Ba).

**Assumption 6-2:** People can acquire external sources of information about the world around us from atlases, books, policy reports, the Internet, or otherwise (respectively Domain Bb).

**Assumption 7:** People can visualize geodata in external representations about the world around us (Domain C).

**Assumption 8-1:** People can develop new, or adapt existing, knowledge about the world around us in their memories by perceiving and assigning meaning to stimuli from the world around us directly, or by perceiving and assigning meaning to stimuli from external sources of information about the world around us. They can also process existing knowledge in human memory (Domain Da).
Assumption 8-2: People can process geodata with analogue or computer-supported techniques (Domain Db).

Assumption 9: People can answer questions by organizing their knowledge about the world around us in answers (Domain E).

Assumption 10: People can process feeling about the world around us. They can construct new, or adapt existing, feelings directly, by perceiving and assigning meaning to stimuli from the world around us. They can also construct new, or adapt existing, feelings by perceiving and assigning meaning to stimuli from external sources of information about the world around us (Domain X).

Assumption 11: People can draw, write down, or speak about their feelings and knowledge about the world around us in, for example, schematic external representations, written texts, and spoken texts. In doing so, they can make their feelings and knowledge external, and communicate them to other people (Domain Y). Presenting the results of geographic inquiry (Domain F) is part of communicating about the world around us (Domain Y).

Assumption 12: People can change the world around us with their actions (Domain Z).

Assumption 13: People’s background knowledge, feelings, values and goals determine the questions that they ask themselves. So there should actually be dashed arrows from the perceived world around us to all domains in Figure 3-2.

Assumption 14: As people collect data, visualize data in external representations about the world around us, and process knowledge and feelings about the world around us in different ways, these data, external representations, knowledge, and feelings are always subjective, incomplete, and imperfect.

Assumption 15: People’s actions are guided by people’s personal (subjective, incomplete, and imperfect) knowledge and feelings, and therefore cannot be predicted with a high degree of certainty.

Figure 3-3: The different types of geographic resources

<table>
<thead>
<tr>
<th>Geographic resources</th>
<th>Geodata</th>
<th>Geodata-based external representations about the world around us (e.g. 3D models, maps, charts)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Non-geodata-based external representations about the world around us (e.g. texts, photos, videos)</td>
</tr>
</tbody>
</table>
The 15 assumptions outlined above are a first step in the elaboration of the model for GIS-supported geographic inquiry. However, the assumptions also raise questions about the nature of the cornerstones and domains of operations. Nine questions have to be answered in order to elaborate the model for GIS-supported geographic inquiry: (Research Question I-I) “How can the world around us be characterised?”; (Research Question I-II) “What is the nature of geodata?”; (Research Question I-III) “What is the nature of external representations about the world around us?”; (Research Question I-IV) “What is the nature of knowledge about the world around us in human memory?”; (Research Question I-V) “What is the nature of cognitive developing and processing of knowledge about the world around us?”; (Research Question I-VI) “What is the nature of external processing of geodata?”; (Research Question I-VII) “What is the nature of asking and answering geographic questions?”; (Research Question I-VIII) “How can geographic inquiry skills be explained in terms of declarative, procedural, conditional, and strategic knowledge?”; and (Research Question I-IX) “What makes GIS-supported geographic inquiry so typically geographic?” These questions are the sub-questions of the first research question: “What is the nature of GIS-supported geographic inquiry?” This set of sub-questions is quite complex and not easy to answer. Nevertheless, Chapter 5 tries to answer the nine sub-questions and elaborate the model for GIS-supported geographic inquiry. But first, the next chapter describes the research approach that was used.
4 Intermezzo

The previous chapter described the main outlines of the model for GIS-supported geographic inquiry. However, the model needs to be elaborated and the nature of some of the cornerstones and domains of operations need to be clarified. Most of the sub-questions were answered by reorganizing the insights from the literature. However, sub-question about the nature of knowledge about the world around us in human memory (Sub-question I-IV), and the sub-question about how people process knowledge about the world around us in their memories (Sub-question I-V) were answered by combining two approaches: (1) specifying the dual-channel model of Baddeley and Hitch (1974) and Paivio (1971) for the cognitive developing and processing of knowledge about the world around us in human memory; and (2) conducting a geographic conceptual analysis. Here we will focus on the conceptual analysis. The goal of conceptual analysis is to gain understanding of a particular concept. It is an analytic approach from philosophy (Foley, 1999). The concept is analysed by breaking it down into its constituent components, and by investigating how the components interact (Beaney, 2003). One thereby tries to construct a list of conditions that correctly classify things that fall under that concept, or things that do not, by formulating examples that explore the boundaries of the conditions. In order to define the nature of knowledge about the world around us in human memory, questions about how the characteristics and functioning of the world around us could be described were combined with questions about the characteristics of knowledge in human memory. Via iterative cycles in which the researcher explored his knowledge and thinking, the researcher tried to identify the key bodies of verbal knowledge about the world around us, and the key thinking operations. Input for the cyclical iterative process consisted of, among other things, the literature about the key concepts and key thinking skills (see Table 2-3 and Table 2-4). Also, the literature about the geographic knowledge and geographic thinking by Abler et al. (1977) and Van Westrhenen (1976; 1987) was read and reread. Activities conducted in the practical part of the PhD study also contributed to the development and elaboration of the model for GIS-supported geographic inquiry. The emerging model was discussed several times with colleagues.

Now that we have learned about the research approach for elaborating the model for GIS-supported geographic inquiry, we can have a look at the results, which are discussed in the next chapter.
5 A model for GIS-supported geographic inquiry (elaboration)

This chapter aims to elaborate the model for GIS-supported geographic inquiry and answer the nine sub-questions of Research Question I (see Chapter 3). Each section answers a sub-question.

5.1 The world around us

The first assumption that underlies doing geography says that world around us is characterised by the presence of natural and human phenomena within time and space, and by relationships between these phenomena (see Chapter 3). The question is: What exactly is a phenomenon? Although geographers frequently talk about phenomena, there are no clear definitions for the term in the literature. DiBiase et al. (2006, p.59) defined a phenomenon as “any subject of geographic discourse that is perceived to be external to the individual, including entities, events, processes, social constructs, and the like”. This section focuses on the question how the world around us can be characterised. A new definition for ‘phenomenon’ is presented at the end of the section.

Within the world around us, objects are present, and events occur, in time and space. Time is unidirectional and has one dimension, while space is multidirectional and has three dimensions. Objects are tangible, while events are not. Humans can be seen as a specific kind of objects. They are objects with a free will. Besides objects and events, there are also fields, which are properties of the world around us itself. The values of fields change in time and space. Examples of fields are the temperature and the elevation.

Besides objects, people can distinguish point-like, line-like, surface-like, and volume-like entities can be distinguished in space. These geospatial entities are called, respectively, places, boundary lines, regions, and volumes. Geographers often use places and regions when they study the characteristics, functioning, or problems of the world around us (see the third component of Harvey’s definition of geographic understanding, Section 2.1.1). People can also distinguish point-like and line-like entities in time. These temporal entities are called, respectively, time instances and time spans. So in summary, there are four types of entities: objects; events; geospatial entities; and temporal entities. Unlike objects and events, geospatial entities are not present within the world around us, and temporal entities do not occur within the world around us. Instead, they come into existence when humans distinguish them.

People often connect names to entities. These names are called ‘identities’. Examples of identities of objects, events, geospatial entities, and temporal entities are, respectively, ‘the main building of the VU University Amsterdam’, ‘the Aceh Tsunami’, ‘the Netherlands’, and ‘the first decennium of the 21st century’. Abstract entities have no identity. Examples are ‘a building’, ‘a tsunami’, ‘a country’, and ‘a decade’. Next to an identity, entities can have several properties.

Entities are often part of super-entities, while at the same time, they can be sub-divided into several sub-entities. For example, a province (= region) is part of a country (= super-region), and can be subdivided into a number of municipalities (= sub-regions). Likewise, a decade (= time
span) is part of a century (= super-time span), and can be subdivided into a number of years (= sub-time spans). Also, a faculty (= social entity) is part of a university (= super-social entity), and can be subdivided into a number of departments (= sub-social entities). The sequences ‘municipality → province → country’, ‘year → decennium → century’, and ‘department → faculty → university’ are called hierarchies in this dissertation. The position of an entity in a hierarchy is called the aggregation level. The size of the entities increases with increasing aggregation levels. In the examples above, the entities are subdivided into sub-entities with similar properties. Entities can also be subdivided into sub-entities with distinct properties. For example, a city can be subdivided into a historic centre, old residential areas, industrial areas, suburbs, and recreational areas. Likewise, a lowland river system can be subdivided into one or more channels, levees, and floodplains. This is also a hierarchy.

Entities can be assigned to classes, and classes can be assigned to higher-order classes. For example, the country ‘Niger’ can be assigned to the class ‘low-income countries’, which, in turn, can be assigned to the higher-order class ‘countries’. The sequence ‘Niger → low-income countries → countries’ is called a taxonomy, and the position of the entity or class in the taxonomy is called the analysis level. The class at the top of the taxonomy is called the ‘closure class’. Examples of closure classes are ‘countries’, ‘settlements’, and ‘services’. The number of members of a class increases with increasing analysis levels. As entities can have several properties, they can be assigned to several classes, and thus be organised in several taxonomies at the same time. For example, ‘Niger’ can be assigned to the class ‘low-income countries’, but also to the class ‘arid countries’. The values of the properties on the basis of which entities are assigned to classes are called extents. The class ‘harbour cities in Europe’ has a spatial extent (‘Europe’) and a thematic extent (‘presence of a harbour’). A specific kind of class is a class of moving entities (people, products, water, money, etc.). An example of such a class is the class ‘refugees from Iraq to Jordan in 2006’. Classes of moving entities have two spatial extents: the source region and the destination region. They can be dissolved to form a new entity, called a flow. For example, the class ‘refugees from Iraq to Jordan in 2006’ can be dissolved to the entity ‘the flow of refugees from Iraq to Jordan in 2006’.

Hierarchies and taxonomies are often confused in the literature, although they are fundamentally different from each other. Compare for instance the statements: “Niger is part of Africa”; and “Niger is a low-income country.” The first statement deals about the position of Niger in a taxonomy, while the latter statement deals about the position of Niger in a hierarchy (Figure 5-1). The difference between hierarchies and taxonomies is even clearer if we use non-geographic examples. For example, a birch tree can be subdivided into a stem, roots, branches, and leaves. The leaves themselves can be subdivided into a twig, nerves and leave material. This is a hierarchy. At the same time, the birch tree can be assigned to the class ‘deciduous trees’, which can be assigned to the higher-order class ‘trees’. This is a taxonomy. We will see later on in this dissertation that the concepts ‘hierarchy’ and taxonomy apply not only to entities and classes, but also to knowledge, operations, questions, and many other things. In order to show the difference, taxonomies are indicated with Arabic numerals, while hierarchies are indicated with Roman numerals in this dissertation (See, for example, Figure 5-1), with an exception made for the chapter numbering. Also, different terminology is used when talking about hierarchies and taxonomies. For hierarchies, we use: “An entity can be subdivided into several sub-entities”; and “An entity can be part of a super-entity”. For taxonomies, we use: “A class can be differentiated into several lower-order classes”; and “A class can be assigned to a higher-order class” for taxonomies.
Classes may show a certain variability shown in terms of property values, space, and/or time. This variability is called a ‘distribution’. Seven types of distributions can be identified. Table 5-1 presents examples of the different types of distributions, and Appendix F2 describes these distributions in more detail.

Table 5-1: The seven types of distributions

<table>
<thead>
<tr>
<th>Type</th>
<th>Dimensions</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type-1</td>
<td>Property distribution</td>
<td>The distribution shown by the lifespan of a set of 100 batteries</td>
</tr>
<tr>
<td>Type-2</td>
<td>Spatial distribution</td>
<td>The distribution shown by law firms in New York over space</td>
</tr>
<tr>
<td>Type-3</td>
<td>Temporal distribution</td>
<td>The distribution shown by outbreaks of the plague in Europe in the second millennium over time</td>
</tr>
<tr>
<td>Type-4</td>
<td>Spatial-property distribution</td>
<td>The distribution shown by the per capita income of neighbourhoods in Amsterdam over space</td>
</tr>
<tr>
<td>Type-5</td>
<td>Temporal-property distribution</td>
<td>The distribution shown by the average temperature of years in the 20th century over time</td>
</tr>
<tr>
<td>Type-6</td>
<td>Spatial-temporal distribution</td>
<td>The distribution shown by outbreaks of the Avian Flu between 2003 and 2009 over time and space</td>
</tr>
<tr>
<td>Type-7</td>
<td>Spatial-temporal-property distribution</td>
<td>The distribution shown by the per capita income of countries over time and space</td>
</tr>
</tbody>
</table>

Notes: P = property value; S = space; T = time.
Relationships are hereby seen as correlations between two distributions. Seven types of relationships can be distinguished, following the seven types of distributions. Table 5-2 presents examples for the different types of relationships.

**Table 5-2: The seven types of relationships**

<table>
<thead>
<tr>
<th>Type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type-1</td>
<td>Relationship between two property distributions</td>
</tr>
<tr>
<td></td>
<td>The relationship between the property distribution in the lifespan (of batteries), and the property distribution in the age (of those batteries)</td>
</tr>
<tr>
<td>Type-2</td>
<td>Relationship between two spatial distributions</td>
</tr>
<tr>
<td></td>
<td>The relationship between the spatial distribution of law firms in New York, and the spatial distribution of banks in New York</td>
</tr>
<tr>
<td>Type-3</td>
<td>Relationship between two temporal distributions</td>
</tr>
<tr>
<td></td>
<td>The relationship between the temporal distribution in the occurrence of large volcanic eruptions in the second millennium, and the temporal distribution in the occurrence of famines in the second millennium</td>
</tr>
<tr>
<td>Type-4*</td>
<td>Relationship between two spatial-property distributions</td>
</tr>
<tr>
<td></td>
<td>The relationship between the spatial-property distribution in the per capita income (of neighbourhoods in Amsterdam), and the spatial-property distribution in the percentage of immigrants (in those neighbourhoods in Amsterdam)</td>
</tr>
<tr>
<td>Type-5*</td>
<td>Relationship between two temporal-property distributions</td>
</tr>
<tr>
<td></td>
<td>The relationship between the temporal-property distribution in the average temperature (of years in the second millennium), and the temporal-property distribution in the number of solar spots (of those years in the second millennium)</td>
</tr>
<tr>
<td>Type-6</td>
<td>Relationship between two spatial-temporal distributions</td>
</tr>
<tr>
<td></td>
<td>The relationship between the spatial-temporal distribution in the opening of new supermarkets, and the spatial-temporal distribution in the closing of small grocery stores</td>
</tr>
<tr>
<td>Type-7*</td>
<td>Relationship between two spatial-temporal property distributions</td>
</tr>
<tr>
<td></td>
<td>The relationship between the spatial-temporal-property distribution in the per capita income (of countries in the world in the 20th century), and the spatial-temporal-property distribution in the trade surplus/deficit (of countries in the world in the 20th century)</td>
</tr>
</tbody>
</table>

Notes: * = Pseudo relationship.

Although the type-4, type-5, and type-7 relationships can be observed in external representations about the world around us, they are in fact the product of type-1 relationships expressed in space and/or time. So instead of saying that “The spatial-property distribution in the per capita income (of neighbourhoods in Amsterdam) is related to the spatial-property distribution in the percentage of immigrants (in those neighbourhoods in Amsterdam)”, one could just as well say “The property distribution in the per capita income (of neighbourhoods in Amsterdam) is related to the property distribution in the percentage of immigrants (of those neighbourhoods in Amsterdam).” So type-4, type-5, and type-7 relationships should actually be seen as pseudo relationships.

The direction and strength of the relationships between two property distributions can be expressed with a correlation coefficient (if both properties are quantitative properties), student-t (if one property is a quantitative property and the other property is a qualitative property), or Chi-square (if both properties are qualitative properties). The value of the coefficient depends on the units of analysis in the relationship. For example, the correlation coefficient for the relationship between the number of primary schools (in neighbourhoods in the Netherlands) and the number of children (in those neighbourhoods) is +0.71, while the correlation coefficient for the relationship between the number of secondary schools (in neighbourhoods in...
the Netherlands) and the number of children (in those neighbourhoods) is only +0.32. As entities are nested in hierarchies, the direction and strength of the correlation depends on the aggregation level. For example, the correlation coefficient for the relationship between the number of primary schools (in regions) and the number of children (in those regions) is +0.71 at the aggregation level of neighbourhoods, +0.84 at the aggregation level of municipalities, and +0.91 at the aggregation level of provinces. As entities are also nested in taxonomies, the direction and strength of the correlation also depends on the analysis level. This can be illustrated by comparing the relationship for the analysis level ‘primary schools’ (low) with the relationship for the analysis level ‘schools’ (high). The correlation coefficient for the relationship between the number of schools (in neighbourhoods) and the number of children (in those neighbourhoods) is +0.60. This is 0.11 lower than the correlation coefficient for the relationship between the number of primary schools (in neighbourhoods) and the number of children (in those neighbourhoods).

In this dissertation, the term ‘phenomenon’ is used as short for ‘the distribution shown by a class in property values, space, and/or time’. See for example the statements: “The distribution of law firms in New York over space is a phenomenon which is related to the distribution of banks in New York over space”; and “The distribution shown by the per capita income of neighbourhoods in Amsterdam over space is a phenomenon which is related to the distribution shown by the percentage of migrants of neighbourhoods in Amsterdam over space.” In the first statement, the term ‘phenomenon’ refers to the spatial distribution shown by the class ‘law firms in New York’. In the second statement, the term ‘phenomenon’ refers to the spatial-property distribution shown by the property ‘per capita income’ of the class ‘neighbourhoods in Amsterdam’. In practice, geographers also use the term phenomenon in other senses, for example to refer to processes (e.g. ‘suburbanisation’, ‘erosion’) or abstract events (e.g. ‘a tsunami’). However, in this dissertation, the term ‘phenomenon’ is only used to refer to distributions.

Another important notion is that entities are part of networks, via which flows (can) occur. For example, cities are connected to each other via roads, along which flows of products (can) occur. Likewise, countries are connected via migrations routes, along which flows of immigrants (can) occur. Because entities are part of networks, they can influence each other. This influence is called a ‘horizontal relationship’ by Van der Schee (2000). However, in this dissertation, the term ‘relationship’ is only used for relationships between two distributions in this dissertation. These are the vertical relationships distinguished by Van der Schee (2000) and the probabilistic/causal relationships distinguished by Van Westrhenen (1987).

5.2 Geodata

Data about the world around us are data about entities that can be identified by humans in the world around us (objects and entities), and entities that can be constructed by humans in the world around us (places, regions, etc.). Data about fields are also geodata. These data can have geospatial and/or temporal references. Explicit geospatial references describe the location and shape of entities in space. An example is ‘52°22’23”N, 4°53’36”E’. Implicit references link the data to geospatially-referenced entities. Examples are ‘the Netherlands’, ‘New York’, or ‘200 Baker Street, London’. Temporal references can also be explicit or implicit. Compare, for example, the references ‘the time span from 1939 to 1945’ and ‘World War II’. Data with