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Evaluating Progression in Students' Relational Thinking While Working on Tasks with Geospatial Technologies

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Abstract

One of the facets of geographic literacy is the ability to think in a structured way about geographic relationships. Geospatial technologies offer many opportunities to stimulate students' geographic relational thinking. The question is: How can these opportunities be effectuated? This paper discusses the results of a process-oriented experiment that aimed to gain insight into the characteristics of students' learning processes and the factors that influence students' learning when they work with geospatial technologies, and to provide ideas on how to optimise the learning outcomes. Eighteen students were observed in a laboratory research setting while working on tasks with a geogame and a WebGIS, and were interviewed about their learning afterwards. The study shows that using appropriate educational technologies is only part of the story. Well-designed tasks and active coaching by the teacher also seem to be indispensable ingredients. The data suggest that, in order to increase the effectiveness of instruction methods with geospatial technologies, teachers should include tasks in which students have to summarize their system knowledge in a conceptual framework, and that teachers should help students structure their system knowledge via dialogical teaching. In the tasks and support, attention should be paid to the grammar of relational thinking.

Keywords: geospatial technologies, relational thinking, learning styles, dialogical teaching

Introduction

Challenges such as climate change, acces to energy and food, poverty, natural hazards, and migration are growing in complexity. They exist at scales ranging from local to global, cut across human and natural systems, involve many interdependent variables

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that are changing over time, and have a strong spatial component. These challenges are important for our future, but are difficult to understand, predict, and solve, as planning measures have effects on the natural and human environment, here and there, in the present and in the future.

Geographic literacy is the ability to translate the challenges that we observe, directly or indirectly via the media, in world around us, into a more coherent understanding. It also includes the ability to formulate judgments about these challenges, and to think about solutions. Geography education aims to contribute to the development of students' geographic literacy, so that they are able to make informed decisions in their future every-day and professional live (Favier & Van der Schee, 2014).

An important facet of geographic thinking is relational thinking (Jackson, 2006; Taylor, 2006). Geospatial technologies (GST) seem to hold promising opportunities for stimulating the students' geographic relational thinking. They offer access to geospatial information via digital representations (such as digital maps), and tools for interaction with those representations. Unfortunately, so far, little is known about effective designs for lessons with GST. This is mainly because we lack insight into the characteristics of students' learning processes when they work on tasks with GST.

This paper tries to contribute to knowledge development in this field, by discussing the outcomes of an exploratory process-oriented experiment. However, before discussing the research questions, methods and results of this study, we should first provide a short theoretical background about 'geographic relational thinking' and 'GST', and discuss what is known about effective strategies for integrating GST in geography education in order to stimulate students' geographic relational thinking.

Theory

First, what actually is geographic relational thinking? Van der Schee (2000) distinguishes two types of geographic relations: vertical relations; and horizontal relations. *Vertical relations* are relations *within* regions, such as the relations between different physical geographic properties in a region (i.e. geology, soil, climate, hydrology, ecology) and relations between different human geographic properties (i.e. demography, sociology, culture, economy, politics) in a region. Human-nature relations are also typically vertical relations. As regions are situated in networks, and as flows may occur between regions, a change in a property of one region may result in a change in a property of another region. This is called a *horizontal relation*. Vertical and horizontal relations are part of geographic systems that provide opportunities and challenges for different land-use functions (e.g. residential, transport, agriculture, recreation, nature). In turn, land-use functions affect the system via environmental pollution, groundwater extraction, fertilising, etc. People could apply planning measures to change the system, and in such a way optimise the opportunities and decrease the challenges.

Geographic relational thinking can be seen as a higher order kind of thinking about relations and effects in geographical systems. Many relational thinking processes fall in the categories 'analysing', 'evaluating' and 'creating' of the revised Bloom Taxonomy

(Anderson & Krathwohl, 2001). Typical processes include recognizing and interpreting correlations between two distributions or patterns in maps; organizing knowledge about relationships in a conceptual framework; and evaluating the effects of planning measures on the geographic system.

Geospatial technologies (GST) offer many possibilities for stimulating students' geographic relational thinking. WebGIS applications offer enormous amounts of map layers about interrelated phenomena. As the map layers cover the same regions and have the same aggregation levels, students can easily explore them to see if there are any associations between spatial distributions and spatial patterns. Furthermore, they also allow students to put map layers on top of each other, to switch them on and off, and to make them transparent. These functionalities make it easier for them to identify spatial associations (Bednarz & Van der Schee, 2006). A special category of GST are the *geogames*, which are games based on schematic maps and rules about the geographic system. They allow students to evaluate the effects of planning measures on the geographic system, and therefore provide insight into the different relations in the system.

The interactive nature of GST makes it easier for teachers to design instruction methods, which focus on stimulating geographic relational thinking. This connects to Palladino and Goodchild's (1993) argument that GST can make it easier for teachers to engage students in "higher order thinking activities that are often so hard to come up with". Geography lessons with GST often have a different design from traditional geography lessons. They are more learner-centred, and connected to constructivistic learning theories.

In this paper, we will explore how students learn when they work on tasks with a geogame and a WebGIS, and how learning can be supported effectively. Important issues are the use of concept-mapping and the role of geographic concepts and grammar.

Research by Hwang, Yang and Wang (2013) showed that integrating concept mapping in game-based instruction could significantly improve the learning outcomes, as it helps students to organise their learning. However, concept maps often depict several kinds of relationships between concepts. As relational geographic thinking focuses on causal relationships only, it is more useful to let students organize their knowledge about relationships in a conceptual framework. Such frameworks visualize the relevant variables with boxes, and the relationships between those variables with arrows. Constructing conceptual frameworks is especially useful in case the system is complex, containing several direct and indirect relationships, interactions, and feedback mechanisms.

Language may play an important role in the development of relational geographic thinking. Wilschut (2013, p. 13) argues that school geography, just like school economics and school history, is known for its linguistic nature, as it tries to describe and explain the natural and human environment with the use of substantive concepts. For example, in order to study water-related challenges or to communicate about these challenges, it is useful to have some understanding of concepts such as 'river' and 'estuary' and more abstract concepts such as 'flood risk'. Such concepts are the geographer's vocabulary. Understanding of the meaning of substantive concepts helps to identify the relevant variables in a geographic system, and, hence, to structure knowledge about relationships. Besides the 'geographic vocabulary', there is also something that can be seen as the 'geographic grammar' (Favier, 2011). Knowledge about geographic relationships could be expressed in a certain format, so that the analysis units, variables, direction of the relationships, types of causality, etc. become clear. Examples of such standard forms are *generalizations* ("Regions with a high A generally have a high/low B") and *rules* ("A change in A is associated with a change in B").

The idea that language plays an important role in developing disciplinary knowledge is the basis of the *content-based language learning*, which connects learning goals for content with linguistic learning goals. Context-rich tasks, interaction and linguistic support are the key components of such an approach (Hajer & Meestringa, 2009). A couple of publications in the field of history education (Coffin, 2004; Woodcock, 2005; Van Drie & Van Boxtel, 2003) suggest that interaction and linguistic support help students to reason in a structured way about causality around historic events. In order to help students learn to think in a structured way about geographic relationships, it seems likely that it is useful to pay attention to the verbal grammar (the standard formats for verbally expressing relationships) and the visual grammar (the conventions for drawing conceptual frameworks). However, this is a currently unexplored terrain. A language-oriented didactic approach in geography education may seem promising, but little is known about how to design effective tasks and coaching by the teacher.

Previous Researches

Although many authors rave about the potential of GST for secondary geography education (Hall-Wallace & McAuliffe, 2002; Baker & White, 2003; Kerski, 2003; West, 2003; Sinton & Lund, 2007; Milson & Kerski, 2012), there is still little concrete evidence for the effectiveness of instruction methods with GST, especially when it concerns the effects on the development of specific facets of geographic thinking, such as relational geographic thinking. For this reason, a field experiment was conducted in which the effects of a lesson series with GST on the development of students' relational thinking was compared with a conventional lesson series in a classroom setting (Favier & Van der Schee, 2014).

Both lesson series covered 3 lessons, and focused on water-related challenges in The Netherlands. The field experiment was conducted in fourteen classes at five schools that could be seen as representative for The Netherlands. Students in the experimental group (n = 139) first played two modules of a geogame called "The Watermanager". After gaming, students worked on assignments in which they had to summarize the system rules in a conceptual framework. Then, students made several assignments with a WebGIS called "EduGIS" in which they had to investigate the spatial variability in flood risks in The Netherlands, and the water management measures that were taken in the past few decades to reduce the flood risks. Students in the control group (n = 146) followed a lesson series with the schoolbook, which consisted of a textbook and workbook. The conventional lesson series covered the same content as the lesson series with GST. The textbook explained the characteristics and functioning of the water system in two regions in The Netherlands, and the planning measures that were carried out in order to deal with water-related challenges. The workbook contained assignments in which students had to process the information from the textbook.

The effectiveness of the two lesson series was tested with a Geographic Relational Thinking Test developed by the first author of this paper, following a pretest-posttest design. Students who followed the lesson series with GST showed higher achievement on all six test items: for near transfer as well as far transfer items; and for items in the category 'analysing', 'evaluating', and 'creating'. The overall effect size of the experimental condition was +0.38, while the overall effect size of the control condition was just +0.04. This can be interpreted as a 'low to moderate' positive effect (Cohen, 1988). Still, the effect study showed that the lesson series with the GST provided only a first step in stimulating geographic relational thinking. In the experimental group, the average pre-test scores increased from 31.7 points to 38.7 points, which was still far below the maximum possible score of 100 points. Students identified only a part of the relations in the representations. Also, they were able to structure their knowledge about geographic systems to a limited extent, and they took only a part of the relevant factors into account when they evaluated the effects of planning measures and sought solutions for spatial challenges. The lower-than-desired learning outcomes might be related to the design of the lesson series. During the field experiment, it seemed as if the tasks worked out well for a large part of the students, but not for all of them. The effectiveness is possibly related to students' learning style. A review of previous research (Coffield, Meseley, Hall & Ecclestone, 2004) suggests that the output of education with technology might be influenced by students' learning styles, and that considering learning styles appropriately could enhance the learning experience. However, the effects seemed to depend on the instrument that was chosen. Other studies delivered no proof that 'matching' students' learning styles with the design of tasks could lead to a significant increase in educational performance. As far as we know, no research has been conducted that connects learning styles, design of tasks with GST, and learning outcomes for relational thinking.

Aim and Research Questions

It is likely that we can increase the achievement of lessons with GST if we have more insight into how students learn when they work on tasks with GST, and the influence of learning styles on students' learning. Lam, Lai, and Wong (2009) argued that in order to support teachers, researchers should provide more insights on how to make the best use of GST in geography teaching. This paper discusses the results of a follow-up study of the effect study described in the previous paragraph. The research aimed to provide more insight into the characteristics of the learning processes of students with different learning styles when they work on tasks with GST, and to explore how effective learning can be supported.

Methodology

The follow-up study focused on the same learning goal ('relational geographic thinking') and used the same applications ('The Watermanager' and 'EduGIS') as the previous effect study, but had a process-oriented character. An experiment was conducted in a laboratory research setting.

Selection of the Participants

Eighteen students with distinct learning styles participated in the experiment. There are many different conceptualizations of the term 'learning style', each with its own background and field of application (Coffield et al., 2004). In this paper, an active view of learning styles was used that takes into account the effects of previous experiences and contextual influences. This connects with Vermunt's (1994) idea of learning styles, who defines a learning style as "a coherent whole of learning activities that students usually employ, their learning orientation and their mental model of learning". According to Vermunt, a learning style deals not only with cognitive processing, but also with metacognitive activities and motivation, effort and feelings. Vermunt distinguishes four learning styles: (1) meaning-directed; (2) application-directed; (3) reproduction-directed; and (4) undirected (Vermunt, 1994). Students with a meaning-directed learning style generally look for relationships between key components, and try to build an overview of the content. They are oriented at self-improvement and enrichment, and are driven by intrinsic interest and pleasure. In contrast, application-directed students try to relate topics to everyday experience. They look for concrete examples, and are interested in practical implications. They learn in order to use knowledge. Then, students with a reproduction-directed learning style select main points to retain. They put in time and effort in order to get good marks. Finally, students with an undirected learning style find it difficult to set goals. They read and re-read. Undirected students are either ambivalent or insecure.

In this study, a shortened version of Vermunt's Inventory of Learning Styles (ILS) test was conducted on 204 3rd grade VWO (pre-university) classes from three schools in the central part of the Netherlands. Students were between 14 and 15 years old. The shortened ILS test is a self-rating instrument, based on 40 items with a 3-point scale (Het Hooghuis, 2014). The output was a set of four scores for each learning style, ranging between 0 and 20.

Vermunt´s learning styles are not mutually exclusive. In fact, more then half of the 204 students had a combination of a meaning-directed and application-directed learning style (i.e. 2 or less points difference between the scores for these learning styles). 89 students had a more distinct leaning style (i.e. 3 or more points difference between the learning style with the highest score and the learning style with the second-highest score). All students with a distinct learning style were asked via the e-mail to participate in the experiment. Participation was voluntary though, and, in total, 18 students participated in the experiment. Figure 1 shows the characteristics of these students, and Figure 2 shows the characteristics of their schools. School A and B are average schools in many respects. School C is a bit different, as it puts more emphasis on inquiry-based learning, and as it has an ethnically more diverse student population. Still, there were no indications that the group of students who participated in the research were not representative for the Dutch student population. However, as background knowledge and school grades were not included in this research, we are not absolutely sure about this.

Student	*School*	*Gender*	*Learning style*	*Difference between highest and second highest score on the ILS*
M1	A	F	Meaning-directed	+6
M2	A	F	Meaning-directed	+4
M3	B	M	Meaning-directed	+5
M4	B	M	Meaning-directed	+7
M5	C	M	Meaning-directed	+5
A1	A	M	Application-directed	+6
A2	B	F	Application-directed	+5
A3	B	F	Application-directed	+5
A4	C	F	Application-directed	+4
A5	C	F	Application-directed	+6
R1	A	F	Reproduction-directed	+3
R2	B	F	Reproduction-directed	+3
R3	B	F	Reproduction-directed	+3
R4	C	F	Reproduction-directed	+3
U1	A	M	Undirected	+4
U2	B	M	Undirected	+3
U3	C	F	Undirected	+3
U4	C	M	Undirected	+3

Figure 1.
Characteristics of the students who participated in the experiment

School	*Location*	*No. of students*	*Student population (ethnic composition)*	*Education system*	*Score on national exams*
A	Suburb of Utrecht (pop. = 30.000)	900	95% Dutch, 5% other	No special focus	0.1 point above national average
B	City of Utrecht (pop. = 300.000)	1100	75% Dutch, 25% other	No special focus	0.1 point below national average
C	City of Utrecht (pop. = 300.000)	600	50% Dutch, 50% other	Focus on inquiry-based learning	0.4 point below average (<1 stdev).

Figure 2.
Characteristics of the schools of the students who participated in the experiment

Data Collection

The experiment was conducted with one student at a time, by the first author of this paper (see Figure 3). Each student first made some items from the Geographic Relational Thinking Test, and then worked on the three tasks with GST as students in the previous effect study using the geogame 'The Watermanager' and WebGIS 'EduGIS'. Students were asked to think aloud while working on the task. The first author, depending on the situation, occasionaly interrupted the learning process to ask students to explain their learning processes: what they were doing; why they were doing it in this specific way; and what they had found. Data was collected by logging the computer screen and sound, and by gathering the filled-out task forms. After working on each task, the student was interviewed about his or her opinion about the learning process and the design of the task (Figure 4). In the interviews, the first author also asked students how their learning could be supported effectively. He thereby asked for their opinion on several designs of tasks and coaching interventions based on ideas about concept mapping and the use of conceptual frameworks and the geographic grammar. At the end of the experiment, as short survey was conducted in which students were asked whether they found the lesson series interesting, useful, fun or difficult.

	Role of the first author	*Data collection*	*Results*
Task 1: Students work on 3 test items from the Geographic Relational Thinking Test	On-task mini-interviews; Interview afterwards	Sound logs; Filled-in test forms	§ 3.1
Task 2: Students play two modules of the geogame	On-task mini-interviews; Interview afterwards	Sound and screen logs	§ 3.2
Task 3: Students work on summative assignments in which they have to draw a conceptual framework	On-task mini-interviews; Interview afterwards	Sound logs; Filled-in task forms	§ 3.3
Task 4: Students work on a highly-structured task with the WebGIS	On-task mini-interviews; Interview afterwards	Sound and screen logs; Filled-in task forms	§ 3.4
Students fill out a short survey		Filled-in survey	§ 3.5

Figure 3.
Set-up of the experiment

1. What is the most important thing that you have learned?
2. The task has the following learning goals: [….]. Do you think that the task was successful?
3. What is your opinion about the design of the task? What are the positive and negative aspects?
4. What is the advantage of lessons with these applications in respect to conventional lessons?
5. Should these tasks be integrated in geography lessons, and if so, how should teachers do that?

Figure 4.
Interview questions asked after the four tasks

Analysis and Interpretation of the Data

The data was analysed and interpreted by the first author of this paper. For each student, a summary was made of the learning process. In these summaries, it was tried to describe the essence of the strategies followed by the student, the output (answers to the questions and the solutions to the design problems), and the opinion of the student about the design of the tasks and the learning outcomes. Next, it was tried to distinguish patterns in these descriptions, and to relate them to students' learning style. However, during the data collection and analysis, it became clear that students' learning is influenced by much more than learning style alone. Background knowledge and experience with technologies also seemed to play a role. The interviews provided some insight into these relationships, as the researcher often asked students to explain their strategies, opinions, etc.

Findings

In this section, the results of the experiment are discussed. For each of the tasks, a short description of the task is given, followed by a summary of the most important findings based on the data collected during the experiment, and a discussion of the implications of the findings.

The Geographic Relational Thinking Test (Part A)

Task description

In the first part of the experiment, each student did three items from the Geographic Relational Thinking Test. The first two items were 'control of variables strategy' items (Chen & Klahr, 1999), which were used to explore how students identify associations in spatial data. In the first item, students had to analyse a figure that contained eight different paper planes, and the test results for each plane. Students were asked to identify the factors that determine how far a paper plane can fly. The eight planes had different properties: material (paper or carton); type of wing (folded or non-folded); type of tail (tail or no tail); etc. The second item was similar but dealt with a geographic problem: salinization of polders in the western part of The Netherlands. Students were shown eight schematic maps and cross-sections from the sea to a polder, and were asked to identify the factors that determine the degree of salinization in polders. Again, the polders had different properties: distance to the shore, width of the dunes; type of land use (dairy farming or crops); etc. In order to perform well on the two test items, students had to search for and compare respectively two paper planes and two polders respectively. These paper planes and polders were similar except for one property. The task with the polders was more difficult as it also included horizontal relationships and spatial factors. Later on in the experiment, students had to perform a similar task with digital maps in a WebGIS.

Results

On average, students were able to name about half of the relevant factors. The data suggest that there are several possible causes for the less-than-optimal outcomes. *First*, only a couple of students (M2, A1 and R3) used a structured approach by themselves, comparing two paper planes and two polders that were similar except for one property. These students identified most factors correctly. In contrast, most of the other students picked a couple paper planes that had covered a short or long distance and a couple of polders with low or high salinification, and subsequently tried to describe the properties of these paper planes and polders. When the first author of this paper explained the control of variables strategy, most students were able to identify all or almost all relevant variables. *Second*, background knowledge played an important role when students worked on these tasks, and it did not always help them. Some students seemed to reason on the basis of background knowledge alone (student M2, A3, U1). They hardly checked their assumptions by analysing the representations. The other students did check their assumptions, although usually not in a very systematic way. Also, it was noticed that most students found it difficult to name the factors properly. Furthermore, the data suggests that most students overlook spatial factors (in the task with the polders) more easily than non-spatial factors.

Implications

In order to help students identify (geographic) relationships in data, the task should provide a considerable amount of guidance, so that students are steered in the right direction. The question "Which factors affect…?" probably did not offer enough guidance, and it might therefore be better to list the factors, and then ask students which of them have a positive, negative and no effect. Also, teachers should explain students the control of variables strategy to the students. Furthermore, teachers should make use of the fact that students often reason on the basis of background knowledge, and stimulate them to formulate assumptions, and to check these assumptions systematically.

The Geographic Relational Thinking Test (Part B)

Task description

The third item of the Geographic Relational Thinking Test was a 'conceptual framework completion task', in which students had to fill in a partially completed conceptual framework about the factors that are related to the water level in Lake Constance. Students were asked to draw arrows between different variables: water level in Lake Constance; discharge of the Upper Rhine (which flows into the lake); discharge of the Middle Rhine (which flows out of the lake); precipitation; evaporation; and temperature. Students were expected to possess the required knowledge, to organize their knowledge and make it explicit. Later on in the experiment, students had to perform a similar task after playing a geogame.

Results

Three students (M2, M3 and A2) performed well on this test item. They included almost all relevant relationships in his framework, with the correct symbols (see, for an example, Figure 5A). Also, they were able to explain their conceptual framework in a structured way. By themselves, they verbalized the relationships in the standard form (see, for example, Figure 5B). It was not exactly clear why these three students performed well on this task. According to the students, constructing conceptual frameworks was not taught structurally at their school, and there was little or no attention for verbalising relationships. The students said that they had learned to do so by themselves. Student M3 argued that it was just "logical thinking".

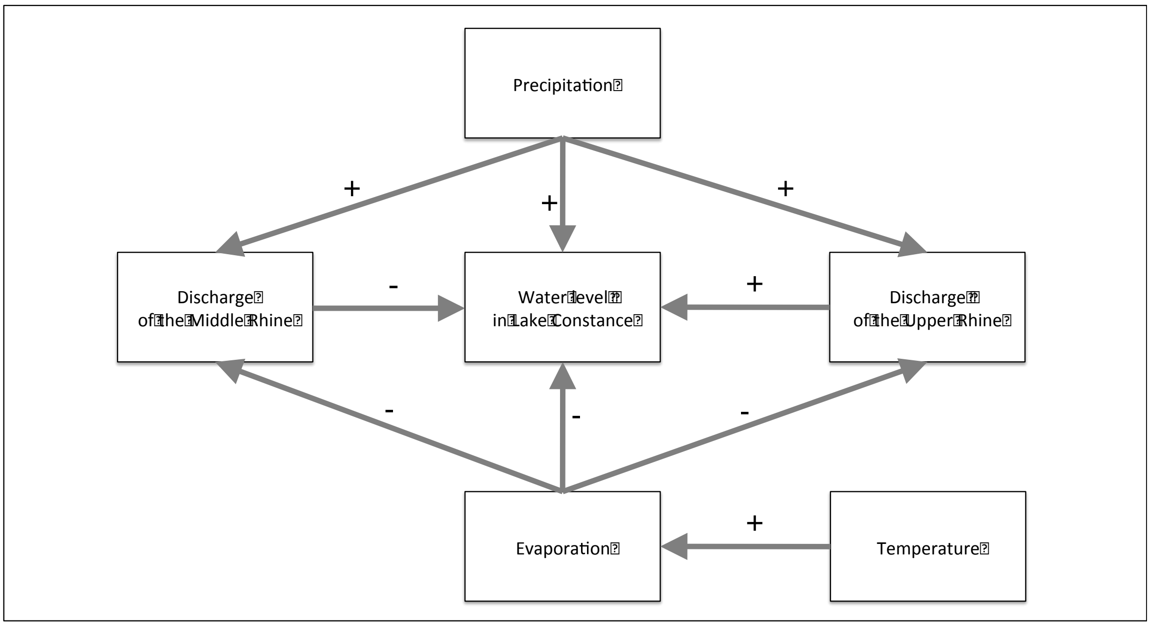

Figure 5A.
Output for test item 3 of a high-performing student M3

Actor	*Spoken*	*Action*
Student M3	"If the discharge of this river increases, the water level [in Lake Constance] will decrease."	*<draws an arrow from the discharge of the Middle Rhine to the water level in Lake Constance, and adds a minus symbol >*
Student M3	"If the temperature increases, the evaporation will increase too."	*<draws an arrow from temperature to precipitation, and adds a plus symbol>*
Student M3	"More evaporation will result in less water here, here and here. Then the water level [in Lake Constance] will decrease.... The discharge of the Middle Rhine and Upper Rhine will decrease too."	*<draws an arrow from evaporation to water level in the Lake Constance, and adds a minus symbol> .* *<draws two more arrows, with minus symbols>*

Figure 5B.
Transcript of some elements of the learning process (thinking aloud) of high-performing student M3

In contrast to the three high-performing students mentioned above, the other students showed a low or moderate performance on this test item, and found it difficult to explain the relationships in a structured way. See for example Figure 6A and B. The example shows a student who incorrectly drew an arrow in the conceptual framework, and was not able to clearly explain why she had done so. Although she talked extensively about the (incorrectly identified) relationship, she did not verbalise it in one of the standard formats.

About half of the students did not completely understand the conventions for organizing relationships in conceptual frameworks. They drew lines instead of arrows or included plus or minus symbols next to the concepts instead of the arrows. Others thought that arrows represented flows of water instead of relationships. In other words: they did not master the visual grammar of relational thinking.

So, in conclusion, the data suggests that high performance in organizing relationships in conceptual frameworks is associated with mastering the visual and verbal grammar of relational thinking. When the first author of this paper explained how to visualize and verbalize relationships, it helped students to structure their knowledge.

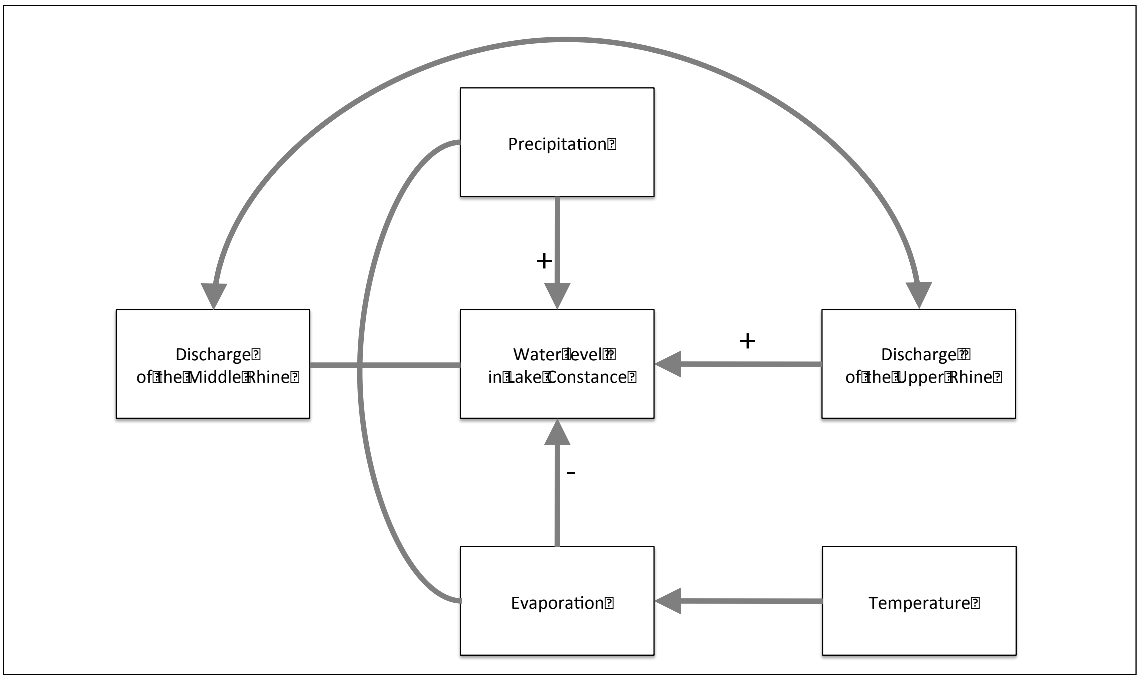

Figure 6A.
Output for test item 3 of low-performing student A3

Actor	*Text*	*Action*
First author	"Can you explain why you drew an arrow here?"	*<points to the arrow between the discharge of the Middle Rhine and the discharge of the Upper Rhine >*
Student A3	"Uhmm.. Yes. They are with each other. If they are both large, and increase, then ... Then they do not really affect it. I think ... They just belong to each other."	
First author	"How does that relationship work, exactly?"	
Student A3	"Yes, well... I don't know. But I think that if there is two times as much discharge in the river that flows in [Lake Constance], than there is also two times from the other side. And then it does not affect the water level [in Lake Constance]. But it does affect each other. The same is for the evaporation and precipitation. But that does not go together."	

Figure 6B.
Transcript of the interview after test item 3, with low-performing student A3

Implications

The experiment suggests that high performance in organizing relationships in conceptual frameworks is associated with the ability to verbalize about relationships in a standard format, and with knowledge about the conventions for drawing conceptual frameworks. Most students did not possess knowledge about the grammar of relational thinking though, but the experiment suggests that this grammar can be learned, and that students find it valuable approach to help them organize their knowledge about geographic systems. So, teachers should pay explicit attention to the visual and verbal grammar of relational thinking. It seems logical to suggest that organizing relationships is best done by alternating between verbalizing and visualizing relationships. In order to raise students' thinking to a higher level, teachers should simulate students to do so, and offer support. This can be done by giving feedback; giving hints; instructing; explaining; modelling; and questioning (Van de Pol, Volman, & Beishuizen, 2010). Teacher-student interaction is therefore essential. Including tasks in which students have to draw conceptual frameworks can only be effective if students are given support during the task, or if the task is extensively evaluated afterwards.

The Geogame Tasks

Task description

In the second part of the experiment, each student played two modules of a geogame called "The Watermanager". The modules focused on water-related issues in the Delta Region and the River Region of The Netherlands. The two modules had the same set up: students first played a quiz game; then played a training game; and finally played a planning game.

In the quiz game, students have to drag photos to the right location in a schematic map of the Delta Region and River Region, and answer questions about the characteristics of the water system in both regions. Students receive textual feedback on their choices. At the start of the training game, it is explained that there are several water-related challenges in the two regions (i.e. increased flood risks, increased fresh water shortages). One by one, five types of planning measures for dealing with these challenges are introduced. Each time, students have to choose the best of five sites in a schematic map. A simulation subsequently shows the effects on the water system. Students also receive visual feedback via score bars for expenditures, profits, and damage (in the Delta Region module), and score bars for different user functions (in the River Region module). Besides this, students also receive textual feedback about their choices. A pop-up explains the suitability of the selected site for a specific planning measure.

The planning game is the most important game. In this game, students take on the role of water manager. They have to find an optimal solution for water-related challenges in the two regions. Students can select multiple planning measures in a schematic map, such as dike displacement (see Figure 7). Every planning measure has its costs, however. When students are finished, they press the 'implementation button' and subsequently receive visual feedback: a simulated map (left inset in Figure 7) and changes in the score bars (middle and right inset) and a final score on a 0 to 10 point scale. Students can then adapt their selection of planning measures in order to improve their scores. They can perform as much iteration as they want.

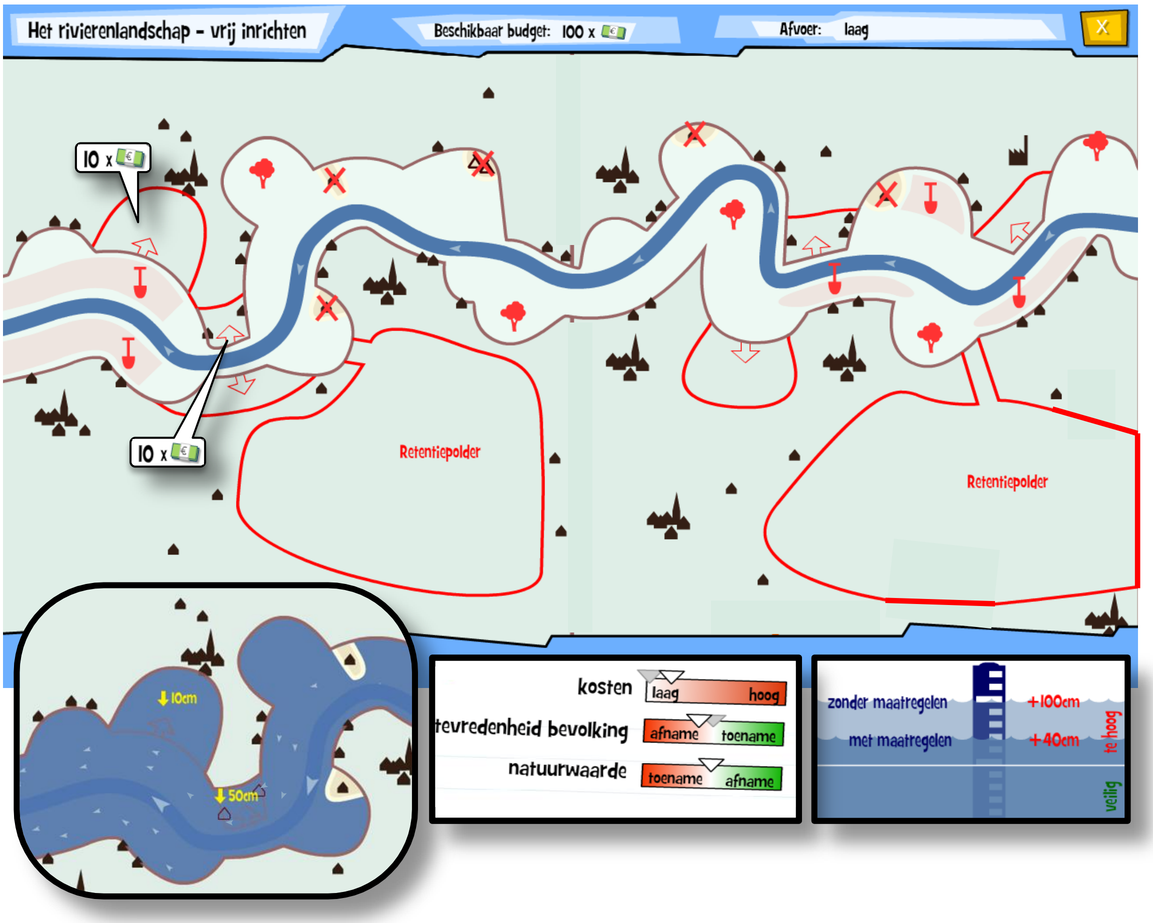

Figure 7.
Screenshots of the module for the River Region

The game aims to shows students that the effects of the planning measures depend on the local circumstances, and that planning measures can have effects at other sites too (i.e. upstream or downstream). For example, the left inset in Figure 7 shows that the lower right dike displacement results in a reduction of the water level at high discharges of 50cm, while the upper left dike displacement results in a reduction of only 10cm. This is because the effect of the measure depends on the width of the floodplain (a moderating variable): The higher the width of the floodplain, the lower the effect. The game also intents to shows students that interests are often conflicting. Therefore, there is not a single optimal solution for the water-related challenges. Instead, there are several good alternatives.

Results
The experiment with the geogame went well. There was no need to support the students while they were playing the game.

All students were enthusiastic about the geogame. They found it a very motivating way of learning about water-related challenges. Students especially liked the interactive character of the game, and the fact that they could actually make decisions. For example, student A4 argued that: “I like it that you can test things. If you do something wrong, you can see why it is bad, and try again. And it is fun. You can actually see the flooding. And then you think: No, no. Look what is happening now!” Many students said that the game stimulated them to think deeply about the system. For example, student M3 argued: “You really have to think about what [planning measures] you can carry out, and why it is good or not. You can’t just do something. You really have to think deeply about it”. Students found working with the geogame more interesting and useful than conventional lessons. Student A3, who performed low on the Geographic Relational Thinking Test, argued: “It definitely has advantages over lessons with a book. It is much more fun than reading a book and then answering questions. The game really made me think. And I think that I will remember it better now, as I actually tried out everything. If you read a text, you don’t actually see it, and don’t experience it.”

In the quiz game and training game, students with an undirected learning style spent less time reading the textual feedback and analysing the visual feedback (the animations in the map, and the score bars) than students with other learning styles. Student U2 and U3 did not read the texts at all. Students with a reproduction-directed learning style, on the other hand, read the texts very carefully. All four students said that the textual feedback was very useful.

In the planning game, students seemed to apply different strategies, depending on their learning style. Students with an undirected learning style seemed to follow an explorative approach with many short iterative cycles. They did not mind doing something wrong, and some students even deliberately tried to cause as many flood casualties as possible. Students with other strategies seemed to plan their solutions for the water-related challenges more consciously, thereby applying the knowledge developed in the quiz game and training game. This was especially the case for students with a reproduction-directed learning style.

Although the strategies applied by the students varied depending on their learning style, all students reached an almost maximum score (9 points) or maximum score (10 points) in more or less the same time (Figure 8). This suggests that the geogame can accommodate different learning styles. This assumption was also supported by the interview data. All students, regardless of their learning style, said that the geogame suited their way of learning.

	*Average time on task**	*Average number of iterations**
Meaning-directed (n = 5)	12:50 minutes	3,6
Application directed (n = 5)	13:20 minutes	3,9
Reproduction-directed (n = 4)	14:10 minutes	3,4
Undirected (n = 4)	13:00 minutes	6.8

Figure 8.
Characteristics of students learning processes while working on the planning games
** = until a score of at least 9 points*

Although all students obtained an almost maximum or maximum score in the planning game, they did not develop a complete picture of the functioning of the system. Also, the system knowledge that they developed varied among the students. This was because there are several good alternative solutions, and students usually find out only one of them. Also, students did not test every planning measure. Doing something wrong is often more effective for the learning process than directly choosing the right option? Third and finally, students often missed certain visual feedback in the schematic map and score bars, and did not see everything that the game wanted to show them.

The interviews conducted right after the students played the game indicated that, in many cases, the knowledge that students developed by playing the game was not well structured and had some characteristics of tacit knowledge. When they were interviewed and asked to explain their choices, most of them answered in short exclamations instead of whole sentences, and the information about relationships in their answers was poorly structured. Furthermore, the larger part of the students mentioned only about half of the relevant relationships that played a role in their solution. They especially overlooked the importance of horizontal relationships. Also, many students reasoned messily: they did not express relationships in one of the standard verbal formats. In contrast, the three students who showed a high performance on the Geographic Relational Thinking Test were able to explain their choices in a structured manner, clearly addressing all the relevant relationships in the form of generalizations or rules. Also, these three students argued that the interests are often conflicting, and explained that they had balanced these interests in their solution. In other words, they showed not only more structured relational thinking, but also deeper and more extensive relational thinking. This suggests that students who master the grammar of relational thinking are also better in evaluating the effects of planning measures and creating solutions for spatial problems, thereby applying system knowledge.

About two third of the students said that there was no need for support by the teacher during the game, but that the teacher should play an active role afterwards, and organize an evaluative talk. For example, student A4 argued that: "The teacher should not explain anything beforehand. Than it's no fun playing the game. Students have to find out themselves how it works. But teachers should discuss it afterwards. And explain clearly how it works". The other one third of the students said that there was no need for an active role of the teacher at all, and that "just letting students play the game is enough".

Implications

The experiment showed that learning by playing the geogame is a motivating and effective way of learning, but that letting students play the geogame is not enough to achieve maximum learning outcomes. More is needed to make sure that students develop complete system knowledge. When students play the game, teachers should include some time-outs, in which they stimulate students to formulate assumptions and to check these assumptions intentionally. Also, teachers should direct students to the visual feedback.

The Summative Tasks

Task description

After having played the game, students worked on tasks in which they had to summarize the system rules in a partially completed conceptual framework. Students had to draw arrows between planning measures (e.g. 'dike displacement'), system concepts (e.g. 'discharge capacity' and 'storage capacity'), and land-use functions or interests (e.g. 'safety' and 'public satisfaction'). This part of the experiment aimed at providing insight into how students learn when such tasks are combined with game playing activities, and how they should be integrated in lesson series with GST in order to optimize the learning outcomes.

Results

Most students found the task useful, as it helped them to summarize what was learned, and to structure their knowledge. For example, student A3, who performed low on the Geographic Relational Thinking Test, argued that: "It was good that the task was done afterwards. Then you can summarize, and test if you really understand it. […] I thought I completely understood everything, but it was at some points still difficult, and I really had to think. For some things, I did not know how to draw them". Although almost all students found the task useful, students varied in their opinion about how motivating the tasks were. A part of the students, especially those with a meaning-directed learning style, found the task fun. They also spent considerably more time on the task. Some other students found the task a bit boring, and tried to finish the task as fast as possible. Still, most students argued that such tasks should be done more often in geography education.

Although all students had reached a maximum or almost maximum score in the game, most of the conceptual frameworks contained some errors. Students especially found it difficult to correctly include indirect relationships in their frameworks. The same counted for interactions (e.g. the influence of the width of the floodplain on the effectiveness of dike displacements on the discharge capacity), although many students implicitly referred to interactions by themselves, by saying things such as: "But is does not always have positive effects"; and "It depends on the location". In about half of the one-on-one discussions, the first author of this paper offered help by explaining the conventions, and modelling the process of identifying a moderating variable and drawing an interaction in the framework. Doing so, he also expressed the interactions verbally in the standard format. Most students said they understood the procedure, but still found it difficult to make the moderating variables and interactions explicit themselves in new situations (Figure 9A and 9B).

Implications

The experiment shows that letting students summarize what was learned in a conceptual framework is a useful way to structure and deepen the knowledge that students have gained while playing a game. When students are not familiar with such tasks (as was the case with the students who participated in this study), teachers should pay attention to the visual grammar of relational thinking, and explain the conventions for constructing such frameworks. Also, teachers should provide support during the task, and discuss the task afterwards. As not all students find it motivating to work individually on such tasks, the teacher could also decide to skip the task and draw the conceptual framework on the digiboard or blackboard for the students, thereby asking them for input. Teachers could help students structure their system knowledge by alternating between verbalizing and visualizing relationships.

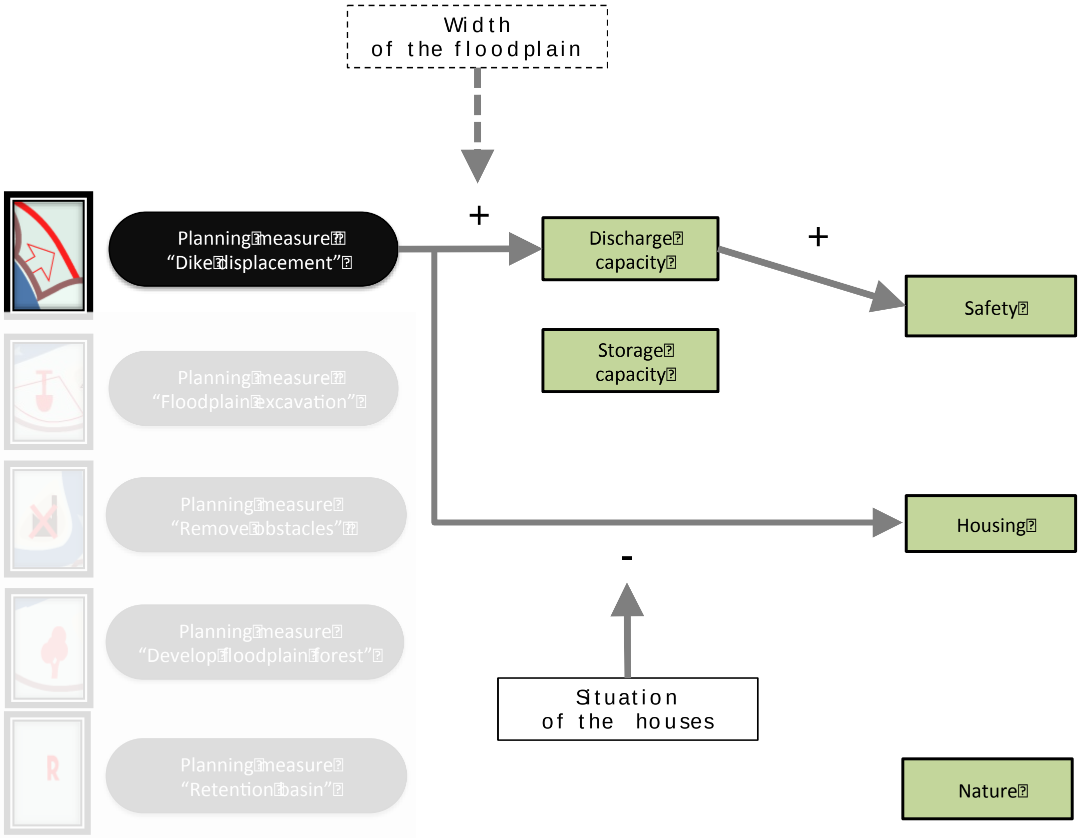

Figure 9A.
Conceptual framework of high-performing student M (Solid blocks and arrows = drawn by student M3; Dashed blocks and arrows = drawn by the first author)

Actor	*Spoken*	*Action*
Student M3	The safety increases.	<draws an arrow from the planning measure “dike displacement” to “discharge capacity”, and from “discharge capacity” to “safety”>
Student M3	But…. Uhmm… that is not always the case. It depends on the local circumstances. And that is often a plus. But at some places it doesn’t matter…. And it also affects the public satisfaction. That is usually negative. But sometimes it does not matter. It could be that …. Uhmm. It depends on where they live.	
First author	Do you know how to include these relationships in the framework?	
Student M3	Plus minus. Something like that? If you …. Wait a moment. I think it is better to indicate per situation what the effect is. It depends on the location. But how… Uhmm…	
First author	What do you mean when you say: “It depends on the location?”	
Student M3	Well, have a look at this location. It [the floodplain] is very wide here. If we move the dike here, where the water already flows well, then it [the dike displacement] doesn’t have a large effect. There is little extra for the discharge capacity. But for this location [a narrow floodplain] it can be the helpful.	< points to a location with a wide floodplain> <points to a location with a narrow floodplain>
First author	How can you draw that in the framework?	
Student M3	Uhmm… I don’t know.	
First author	Well, what you are saying is that the strength of this relationship is influenced by something else: the width of the floodplain. What we can do is, we can write “width of the floodplain” here, and draw and arrow to the plus symbol. The effect depends on the width of the floodplain. At places where the floodplain is wide, …	<points to the arrow between the measure “dike displacement” and “discharge capacity”> <writes an new moderating variable: “width of the floodplain”, and draws an arrow to the relationship>
Student M3	...it will not matter very much…. Yes, the effect will then be small. And at places where the floodplain is narrow, the effect will be large. You see? The width of the floodplain influences the strength of the relationship. …. Ant the safety.	
First Author	Yes. So, let’s have a look at the effect of a dike displacement on the public satisfaction. You also said: “It depends on the location”. How can you include this in the framework?	
Student M3	Whether there are houses or not.	<includes a new moderating variable: “houses on the dike?”, and draws an arrow to the relationship>

Figure 9B.
Transcript of the learning process of high-performing student M3

Implications

The experiment shows that letting students summarize what was learned in a conceptual framework is a useful way to structure and deepen the knowledge that students have gained while playing a game. When students are not familiar with such tasks (as was the case with the students who participated in this study), teachers should pay attention to the visual grammar of relational thinking, and explain the conventions for constructing such frameworks. Also, teachers should provide support during the task, and discuss the task afterwards. As not all students find it motivating to work individually on such tasks, the teacher could also decide to skip the task and draw such the conceptual framework on the digiboard or blackboard for the students, thereby asking them for input. Teachers could help students structure their system knowledge by alternating between verbalizing and visualizing relationships.

The WebGIS Tasks

Task description

In the fourth part of the experiment, students had to study real water-related challenges, with the help of a WebGIS called '*EduGIS'*. Students worked on tasks in which they had to investigate which planning measures were taken in the Delta Region and River Region in The Netherlands in the past few decades, and explain why these planning measures were taken at these locations. In order to do so, students had to analyse several map layers: map layers of the water system in 1950 and 2010; map layers of land use in 1950 and 2010; a population density map; an elevation map; and a map layer of the inundation depth in case of a dike breach. In this task, students had to apply the system knowledge that they had gained when playing the geogame. The task was highly structured: the handout exactly explained which map layers to add, where to zoom in or out, and where to focus attention.

Results

All four students with a reproduction-directed learning style, and some other students (among them students M2 and A1, who used a structured approach in the first task), conducted the tasks entirely as intended. These students were able to describe the measures that were taken, and give reasonable or good explanations, thereby applying the knowledge they had developed by playing the geogame. Other students did not answer the questions correctly, or could not find any answer at all. Those who deviated only a little from the handout did not switch the right map layers on, did not zoom in to the right location, or did not focus attention to the right phenomena, and subsequently missed the necessary information. Some of them (especially A4, A5 and U3) got stuck or skipped parts of the task.

Almost every student who completed the task as intended found the task useful. Some argued that the set-up of the lesson series was good: first developing system knowledge by playing a geogame; then organizing the system knowledge in conceptual frameworks; and finally applying the system knowledge in real-world situations. For example, student M3 argued that: "The game had already shown how the problem is structured, and what you can do about it. The game was realistic, but also simple. Now you can see how it really is. And in reality it is more complex than in the game, but the most important things were also in the game. Without the game, I would not have thought of taking farmers into account. And that they need fresh water."

Although these students found the highly structured task with the WebGIS useful, they had mixed feelings about the 'degree of fun'. Students with a reproduction-directed learning style appreciated the tasks as they were told exactly what to do. For instance, student R2 argued that: "Yes, I liked the task. It was not too difficult. The handout was very clear and told me exactly what to do." In contrast, the four students with an undirected learning style and some other students said that the task was boring and did not connect to their way of learning. For these students, the task was too much "do this, does that". Some said that they preferred tasks in which they could explore issues themselves, while others thought that highly structured handouts are the only option for reaching the learning goals. For example, student U1 argued that: "I understand that it is necessary [to follow a highly-structured handout], because otherwise you do not see it [the relationships]. But it is much less fun than the game".

Implications

The experiment with the WebGIS provided a dilemma. On one hand, it seems necessary that tasks with a WebGIS should offer a lot of structure, so that students see what we want them to see. On the other hand, providing students with a highly structured handout does not match with all learning styles. Some students will miss certain information or get stuck because they find it difficult to follow the handout carefully, while others will drop out because they find the task boring. We should therefore explore alternative designs for the task, and possibly offer students differentiated tasks, depending on their learning style. When exploring alternative designs for tasks with a WebGIS, it is important to note that relationships in digital maps only become apparent for students if they consciously search for them. In the experiment, the task provided a motive. However, it would be better if students formulate assumptions about relationships themselves. This will drive them to search for relevant new map layers, zoom to the right location, and focus attention on the right information in the map window. Again, this requires an active role of the teacher. The teacher should stimulate students to formulate assumptions about relationships, and to systematically check their assumptions.

The Survey

Task description

At the end of the experiment, the eighteen students filled in a short survey in order to collect some quantitative data about students' opinion of the lesson series as a whole. The same survey was also conducted in the previous effect study, but the results were not reported in the previous paper (Favier & Van der Schee, 2014)

Results

The survey data shows that the students who participated in this study found the lesson series with GST as a whole interesting, useful and fun. Average scores for these items ranged between 4.1 and 4.3 on a 5-point Likert scale. According to most students, the degree of difficulty was 'just right' (Figure 10). When the same lesson series was conducted in realistic classroom settings in the previous effect study (n = 139), the scores were slightly lower. This may be because the students who participated in the process-oriented experiment received a more personalized treatment. An unpaired t-test showed that this difference was not significant though (p values between 0.06 and 0.26). However, the students who had followed the lesson series with GST found the lesson series significantly more interesting, useful and fun ($p < 0.0001$) than the students who had followed an equivalent lesson series with the schoolbook ($n = 148$). So, the effect study indicates that lessons with GST can contribute to higher student achievement as well as higher student engagement. The interviews conducted in this study suggest that students are, on average, more engaged when they work on tasks with a geogame than when they work on highly structured tasks with a WebGIS.

	This study		*The previous effect study*			
	Lesson series with GST		*Lesson series with GST*		*Lesson series with the schoolbook*	
	Laboratory setting		*Classroom setting (experimental group)*		*Classroom setting (control group)*	
	n = 18		*n = 139*		*n = 148*	
	M	*SD*	*M*	*SD*	*M*	*SD*
Interesting	4.1	0.5	3.8	1.1	3.0	1.2
Useful	4.3	0.5	3.8	1.0	3.1	1.1
Fun	4.1	0.5	3.7	1.1	2.7	1.1
Difficult	3.0	0.8	2.7	1.0	2.7	0.9

Figure 10.
Average scores on a 5-point Likert scale for the survey question: "How did you experience the lessons series?" for students who participated in this study and in the previous effect study

Conclusions and Discussion

A previous effect study showed that a lesson series with a geogame and a WebGIS had low to moderate positive effects on the development of students' geographic relational thinking, in comparison to a conventional lesson series with the same learning goals (Favier & Van der Schee, 2014). This study, which had a more process-oriented character, provided more insight into the characteristics of students' learning processes when they work on tasks with these applications, and the factors that determine the success of students' learning. As the number of students was small, and students were not selected at random, we have to be careful in generaziling the results of this study for geography education as a whole. Nevetheless the results of both studies give food for thought.

First, the findings of the study indicate that students with different learning styles use different strategies when playing the geogame and when working on highly structured tasks with the WebGIS. However, the geogame seems to accommodate these differences in learning styles, as all students were able to complete the game. In contrast, the highly structured tasks with a WebGIS fit well with a reproductive learning style, but poorly with an undirected learning style. It matches on partially with a meaning-directed and application-directed learning style. Therefore, a follow-up study should explore alternative designs for the task with the WebGIS, so that we can provide students with differentiated tasks.

Second, the findings of the study suggest that formal relational thinking and functional relational thinking go hand in hand. Students who master the grammar of relational thinking are better able to recognize geographic relationships, organize their knowledge about geographic relationships, evaluate the effects of spatial planning measures, and create solutions for spatial problems. Tasks and coaching should therefore pay attention to the linguistic aspects of relational thinking.

This study suggests that even higher learning outcomes can be achieved than were reported in the previous study. In order to realize higher learning outcomes, all components of the design require attention. We do not only need appropriate educational applications, but also well-designed differentiated tasks and an active role of the teacher. When students work on tasks in which they have to recognize relationships in digital maps, teachers should clearly explain to them the procedures, perhaps providing a couple of examples. Also, students should be stimulated to formulate assumptions about relationships in the maps, and to check these relationships systematically, as students do not always do that by themselves. In order to help students structure their system knowledge, it seems to be effective to include tasks in which they have to complete conceptual frameworks. As such tasks are difficult for students, teachers should offer support and discuss these tasks afterwards. In one-on-one or whole class discussions, teachers should try to stimulate students to explain their thinking, and to structure their system knowledge via dialogical teaching. They should stimulate students to make relationships explicit in the verbal form (as generalizations and rules) and visual form (as arrows in a conceptual framework).

This experiment was only a small qualitative research, and more research should be done to establish the factors that determine the learning outcomes of geography education with GST. We recommend conducting a largescale quantitative research that takes all relevant independent variables into account, including learning styles, background knowledge, and experience with technology and task design. Although the test group in this study was too small to provide reliable insight into the different factors that determine the learning outcomes, the experiment does indicate that relational thinking is learnable at least for a large part of pre-university students. The question is, is it also teachable? The lessons series uses relatively simple GST applications. In the previous effect study, teachers' GST skills were not a limiting factor for conducting the lessons with the geogame and WebGIS. However, developing deep relational thinking with GST requires an active role of the teacher. During the effect study, it was noticed that some teachers did little more than letting students work on the tasks with GST, while others actively supported students and also tried to organize evaluative discussions at the end of the lessons. The support and evaluative discussion usually had more characteristics of a one-way instruction from the teacher to the students than of dialogical teaching. So, for teachers, stimulating deep relational thinking would imply somewhat of a mind shift. Next to this, it also requires them to have extensive Pedagogical Content Knowledge. Not only should teachers be able to structure their own system knowledge and make it accessible for students, they should also be able to design good tasks and interventions to raise students' relational thinking to a higher level. It is not strange that the teachers found it difficult to provide good support, as they were not trained in stimulating relational thinking in a systematic way. Teachers need help, and should be supported by providing in-service teacher training courses. However, such courses are non-existent, as stimulating relational geographic thinking via dialogical teaching is an almost unexplored terrain. Researchers in geography education should therefore provide more insights in this field, which can be used by teachers in practice. In this respect, this study is only a first step.

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