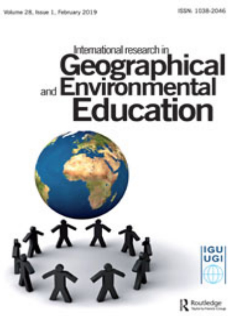

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Students' geographical relational thinking when solving mysteries

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ABSTRACT

Geographical relational thinking is an important part of geographical thinking. This descriptive research was conducted to seek evidence on students' ability to establish geographical relationships which could help teachers to foster their geographical relational thinking. Sixty-nine small student groups from six secondary schools in the Netherlands were observed when solving a mystery. All relationships students established were analysed and the SOLO-taxonomy was used to analyse how coherent their solutions were. The results revealed that students had difficulties with complex, abstract and physical geographical relationships. A large proportion of the groups also had difficulties understanding the interdependence of the relationships. These findings underpin the usefulness of activities like mysteries which offer opportunities to practise, assess and teach geographical relational thinking in geography lessons.

KEYWORDS
Geographical relational thinking; mysteries; geography teaching; students, thinking skills

Introduction

Relational thinking is at the core of the secondary school subject of geography. Thinking about interconnections from global to local scales characterises the geographical perspective (Geographical association, 2012; Jackson, 2006). Lambert (2004, p. 1) argues that interdependence is "perhaps the key geographical concept." Recent research has revealed, however, that identifying, analysing, explaining and evaluating geographical relationships is difficult for many students in secondary education (Favier & Van der Schee, 2014a; Karkdijk, Van der Schee, & Admiraal, 2013). For this reason deliberate attention should be paid to geographical relational thinking in education and research. We conducted this descriptive research to gain more insight into which geographical relationships students were able to establish and which caused difficulties. We used the mystery, a problem-solving strategy devised to provoke geographical reasoning and relational thinking by students (Leat & Nichols, 2003). We also wanted to know how coherent students' solutions to the mystery would be. Our research aim was to provide more evidence on students' ability to establish geographical relationships, which can help teachers to find ways to advance their geographical relational thinking.

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Relational thinking in school geography

How can we describe geographical relational thinking? The International Charter on Geographical Education declares "the study of human activities and their interrelationships and interactions with environments from global to local scales" as the content of geography (International Geographical Union, 2016, p. 4). Understanding human–environmental relationships has always been important within the discipline (Golledge, 2002). The units of analysis to study these relationships are concrete regions (Favier & Van der Schee, 2014a), which change continually in our globalised and interconnected world. In order to describe geography as a school subject, Van der Schee (2000) designed a geographical analysis model. This model distinguishes two kinds of interactions that cause regional change. First, vertical relationships are distinguished: interactions within and between human and natural systems, within regions. These interactions are also possible between factors on different scales but they cause changes in particular regions. For example, global climate change will affect farmers' practices in the inner Niger Delta. Second, the model distinguishes horizontal relationships: interactions between (sub)regions. Changes in one region cause changes in another connected region. For example, a flow of migrants from one region to another causes changes in both regions. Horizontal and vertical relationships together are geographical relationships: they make and change regions where people live.

We define geographical relational thinking as a core element of geographical thinking, containing the analysis, explanation and/or evaluation of the vertical and horizontal relationships (the geographical relationships) that cause change in regions on different interconnected scales. In this reasoning process, students have to apply their geographical conceptual knowledge to specific regional contexts. It therefore demands higher order thinking skills (Favier & Van der Schee, 2014b).

Mysteries in geography education

A mystery is a complex strategy of the thinking through geography (TTG) program. Developed in the 1990s in the UK, the TTG-program focuses on the "infusion" of higher order thinking skills in geography lessons (Moseley et al., 2005, p. 28) such as creative thinking, reasoning and establishing relationships (Leat, 2001, Leat & Nichols, 2003; Vankan & Van der Schee, 2004). The mystery is a complex strategy and therefore not widely used by geography teachers (Hooghuis, Van der, Van der Velde, Imants, & Volman, 2014; Leat, Van der Schee, & Vankan, 2005), but it is "probably the most powerful strategy" of the program (Leat, 2001, p. 51). The problem of the mystery is always an open question formulated as a cognitive conflict that triggers students to think. A mystery consists of three parts: first, the introduction of the problem and the required instructions; second, small group collaboration where students have to use 20–30 information strips to solve the mystery; and third, a whole-class debriefing. Mysteries offer teachers opportunities for diagnostic and formative assessment. Teachers can listen to students' discussions and observe their manipulation of information strips to signal misconceptions and assess their level of understanding (Leat & Nichols, 2000, 2003).

To date little research has been done to analyse student learning by solving and evaluating mysteries. Leat and Nichols (2000) conducted a descriptive study into student activities in small groups to solve a mystery in secondary education. They focused on the process of manipulating the information strips and observed five stages. In the *display stage*, the strips were read to comprehend the information they contain. In the *setting stage*, groups analysed and classified the information on the strips. Most groups proceeded to the next stage, the *sequencing and webbing stage*, where relationships between information strips were established. In the *reworking stage*, new and more coherent relationships were established. A few groups moved to the *abstract stage*, where discussions were more abstract, extending beyond the given data. According to the authors, student activities and discussions in these stages coincided with the thinking processes described by the levels of the SOLO-taxonomy, indicating a progress in complexity of thinking as a group moved from one observed stage to the next (Leat & Nichols, 2000, 2003). The SOLO-taxonomy, developed by Biggs and Collis (1982), describes the quality of responses on the basis of the structure of the learning outcomes (SOLO) and has five levels:

(1) the *prestructural level*: no relevant datum is given to the question;
(2) the *unistructural level*: one datum is correctly related to the question;
(3) the *multistructural level:* two or more data are correctly related to the question but without interrelationships between the data;
(4) the *relational level*: two or more data are correctly related to the question and interrelationships between these data are given to make a coherent explanation;
(5) the *extended abstract level* where abstract principles are used to hypothesise beyond the given data (Biggs & Collis, 1982).

Two effect studies showed the positive effect of the use of mysteries on students' relating skills. Van der Schee, Vankan, and Leat (2006) measured a significant positive effect of using three TTG strategies (five W's, reading photographs and mystery) on the number of relationships established by students in lower secondary education. A larger scale research study revealed that the repeated use of mysteries helped secondary school students to establish relationships (Karkdijk et al., 2013).

Although some research has been carried out on the learning processes and the effects of the use of mysteries, there is a lack of evidence on the nature of students' geographical relational thinking while solving a mystery.

Research aim and research questions

The aim of this descriptive study was to seek more evidence on students' ability to establish geographical relationships, which could help teachers to find ways to advance their geographical relational thinking. We used mysteries to elicit students' reasoning. Our research questions were:

(1) Which geographical relationships do students in small groups establish to solve a mystery?
(2) How coherent were the solutions to the mystery posed?

We expected our study to provide insights into possible deficiencies in students' geographical relational thinking. Deficiencies could consist of a lack of certain important relationships within their reasoning or the formulation of incomplete relationships (first question). Because of the difficulties students have with relational thinking, we also expected that a large proportion of the students would come up with a solution below the relational level of the SOLO-taxonomy, showing a lack of insight into the interdependence of relationships (second question).

Methodology

Materials

We designed two mysteries using the design principles of Leat and Nichols (2003). Both were reviewed by an educational geographer familiar with the TTG-program and mysteries and tested by two geography teachers in classrooms. The mysteries were regional case studies concerning relationships between man and environment and between local actors within a specific region, and hence we considered them to be geographical mysteries. The Rio mystery questioned the decision of a slum dweller (Fabio) not to move out of his favela which was threatened by landslides into another house in the suburbs of Rio. The focus was on understanding the geography, society and economy of Rio to explain his decision. The Jakarta mystery asked students to evaluate the complaint of a Jakarta official that slum dwellers along rivers in Jakarta were causing the floods in Jakarta. The focus was on understanding the hydrological system of the river basin and delta where Jakarta is situated in order to evaluate the accusation. We present the content of each mystery in more detail in the "Results" section of this study.

Participants

Twelve qualified and experienced geography teachers and 205 students from six secondary schools in the Netherlands participated in our research project. The project was carried out between January and June 2015 in the senior years of Higher General Secondary Education (HAVO, fourth and fifth years) and Pre-University Education (VWO, fourth, fifth and sixth years) with students in the age range 15–18 years. The teachers formed three groups of three students each from their class, using their geography grades: one group of students belonged to the highest 30% of the class, one group to the lowest 30% and one was a mixed group (1 student from the highest group and 2 from the lowest). Because of absenteeism among the selected students, the teachers had no option other than to select another student in some cases. In 11 cases, therefore, the group composition did not fit into one of the three categories and those groups were assigned an intermediate position (Table 1). The teachers decided which class would work on the mystery, because it had to match the content of their curriculum. We observed 69 groups: 35 groups solved the Rio mystery and 34 groups solved the Jakarta mystery. Table 1 shows the distribution of the groups regarding geographical ability, gender, educational level and year.

Intervention

After the teacher had introduced the mystery and given the instructions to all the students, each of the three selected groups had to work in separate rooms. They had to represent their solution as a free style concept map (structured by the group as they wanted to

Table 1. Distribution of groups regarding geographical ability, gender, educational level and year.

	Rio	Jakarta
Total number of groups	35	34
Geography grades		
Groups in highest 30%	11	11
Groups in lowest 30%	9	12
Mixed groups	8	7
Intermediate groups	7	4
Gender		
Girls only groups	5	11
Boys only groups	7	5
Mixed groups	23	18
Educational level and year		
HAVO 4	17	3
HAVO 5	0	19
VWO 4	9	3
VWO 5	6	6
VWO 6	3	3

represent their solution). There is evidence that concept maps are a representation of learners' knowledge structures and give insights into students' understanding of relationships between concepts (Srinivasan, McElvany, Shay, Shavelson, & West, 2008). Because the teachers lacked the time, their students did not practise with constructing a concept map, but were given an example and a short instruction on how to construct it. They had to formulate the concepts, draw the cause and effect arrows and verbalise the linking phrases by themselves. This task was clearly at the low end of teacher-directedness, to be as "content rich" and "process open" as possible (Ruiz-Primo, Shavelson, Li, & Schultz, 2001, p. 102). Evidence suggests that this construct-a-map-technique is the best, the "gold standard", for revealing students' knowledge structures (Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005, p. 166). Although more difficult to analyse, "concept mapping tasks that do not constrain the responder have the highest validity for measuring student knowledge" (Wehry, Monroe-Ossi, Cobb, & Fountain, 2012, p. 86). Each group was given the time they needed to complete their work and received only limited scaffolding from the researcher (how to construct the concept map). A camera captured the group discussions.

Analysis

Relationships

The observed group discussions were transcribed in full and analysed in conjunction with the concept maps for formulated correct and relevant relationships. All relevant connections that the groups established between pieces of information provided within the mystery or added from outside to solve the problem, were considered as correct geographical relationships. Some connections were on the conditional side of the problem, others on the direct cause and effect side or on the spatial side, but we did not draw a distinction between these different kinds of connections, since we were only interested in the students' ability to establish the necessary relationships in order to understand and explain the regional problem of the mystery. We also decided not to distinguish between vertical and horizontal relationships, because our focus in this contribution was on the establishment of geographical relationships to solve the mysteries, no matter whether they were horizontal or vertical.

Concept maps

The scoring system for the established relationships on the concept maps, and within the transcriptions of the group work, was constructed with two raters who were qualified and experienced geography teachers. As many relationships as possible were discussed for each mystery and then formulated and summarised in an "ideal" concept map. These relationships consisted of concepts provided within the mystery and of concepts that students added to their solutions. After the scoring system was completed, each rater analysed four groups for established relationships. The inter-rater reliability between the researcher and the two raters for concept maps and transcriptions together was satisfactory (κ = 0.823). The intra-rater reliability test of four groups (two from each mystery) for concept maps and transcriptions together was also satisfactory (κ = 0.725).

Groups represented the structure of their solutions in their concept maps, visualising the degree of coherence of the relationships. However, great representational differences between maps hindered analysis. For this reason, the relationships a group established were put into the same standard format of the raters' "ideal" concept map. This standard concept map consisted of relationships a group established, grouped together into one of the main causes (factors) for the problem of the mystery. These factors were determined by the designer of the two mysteries (first author) and discussed with both raters. The factors were used to design the ideal concept map. For example, Figure 1 gives the factors "house" and "government actions" and some of their relationships (Rio mystery). The factor "house" in the standard concept map contains all relationships concerning the quality of Fabio's house and the factor "government actions" contains all relationships concerning past and present government actions on housing, demolition of favelas, construction of new apartments et cetera.

As groups did not include all their established relationships in their concept maps, we added all other correct and relevant relationships established in the group discussion to

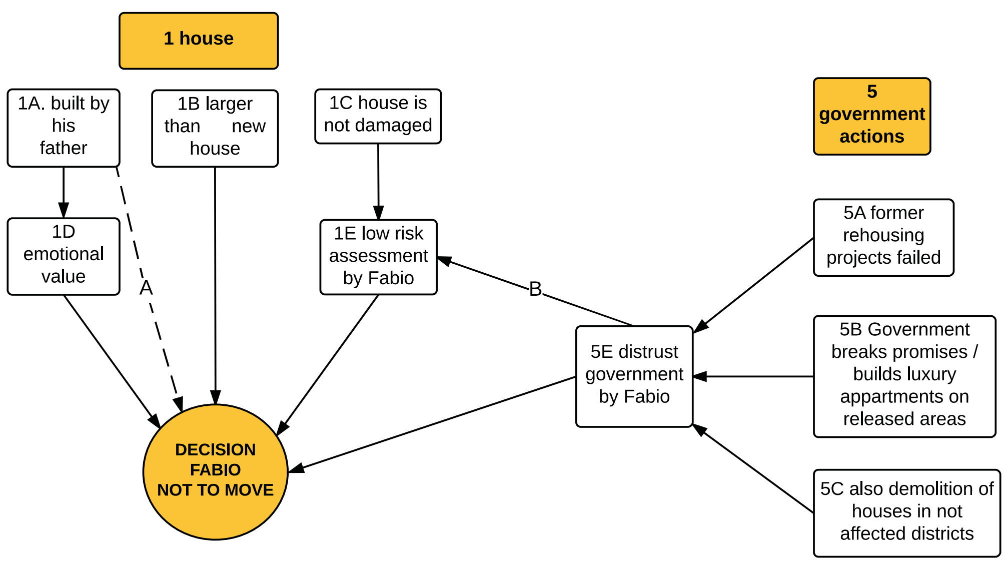

Figure 1. The factors "house" and "government actions" and some of their relationships.

construct a "complete" standard concept map for each group. Finally, we constructed a "total" concept map of relationships established by all groups together for each mystery and analysed these for established relationships.

SOLO-levels

The complete standard concept map of each single group was used in conjunction with the transcriptions of their group discussions to determine the SOLO-level of the solution of each group. We carefully followed the general description of the SOLO-taxonomy of Biggs and Collis (1982), their approach to operationalising the criteria for each SOLO-level for their geography study and Stimpsons' approach (1992), which is in line with Biggs and Collis' approach. In order to analyse students' geographical explanations (Biggs and Collis) or to design SOLO-based ordered outcome questions for geography (Stimpson), three criteria were used to distinguish between SOLO-levels. They were: (1) the number of explanatory factors/pieces of information needed; (2) the interrelationships between these factors; and (3) the use of deductive, abstract arguments, alternative hypotheses and/or generalisations. Our criteria for distinguishing between SOLO-levels, in line with this approach, were: (1) the number of factors correctly connected with the question of the mystery; (2) the use of branches and cross-links as expressions of interrelationships within and between factors; and (3) abstract reasoning and the transfer to other regional contexts. An incompletely connected factor was characterised by one or more incomplete relationships. Incomplete relationships lacked one necessary concept, and thus remained partly unclear. For example, within the relationship: "house built by his father → Fabio's decision not to move" (arrow A in Figure 1), the necessary concept "emotional value" is lacking. If this was the only relationship a group established in the factor "house", this factor would be incompletely connected with Fabio's decision. The use of branches, several relationships coming together in or departing from one concept (5E and 1E in Figure 1), illustrated the ability to establish interrelationships within a factor. Cross-links indicated the ability to formulate interrelationships between factors, and gave the mystery solution coherence (arrow B in Figure 1). A cross-link with an incompletely connected factor was considered as an incomplete cross-link. Group discussions were analysed for the use of abstract reasoning (using alternative hypotheses and/or reasoning with generalisations) and transfer to other regional contexts.

An outcome on the prestructural SOLO-level indicated that no factor was correctly connected with the question of the mystery. An outcome on the unistructural level indicated that the group was able to connect only one factor correctly to the question of the mystery. One or more incompletely connected factors besides the correct one resulted in the transitional level to multistructural. A multistructural response indicated that several factors were correctly connected with the question of the mystery, but without any cross-link between factors. When a group established only incomplete cross-links between factors, the output was on the transitional level to relational. An output on the relational level indicated the use of most factors, the establishment of branches within factors and the establishment of one or more cross-links between factors. The transcriptions of groups with an output on the relational level were analysed for the use of abstract reasoning and other regional contexts. If a group used both, their work was classified as extended abstract. If a group used only one of these, their work was classified as transitional to extended abstract. After detailed instructions and several try-outs and discussions, an experienced geography teacher analysed the work of 12 groups as a second rater and found the same SOLO-levels as the researcher had established.

Results

The results for each mystery are presented separately. After a concise description of the explanatory factors necessary for the solution of the mystery, we present a set of two concept maps of relationships that were established by all groups: one of relationships without cross-links and one of only cross-links (separate for clarity reasons). These concept maps are to be found in Appendices 1–4. The concept maps were designed in a non-hierarchical way to illustrate the essence of each mystery. The weight of an arrow between the concepts is an expression of the number of groups that established that relationship; that number is shown in each arrow. Concepts which were provided within the mystery have a dashed frame. Finally, we present the structure of the solutions, using the SOLO-taxonomy.

Study 1: Jakarta mystery

Six factors were necessary in order to clarify the causes of the annual floods, the contribution of slum dwellers to these floods and to evaluate the complaint of the government official. These were: (1) the deforestation and urbanisation in the region that cause peak flows in the Ciliwung, the main river in Jakarta; (2) the on-going construction of slums in the river beds in Jakarta that causes obstruction, narrowing and hardening of these river beds; (3) the lack of municipal services in Jakarta especially for slum dwellers, resulting in blockages with waste and garbage of the rivers and badly maintained drainage channels; (4) the geomorphology of the region, where rivers come down from the mountains into the delta and lose velocity; (5) the relative sea level rise caused by the absolute rise in sea level and the subsidence of downtown Jakarta as a result of groundwater withdrawal; and (6) the torrential rains of the monsoon that cause peak flows in the river. These factor numbers correspond with the numbers in Table 2 and in the concept maps (Appendices 1 and 2).

Appendices 1 and 2 show, respectively, the number of relationships without cross-links and the number of cross-links established by all groups on their concept maps and in their group discussions. The share of total relationships each factor had is presented in Table 2.

Table 2 gives the percentages of the total relationships per factor and the indexes which show whether a factor had an above or below average share of total relationships (mean = 100). Table 2 shows that factors 2 (slums along the riverside) and 3 (municipal services in Jakarta) had an above average share of total relationships, while factors 1 (deforestation), 5 (relative sea level change) and 6 (monsoon) took a position in the middle ground. Factor 4 (geomorphology) had a far below average share, indicating its possible difficulty for students. Factor 6 (monsoon) also had a below average share, but it only had one concept. This pattern was fairly similar for each year.

Table 2. Relationships per factor within the Jakarta mystery.

Factor	1	2	3	4	5	6	Total
1. Total number of relationships	86	160	131	19	97	55	548
2. % of total relationships	15.7	29.2	23.9	3.5	17.7	10.0	100.0
3. Index total relationships (548/6 = 91.33 = 100)	94.2	175.2	143.4	20.8	106.2	60.2	600.0
4. Concepts per factor	7	9	5	5	7	1	34

A more detailed analysis of the relationships within each factor (see Appendices 1 and 2) revealed differences between the frequencies of the use of concepts (this was also fairly similar for all years). Within three factors (1, 2 and 5), relationships between only a small number of concepts dominated. Within factor 1 (deforestation), the relationships "deforestation causes less infiltration and more sheet flows, which causes floods", were dominant. The other relationships within this more physical geographical factor were mostly neglected. Most cross-links were also established using the concepts of deforestation and less infiltration in combination with peak flows, the monsoon (factor 6) and narrower riverbeds (factor 2). Within factor 2 (slums in riverbeds), the difference in use of concepts was somewhat less pronounced. Most groups formulated the relationships "migrants come to Jakarta and lack of cheap space in Jakarta causes migrants to build slums in riverbeds". The more complex relationship between the building of slums in the riverbeds and the narrowing of these riverbeds to explain floods was established by only approximately half of the groups. Most groups that established this relationship connected this with the not provided concept "less water storage" to explain floods. Within factor 5 (relative sea level rise), three straightforward relationships dominated: "shopping malls pump ground water up which causes soil subsidence which causes floods" and "absolute sea level rise causes floods". The more complex relationship using the not provided concept "river blocked" to explain why absolute sea level rise causes floods was only rarely formulated.

Almost all of the provided, fairly simple and concrete concepts belonging to factor 3 were used by most groups. The physical geographical relationships belonging to factor 4 were complex and abstract: students needed to relate the decreasing slope of the riverbed to the decreasing water velocity in the delta that causes Jakarta's vulnerability to flooding. Factor 4 was also hardly ever used to make cross-links. Factor 6 (heavy rains of the monsoon cause floods) was used by most groups, but the necessary, not provided physical geographical concept "peak flows" to explain this relationship, was far less used. The monsoon, as a source of extra water transportation, was used most frequently of all the factors to formulate cross-links.

Structure of solutions

Table 3 shows the distribution of the groups on SOLO-levels. Fifteen groups had an outcome on relational level or higher: they had a coherent solution with the use of most factors and characterised by interconnections between factors. Four of these groups also used abstract reasoning to explain the floods. Seven groups had an outcome on the transitional level towards the relational level and showed only rudimentary coherence in their solutions. Twelve groups operated (almost) on a multistructural level. Their solution was limited to some isolated factors and was not coherent. There were no groups operating on the prestructural or unistructural level. The mean SOLO-level of groups working on the Jakarta mystery was 4.21: on the transitional level towards the relational level. We found no significant relationships between SOLO-level and educational level (HAVO or VWO) or SOLO-level and year (4, 5 or 6). Our research on the structure of the solutions also gave insight into "loose" relationships, relationships without any connection to floods in Jakarta. For example, one group related the heavy monsoon rains to peak flows in the rivers, but did not relate peak flows to floods. The Jakarta mystery had 58 loose relationships out of a total of 530 relationships (10.9%).

Table 3. Distribution of groups on SOLO-levels and means of correctly connected factors and relationships and loose relationships per level in the Jakarta mystery.

SOLO-level	Number of groups	Correctly connected factors	Correctly connected relationships	Loose relationships	% Loose relationships
1. Unistructural U	0	0	0	0	0
2. Transitional U/M	1	2	3	6	66.7
3. Multistructural M	11	4.5	11.5	2.2	15.9
4. Transitional M/R	7	4.1	11.6	2.1	15.6
5. Relational R	11	5.3	16.2	0.8	4.8
6. Transitional R/EA	3	5.7	20.3	1.3	6.2
7. Extended abstract EA	1	6	22	0	0
Total	34	4.7	13.9	1.7	10.9

Study 2: Rio mystery

Six factors were necessary to explain Fabio's decision to stay in his neighbourhood which was threatened by landslides. These were: (1) the emotional value of his house that was built by his father; (2) the neighbourhood with migrants also coming from north-east Brazil that binds to the community; (3) the great distance from his new home to his work in the centre of Rio that would cause loss of time and money or even put him at risk of losing his job; (4) high land values in the centre of Rio that give opportunities to developers to force favela dwellers out to build luxury apartments for high profits; (5) government actions that reveal that government concerns for the safety of favela dwellers was not the only incentive for the rehousing project; and (6) the organisation of the football World Cup in 2014 and the Olympics in 2016 in combination with the fact that Rio is a major tourist destination. As a consequence of this last factor, Rio attracts many people, which creates a lot of work but could also trigger the government to move the slums away from the centre in order to create a better image of the city. Distrust of government intentions with their rehousing project (an underlying concept not explicitly provided within the mystery) was therefore one of the Fabio's main reasons for deciding not to move. These factor numbers correspond with the numbers in Table 4 and in the concept maps (Appendices 3 and 4).

Appendices 3 and 4, respectively, show the number of relationships without cross-links and the number of cross-links established by all groups on their concept maps and in their group discussions. The share of total relationships each factor had is presented in Table 4.

Table 4 gives the percentages of total relationships per factor and the indexes which show whether a factor had an above or below average share of total relationships (mean = 100). The pattern which Table 4 shows was again fairly similar for each grade. Factors 1 (house) and 3 (location and work) had an above average share of total relationships, as had factor 5 (government actions). Factor 2 (neighbourhood), with a far below average share, was more complex, for students first had to recognise that migrants from the same region in Brazil often constitute close communities in cities by chain migration (not provided in the information). Factor 4 (location and land values), the most abstract one, also

Table 4. Relationships per factor within the Rio mystery.

Factor	1	2	3	4	5	6	total
1. Total number of relationships	110	11	93	56	85	65	420
2. % of total relationships	26.2	2.6	22.1	13.3	20.2	15.5	100
3. Index total relationships (420/6 = 70 = 100)	157.1	15.7	132.9	80.0	121.4	92.9	600
4. Concepts per factor	5	2	6	5	5	7	30

had a below average share of total relationships. Factor 6 (World Cup, Olympics and tourists) had a slightly below average share. This factor was a more complex one, for students had to add intermediate concepts to understand Fabio's decision, like the image of Rio.

A more detailed analysis of the relationships within each factor revealed the differences in use of concepts within each factor (Appendices 3 and 4). The more concrete and fairly simple relationships within factor 1 between the concepts "house built by his father" and "old house larger than the new house" and Fabio's decision were the most used. Within factor 3, the relationships "new house on outskirts of Rio" means "great distance to work" and "long and expensive journeys to central Rio" so Fabio will not move, dominated. Information on the actual location of Fabio's work was not provided; students had to make this inference by themselves. Approximately half of the groups concluded that Fabio's move to the outskirts of Rio would mean a great distance to or loss of his work in central Rio, so they included the concept "great distance to work" in their reasoning. Ten other groups made a shortcut by simply relating a house on the outskirts of Rio to longer and more expensive journeys to central Rio, without any consideration as to why Fabio has to travel to central Rio. Factor 4 was a difficult one, because its concepts were abstract and not all provided. Information was provided on land values in Rio and on the location of Fabio's favela close to the central business district. Students had to make the inference from this information that this central location is very expensive and therefore gives good opportunities for investors (also the government) to make high profits in real estate. Cross-links were mainly established with factor 5 (distrust of government intentions). The relationship "suspicion of the government" with Fabio's decision not to move was a dominant one within factor 5. This relationship was important within the mystery to understand Fabio's decision and students had to make this inference by themselves. Almost half of the groups explained Fabio's decision by using this relationship. Most cross-links were made with factor 5, with the profits to be made by replacing favelas by luxury apartments (factor 4) and with the good image that Rio needed as a tourist city and as host of the World Cup and the Olympics (factor 6). Within factor 6 no relationship clearly dominated.

Structure of solutions

Table 5 depicts the distribution between the groups on SOLO-levels. Fourteen groups working on the Rio mystery operated on relational level or higher; only one of these also explicitly used general rules to explain Fabio's decision. Fourteen groups working on the Rio mystery (almost) operated on a multistructural level and six groups took a transitional

Table 5. Distribution of groups on SOLO-levels and means of correctly connected factors, relationships and loose relationships per level, Rio mystery.

SOLO-level	Number of groups	Correctly connected Factors	Correctly connected relationships	Loose relationships	% loose relationships
1. Unistructural U	1	1	2	5	71.4
2. Transitional U/M	3	2.3	5.7	0.7	10.5
3. Multistructural M	11	2.5	6.3	0.4	5.5
4. Transitional M/R	6	3.2	9.3	1.8	16.4
5. Relational R	13	4.3	14	1.2	7.6
6. Transitional R/EA	1	6	24	2	7.7
7. Extended abstract EA	0	0	0	0	0
Total	35	3.3	10	1.1	10

position between the multistructural and the relational level. There were no groups operating on the prestructural level. The mean SOLO-level of the output of groups working on the Rio mystery was 3.86, between the multistructural and the transitional (M/R) level. We found no significant relationships between SOLO-level and educational level (HAVO or VWO) or SOLO-level and year (4, 5 or 6). In the Rio mystery, groups made 58 loose relationships out of a total of 389 (10%).

Discussion

This descriptive study was conducted to gain insight into which geographical relationships students establish to solve a mystery (first research question) and how coherent their solutions to the mystery posed were (second research question). Both types of information can be understood as indicators of students' geographical relational thinking skills. Concerning the first question, we found that more complex and abstract relationships were formulated less than other relationships and also led to incomplete reasoning.

Concerning the second question, we found that although a large minority of the groups had an outcome on the relational SOLO-level or higher, a large number still had an outcome on the multistructural level or lower, neglecting the interdependence of the factors that caused regional change. Only five groups had an outcome above relational level. Although the mysteries did not ask the students to compare the regional situation in Rio or Jakarta with other regions, groups could have applied theoretical reasoning, using generalisations.

Implications

These findings of deficiencies in students' geographical relational thinking when solving a mystery raise the question of how teachers could help students to advance their geographical relational thinking skills. We make three suggestions.

First, the regular use in geography lessons of teaching strategies like mysteries, focused on geographical reasoning and involving the construction of a coherent solution or explanation, is indispensable. The repeated use of mysteries fosters students' relational skills (Karkdijk et al., 2013). Mysteries also give teachers the opportunity to teach with an explicit focus on interdependence. Renshaw and Wood (2011) used interdependence explicitly as a structuring tool for lessons about interconnected physical geographical themes and conclude that it acted as a threshold concept, giving students new insights into geography as an interconnected whole. Strategies like mysteries also offer teachers opportunities to gain insight into students' shortcomings and difficulties in geographical relational thinking. These insights can be detected from the group discussions and representations, but also during whole-class discussions at the debriefing sessions. These whole-class discussions should be focussed on relationships that are difficult for students, like more complex, abstract and physical geographical relationships.

Second, whether it be when teaching with mysteries or with other geographical assignments or exercises, it would be very useful to ask students to speak aloud in class mentioning all relational steps. Incomplete reasoning and misconceptions would then be detected and could be corrected. In order to be able to help students in their reasoning, teachers should have the necessary subject knowledge of the regional problem at hand.

Third, although our research was descriptive, we suggest the relevance of geographical subject knowledge as an important prerequisite for understanding the problem of the mystery. Knowledge of the spatial pattern of land values in mega cities like Rio will help students understand the economic forces that push favela dwellers away from central locations. Physical geographical knowledge about relationships between a location in a delta and diminishing river velocities on the one hand, and between rising sea levels and water levels in rivers on the other, can help students understand the significance of living on the edge of a delta. This conceptual subject knowledge also facilitates its application to other regional contexts.

Limitations and strengths

A limitation of our research was our decision not to distinguish between different kinds of connections that students made. More detailed research into difficulties that may emerge when students have to differentiate between regional conditions and direct cause-effect relationships or between vertical and horizontal relationships could reveal other obstacles to sound geographical relational thinking. Another limitation was the reliance on students' discussions and concept maps, without being able to talk to the students afterwards and evaluate their results with them. This would have elicited why certain concepts were employed less than others. One of the merits of our research was that it covered many groups from different schools and that students had enough time to work on the mysteries.

Conclusion

We conclude that the use of mysteries, as a tool to engage secondary school students in the geography of changing regions, provides teachers with great opportunities to foster their geographical relational thinking. Attention to students' shortcomings in establishing geographical relationships and a clear focus on interdependence should help students to understand regional change within our dynamic and interconnected world. Being able to reason with geographical relationships should also be an area for teacher trainers in higher geography education to focus on, because teachers' shortcomings will inevitably have repercussions in secondary geography classrooms. Continuing research on the ability of students and teachers to reason with geographical relationships in order to understand, explain and evaluate regional change is strongly recommended.

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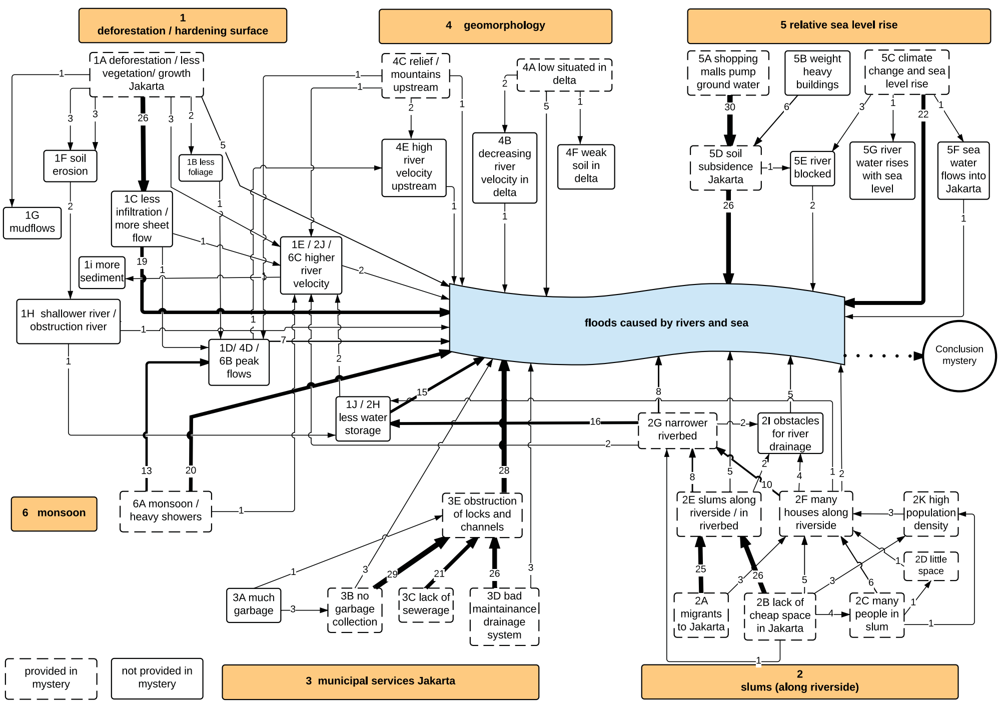
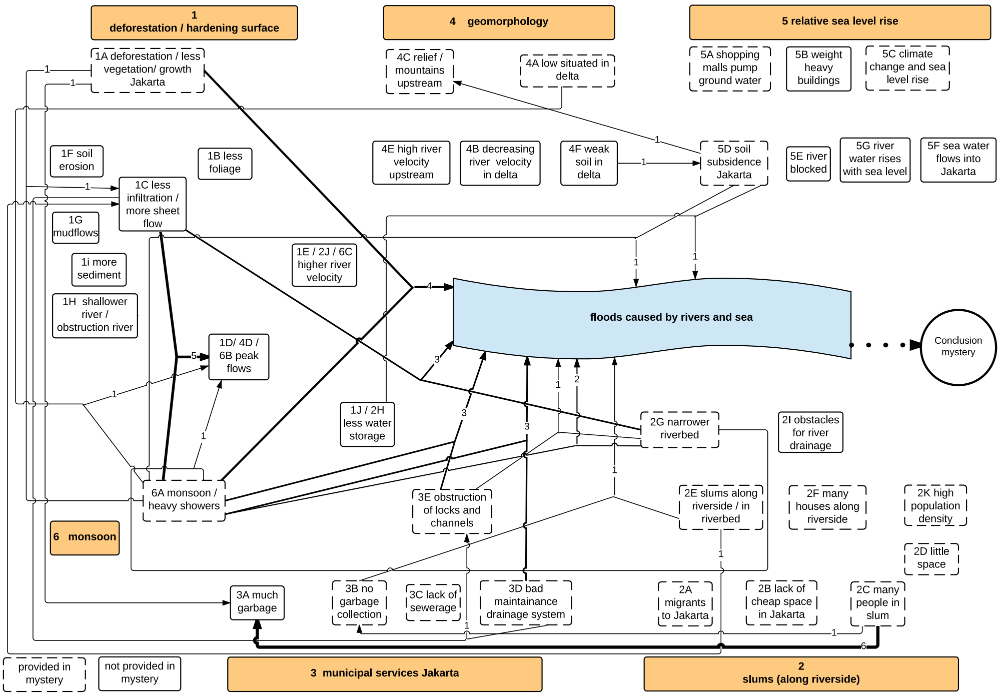
Appendices

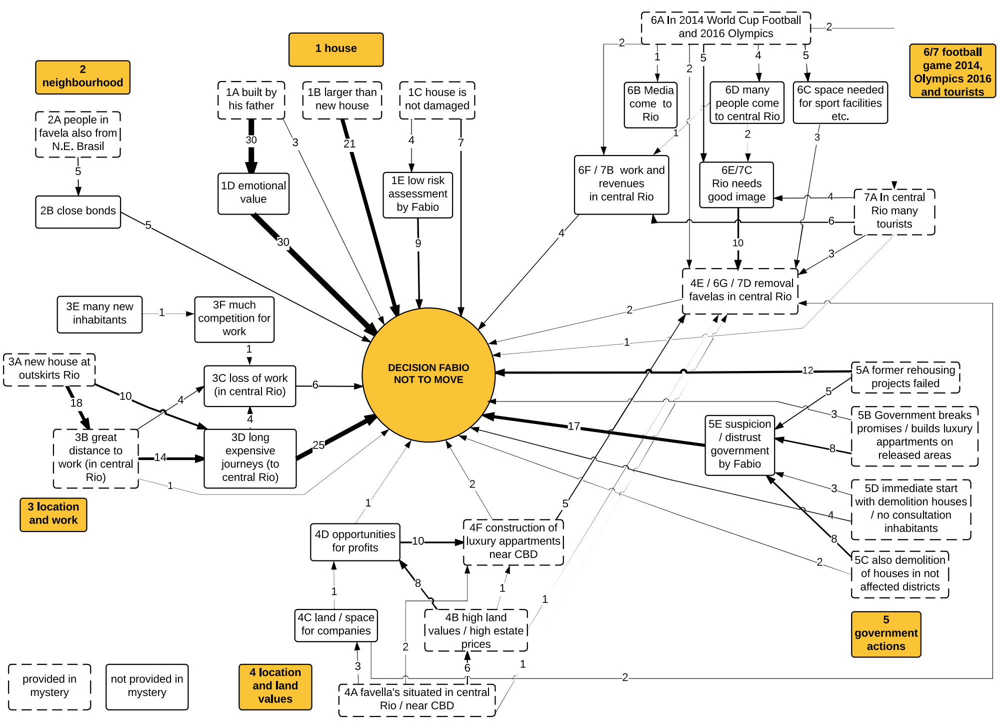
Appendix 1



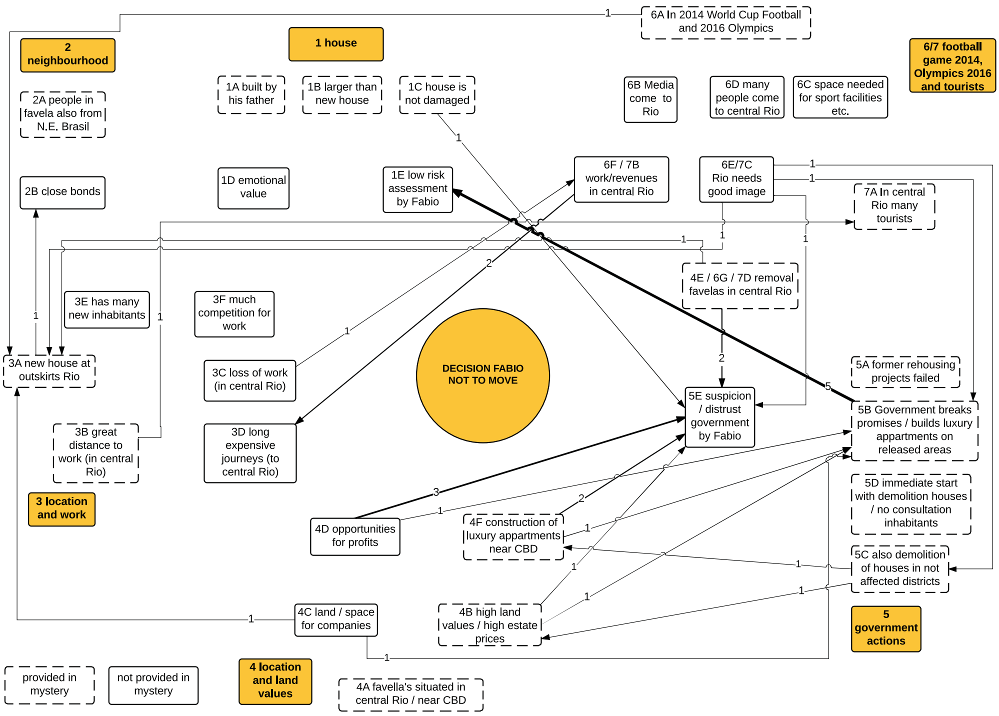
Appendix 2



Appendix 3



Appendix 4



6A In 2014 World Cup Football and 2016 Olympics
2 neighbourhood
1 house
6/7 football game 2014, Olympics 2016 and tourists
2A people in favela also from N.E. Brasil
1A built by his father
1B larger than new house
1C house is not damaged
6B Media come to Rio
6D many people come to central Rio
6C space needed for sport facilities etc.
2B close bonds
1D emotional value
1E low risk assessment by Fabio
6F / 7B work/revenues in central Rio
6E/7C Rio needs good image
7A In central Rio many tourists
4E / 6G / 7D removal favelas in central Rio
3E has many new inhabitants
3F much competition for work
DECISION FABIO NOT TO MOVE
3A new house at outskirts Rio
3C loss of work (in central Rio)
5A former rehousing projects failed
5E suspicion / distrust government by Fabio
5B Government breaks promises / builds luxury appartments on released areas
3B great distance to work (in central Rio)
3D long expensive journeys (to central Rio)
5D immediate start with demolition houses / no consultation inhabitants
3 location and work
4D opportunities for profits
4F construction of luxury appartments near CBD
5C also demolition of houses in not affected districts
4C land / space for companies
4B high land values / high estate prices
5 government actions
provided in mystery
not provided in mystery
4 location and land values
4A favella's situated in central Rio / near CBD