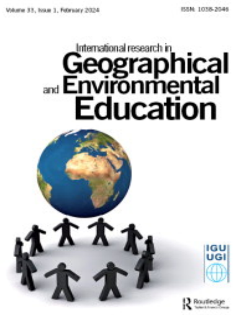

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Causes, processes and consequences of earthquakes. Investigating Swedish 12-13-year old students' geographical understanding

Mattias Arrhenius[a], Gabriel Bladh[b] and Cecilia Lundholm[a]

[a]Department of Teaching and Learning, Stockholm University, Stockholm, Sweden; [b]Centre for Social Science Didactics, Karlstad University, Karlstad, Sweden

ABSTRACT

The aim of this study was to investigate students' conceptions of causes, processes and consequences of earthquakes and to examine their geographical understanding of such hazards in terms of spatial and societal-nature relations. Data consists of 134 responses from 12 to 13-year-old students who had completed an assignment in the Swedish national test in geography (2013). The responses were analysed using content and thematic analyses. Data was complemented with interviews. Results show that many students hold alternative conceptions of processes causing earthquakes at different plate boundaries, and why poor societies are more severely affected by earthquakes than rich societies. Furthermore, results show that students have a limited understanding of the extent and location of earthquakes in the world. We conclude that instruction aiming to develop students' understanding of earthquakes as a geographical phenomenon and hazard may integrate map-reasoning skills with examples that support contextual thinking. We also suggest that in order to develop students' relational thinking on society and nature, instruction can utilise the concept of "capital". Furthermore, teaching needs to take in to account and design instruction to meet students' alternative conceptions that societal consequences of earthquakes are solely predetermined by natural factors such as climate or heat.

KEYWORDS

Alternative conceptions; capitals; causes; earthquakes; geography education processes; society

Introduction

This paper engages with students' conceptions of earthquakes, a geographical phenomenon and hazard which leads to loss of human life and property as well as causing severe risk and threats for livelihood and the economy. Natural hazards and vulnerable places and the relation between nature and society are important themes in the geography curriculum in many countries. In Sweden, knowledge about *plate tectonics*, origins and impacts of *earthquakes* is a part of the geography syllabus, in years 4-6 (Swedish National Agency for Education 2011), since 2011. These themes

CONTACT Mattias Arrhenius mattias.arrhenius@su.se Department of Teaching and Learning, Stockholm University, Stockholm, Sweden.

comprise theories related to both physical and human geography. However, both integrating and differentiating between these two scientific domains is a challenge for young students. Here we focus on earthquakes as they are an important case of a natural hazard, where an integrated geographical perspective could provide a better understanding of the composite context of causes and consequences. In this paper we present results on students' conceptions of earthquakes and their consequences for societies and discuss how instruction can support learning.

Students' conceptions of earthquakes were investigated from a conceptual change perspective, focusing on students' *alternative conceptions,* which implies that these differ from scientific expert views, and are generated from everyday experience and culture (Lane & Coutts, 2012; Lane, Carter, & Bourke, 2019; Mills, Tomas, & Lewthwaite, 2017). Findings in geoscience and geography education research show that students bring their alternative conceptions into the classroom and use these mental models as a lens for organising and interpreting science in order to construct meaning. Alternative conceptions, may appear functional and useful to students in their everyday life, and therefore be firmly embedded in students' wider conceptual framework, hindering them from developing new complex scientific conceptions (Lane et al., 2019).

Previous research has identified alternative conceptions among young students, such as relating the *cause* of earthquakes to heat or climate in general (Ross & Shuell, 1993; Licona, McDonald, Furman, & Guertin, 2013). Research also shows that students have difficulties understanding tectonic *processes* at plate boundaries (Mills et al., 2017) and understanding earthquakes from a geographical point of view, (e.g., *location* in the world) (Licona et al., 2013). The origin of earthquakes and nature of plate boundaries represent challenging topics for teachers, as research shows that students hold persistent alternative conceptions in this domain (Francek, 2013). Furthermore, discussing impacts of hazards such as earthquakes means considering both natural and societal processes and systems (Mitchell, Borden, & Schmidtlein, 2008), which is a cross-disciplinary topic in need of further research in geography education (Stoltman, Lidstone, & Kidman, 2015).

Geoscience and geography education share a joint interest in developing students' scientific understanding of causes and processes of natural hazards (e.g., earthquakes). However, geography education also includes distinct geographical concepts and perspectives which provide students with a holistic understanding of natural hazards by focusing on geographical questions such as 'why', 'to what extent', 'where' and 'how' (Lane & Coutts, 2012; Ishikawa, 2016). This means that students with deep geographical knowledge of earthquakes should not only be able to explain the *causes* and *process* involved in earthquakes, but also understand earthquakes in relation to geographical concepts such as *scale*, *distribution* and *location* and *interaction* with humans. Using such concepts implies relational geographical thinking, both in terms of spatial relations and societal-nature relations. Presently, there is little research on students' alternative conceptions of causes and processes of earthquakes focusing on integrating geoscientific processes with distinct geographical perspectives (Lane & Coutts, 2012). In the light of the on-going discussion on large-scale assessments in geography (Alm Fjellborg & Kramming, 2022; Lane & Bourke, 2017; Stoltman, Lidstone, & Kidman, 2014) and how results from these can contribute to the worldwide geography community, we investigate such conceptions by analysing students' responses in the Swedish national geography test in year 6.

The following questions directed the study:

1. What are students' conceptions of causes and processes of earthquakes?
2. What are students geographical understanding of earthquakes and their consequences in terms of spatial and societal-nature relations?

We first present research on causes and processes of earthquakes, and in relation to geographical concepts. We then present methods and results followed by a discussion on implications for instruction.

Background

Earthquakes, causes and plate boundary processes

Earthquakes occur mainly as a result of large-scale movements of Earth's lithospheric plates. More than 90% of the larger earthquakes (over 8,5 M) in the world occur at the plate boundaries, which covers approximately 15% of the Earths' surface, ranging spatially from single faults systems to diffuse regions of deformation (Cassidy, 2013; Duarte & Schellart, 2016). However, earthquakes may also occur away from the plate boundaries, in intra-plate regions, or induced by human activities such as mining or impoundment of water reservoirs (Foulger, Wilson, Gluyas, Julian, & Davies, 2018). There are three main types of plate boundaries, 1) the plates move apart (*Divergent boundary*), 2) the plates slide past each other (*Transform boundary*), 3) the plates collide (*Convergent boundary*) (Cassidy, 2013). The mechanisms driving the plates are mainly mantle convection and slab-pull. However, seismic tomography has not yet been able to identify convections cells large enough to drive the plates, but instead found cold dense slabs sinking at convergent boundaries and a "slippery layer" at the base of plates. Therefore, slab pull is presently regarded as the main driving force of plate movement (Hawley & Lyon, 2017).

Although the plates move continuously, the boundaries are often "locked" and therefore do not move most of the time. In a timescale of hundreds of years, the boundaries suddenly "unlock", and in this process accumulated motion is released which we know as an earthquake (Kanamori, 2003). The fault type mechanisms (e.g., normal fault, strike-slip, thrust) and magnitude seismicity all vary at the plate boundaries, resulting in different geological events/hazards. For example, transform boundaries (strike-slip mechanism) do not produce tsunamis, nor do divergent boundaries (as long they involve normal faults below sea level). Volcanism on the other hand is associated with divergent and some types of convergent boundaries (e.g., subduction) but not with transform boundaries (Duarte & Schellart, 2016). Apart from destroying buildings and infrastructure, earthquakes cause fatalities and affect the economy and livelihood of people. Besides primary effects such as ground shaking due to energy released in earthquakes there are also secondary effects (e.g., fires, tsunamis, landslides) and tertiary effects (e.g., epidemics, starvation) (Daniell, Schaefer, & Wenzel, 2017).

Hazards, social vulnerability and community capabilities

Mitchell et al. (2008) suggest that students' understanding of hazards is best fostered when using a teaching approach where natural and social processes are equally considered. Investigating earthquakes from a geographical lens, in this case through the geographical concept of *interaction*, directs teaching to an exploration of society-nature relations. Furthermore, using and understanding maps constitute the core of geography and represents the major form of spatial thinking. Thus, investigating hazards through spatial geographical concepts (e.g., *scale, distribution, location*) and spatial relations in vulnerability analysis, contributes positively to students understanding of the totality of a system (Ishikawa, 2016; Shitangsu, 2013).

An important sub concept when analysing hazards is social vulnerability, which means the likelihood for societies to suffer losses from extreme events, and the ability to absorb and withstand impacts (Shitangsu, 2013). This implies that vulnerability is socially and geographically differentiated (Adger & Brown, 2009). The sustainable livelihood framework (Scoones, 1998) is a widely used model for exploring community capabilities when addressing global environmental hazards and defining adaptive capacity when making vulnerability assessments (Birkmann, 2006). Key elements here are the five livelihood assets or capitals (*human, natural, financial, social* and *physical* capital), which can serve as accessible indicators of community capabilities to handle environmental change and hazards like earthquakes. As societies in the world have access to different capitals they are more or less vulnerable to earthquakes. For example, many developing countries have low access to financial, physical and human capital. Approximately 90% of all earthquake fatalities take place in developing countries, often due to aspects such as poor engineering design and construction practices, as well as corruption and lack of preparedness and awareness (Baytiyeh & Öcal, 2016). Many of the buildings that collapsed in the earthquake in Haiti 2010, were poorly constructed (e.g., concrete frames were not reinforced) (Theilen-Willige, 2010).

From a geography curriculum perspective, the above background demonstrates that the theme of earthquakes as hazards provides a fertile context to explore the connections and relationships between the knowledge domains of physical and human geography.

Methods and material

Content and thematic analysis were used for analysing students' written responses in the Swedish national test in geography in grade 6, and the analyses were complemented by focus groups interviews with students.

Sampling process

Written responses from the national test in geography

From the Swedish national test in geography year 2013, data were collected from a total of 134 students in the ages 12 to 13. This was completed with permission by the ethical review board in Sweden. As the study only involved students' written responses, and not included any personal data, the requirement for consent was waived by the ethical review board. In 2013 the national tests in the four social science subjects were dispersed randomly across all schools in Sweden for students in year 6, meaning that students were only tested in one of these subjects. Which test students in a particular school were given was announced to teachers two weeks in advance. In 2013, 23969 students took the test in geography, approximately one quarter of all students in this age group. The purpose of the national test in geography was to a) support an equal and fair assessment and grading in geography, and b) generate data for analysis regarding to what extent the knowledge requirements (grade criteria) in geography are fulfilled on different levels (school, mandator, national). The national test year 2013 contained 28 items concerning four geographical capabilities; natural processes and landforms, geographical relationships, knowledge and skills in maps and sustainable development. All items in the tests were intended to measure one of these capabilities and together cover the syllabus in geography year 4-6 (cf. Arrhenius, Bladh, & Lundholm, 2022). In this study we focus on two items concerning earthquakes, and the specific questions in the assignment asked the students to describe:

a. What causes earthquakes? Explain:
b. Consequences of earthquakes are often more severe in poor countries than in rich countries. Why is it so? Explain:

The assignment included a plate boundary map (question a), and two images taken from the earthquake in Haiti, in 2010 (question b). Next to the plate boundary map there was a text stating "At the plate boundaries earthquakes and volcanic eruptions are common (Figure 1)".

In grading instruction for teachers in the national test in geography year 6, students were expected to have the following knowledge of earthquakes for a pass (grade E).

- Knowing that earthquakes are connected to movement along the plate boundaries.
- Being able to provide a relevant explanation of why poor countries are more severely affected by earthquakes.

The Swedish National Agency for Education (SNAE), in collaboration with the national geography test unit, gathered results from a pre-selected amount of all completed tests, using a sampling procedure based on students' birth date. This is done in order to conduct statistical analysis on the test results. The teachers administrating the test were instructed to report the result of students who were born on the 10th, 20th, 30th every month. In addition, teachers were also instructed to send a copy of the complete paper test of the students born the 10th, thus containing both students' responses and results of the national test. In total, results from 1944 students were reported in 2013 to the SNAE, including 578 complete paper tests. These tests represented the "larger sample" from where data were sampled to this

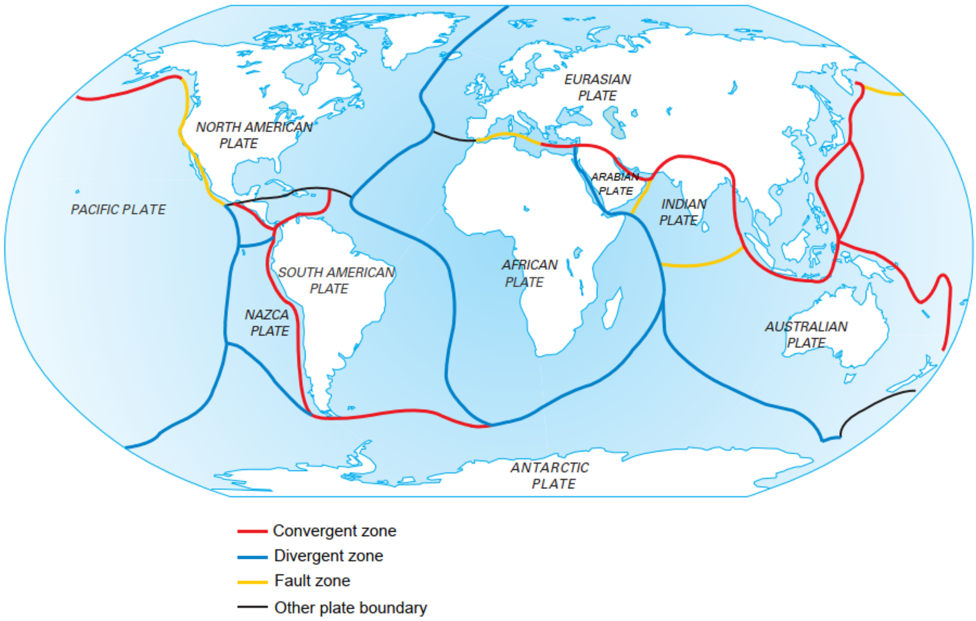


Figure 1. Map in the assignment (translated from Swedish to English). (Permission by Liber AB).

study. As we were interested in investigating students' conceptions on a national level, a randomised sampling procedure was undertaken. Every third response on the assignment of earthquakes in a complete test was extracted from the larger sample until saturation was reached (134 responses), where no additional categories and themes could be identified. Similar to the large sample, the characteristics of the smaller sample represented different schools and geographical areas in Sweden, different grades and were made up of approximately a 50/50 split between boys and girls (cf. Arrhenius, Lundholm, & Bladh, 2021).

Focus group interviews

With parental consent and permission by the ethical review board in Sweden, focus group interviews with 24 students aged 12-13 were conducted in 2017. The purpose of the interviews was to gain a deepened contextual understanding of students' conceptions in the national test. The focus groups interviews were conducted with students of the same age as in the national test at three schools with students of different socioeconomic background and in groups of 6-8. Before the focus group interviews started, students were instructed to complete three assignments from the test in 2013, where one of these was the assignment on earthquakes. The students were given the same questions as in the assignment in the national test, and were also encouraged to elaborate their answers. Importantly, the students were given follow-up questions and questions for clarification in relation to their responses to the questions (a, b) in the assignment (cf. Arrhenius et al., 2022). Gill, Stewart, Treasure & Chadwick (2008) suggest that focus group interviews are a suitable method for exploring possible explanations but also to clarify and challenge data collected by other methods. The interviews can be described as semi-structured (Brinkmann, 2013).

Analysis

Responses from the test-takers in 2013 were analysed manually by two of the researchers using qualitative content analysis regarding *causes* (Elo & Kyngäs, 2008) and thematic analysis regarding *processes* and *geographical concepts* (Braun & Clarke, 2006). Thematic analysis is similar to contemporary qualitative content analysis often used for providing a rich description of students' understanding of an under-researched topic (Braun & Clarke, 2006; Drisko & Maschi, 2015). In the analyses students' conceptions were labelled as alternative, scientific or partial scientific, where partial scientific conceptions can be described as more or less scientifically correct, but lacking important components (cf. Arrhenius et al., 2022).

Students' conceptions of causes and processes of earthquakes

The introduction of question a) in the assignment directed the students to understand that plate boundaries are important places for earthquakes. Consequently, students' conceptions of what type of plate boundaries causing earthquakes were focused in the analysis of the causes. The main categories *convergent boundary, divergent boundary*, *transform boundary* were initially chosen for the analysis, but complemented with *multiple boundaries* and *unclear plate boundary* in order to encompass all students' conceptions of causes in relation to question a). Thus, the analysis involved both a deductive and an inductive approach, which is often used when analysing newly collected data as it may contain aspects not identified in previous research (Drisko & Maschi, 2015). Content analysis involves focusing on either the *latent* or the *manifest* content, thus a choice between levels of depth and repeatability (Downe-Wamboldt, 1992). The analysis of causes focused mainly on manifest meanings and categories were developed representing a descriptive level of content (Graneheim & Lundman, 2004). The content analysis therefore focused on the use of concepts such as "convergent" or "divergent" in students' descriptions of the plate boundary involved in earthquakes. However, as students used everyday words to describe plate boundaries, such as "*plates smash together*" or "*plates split*", latent meanings were also analysed. After coding procedure was completed, frequency was calculated.

Responses belonging to the five main categories of plate boundary related causes were analysed a second time, focusing on students' understanding of processes in earthquakes and using thematic analysis. The thematic analysis involved the following steps, described by Braun and Clarke (2006): 1) familiarising yourself with data, 2) generating initial codes 3) searching for themes 4) reviewing themes 5) defining themes 6) producing the report. Although the first part of the analysis of the processes contained a deductive component (categories to themes), the second part of the analysis was conducted in an inductive manner. The familiarisation process involved looking for patterns, moving back and forward through the entire data set (step 1). The initial coding (step 2) involved generating codes and relating data to these codes, similar to Lane and Bourke (2017). In the analysis of the processes, coding focused on students' conceptions of plates interacting and processes (e.g., tension, release) involved in earthquakes. The analysis concluded on eight different subthemes (e.g., two plates collide) within the five main categories/themes of causes (step 3-5).

Students' geographical understanding of earthquakes and their consequences in terms of spatial and societal-nature relations

The thematic analysis of students' understanding of earthquakes in terms of spatial relations (scale, distribution, location) took an inductive approach, focusing on the responses to question a) in the assignment. In the analysis of the scale and distribution, the initial coding (step 2) focused on different plate boundaries that students associated with earthquakes. In the analysis of location, the initial coding (step 2) focused on places that students associated with earthquakes and whether these were relevant or not in relation to the plate boundary described by students. The analyses concluded on three themes concerning scale and distribution, and three themes of location (step 3-5).

The thematic analysis of students' understanding of earthquakes in terms of societal-nature relations (interaction) focused on responses to the second question b). The initial coding (step 2) focused on the factors/explanation that students discussed as to why consequences of earthquakes are more severe in poor than in rich societies. The analysis concluded on two themes; students' conceptions related to societal factors and societal explanations, and students' conceptions related to natural factors and natural explanations. In a *second* phase subthemes within these themes were identified. Here we use the "sustainable livelihood" framework including five capitals as a broad analytical framework (step 3-5).

Trustworthiness

By letting researchers with similar educational and professional backgrounds, code the material and then compare results, high reliability is likely to be ensured (Krippendorff, 2004; Drisko & Maschi, 2015). The two researchers who were involved in coding procedure are experienced geography teachers at high school level and university level and share experience in using content and thematic analysis. Concerning the analysis of the causes of earthquakes, Cohen's Kappa interreliability test was conducted after 50% of the responses were coded, showing a good match (0,92), which is considered a desired level of agreement (Downe-Wamboldt, 1992). As for the thematic analysis, the coders discussed their individual coding and potential themes and subthemes together. Discussions concerned deviant interpretations of some responses, whether conceptions were alternative or not, or to which subtheme these belonged. This discussion led to validation, concluding that the main themes and subthemes were representative of the material.

Results

This section presents students' conceptions of earthquakes in terms of causes and processes and in relation to the geographical concepts of scale, distribution, location, and interaction. The graph (Figure 2) shows students' conceptions of causes of earthquakes. Tables 1–3 describe students' understanding of earthquakes in terms of processes and in relation to the geographical concepts and excerpts from students' written responses together with illustrations made by the authors.

Students' conceptions of causes and processes of earthquakes

National test

Causes. Results in Figure 2 show that the majority of students relate causes of earthquakes to a convergent boundary and to a not defined (unclear) boundary. Furthermore, some students also relate causes of earthquakes to several plate boundaries (multiple boundaries), but few to only a divergent or transform boundary. 13 students did not respond to question a) in the assignment.

Processes. The responses in the categories described in Figure 2 were later analysed focusing on students' conceptions of the processes involved. The results are presented along with authors drawings illustrated in Table 1.

Convergent boundaries. Two plates colliding (Table 1A) was the most common conception and included the idea of earthquakes occurring as a onetime event. An example *"An earthquake occurs when two plates collide. Then a tremor comes which makes the ground shake"*.

One plate pushes over another plate (Table 1B), often included the idea of a continental plate that is pushed over another plate without breaking or being deformed. An example *"Plates collide, and one is pushed over the other one, and earthquakes happen"*.

One plate sliding under the other (Table 1C) was the third most common conception and included the idea of a plate being subducted under another plate. An example *"Earthquakes occur when two lithospheric plates collide. They lie there and push against each other until one of them gives in and goes down under the other. Then a forceful tremor occurs. If it happens under the water a tsunami will occur"*.

Unclear boundaries. Plates moving or vibrating (Table 1D) was the second most common conception, and included the idea of a plate causing earthquakes (e.g., vibrating, moving) without interacting with another plate. An example *"When continental plates move earthquakes can occur"*.

Plates move under the earth (Table 1E), was a rare conception and included the idea of two plates subducting. An example *"When two plates move under the earth, earthquakes occur"*.

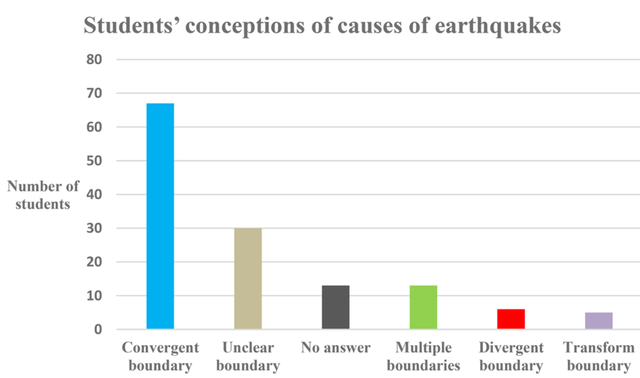


Figure 2. Students' conceptions of causes of earthquakes, $N = 134$.

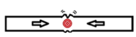
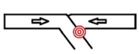
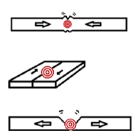
Multiple boundaries. Plates, colliding, spreading, or sliding along (Table 1F), included the idea that earthquakes occur at two to three different plate boundaries (in different combinations). An example *"Earthquakes can occur in different ways; one is when two plates collide and the ground shakes. Earthquakes can also occur when two plates slide along each other, but also when two plates spread apart so an earthquake occurs"*.

Divergent boundaries. Plates spreading apart (see Table 1G), included the idea of a plate splitting up causing an earthquake. An example *"The crust/the plates spread, and a forceful wave is created in the ground which makes noise and an earthquake occurs"*.

Transform boundaries. Two plates sliding along each other (see Table 1H), included the idea of two plates sliding along each other in different directions causing earthquakes. An example *"When two crusts get stuck with each other and they want to go in different directions, then an earthquake occurs"*.

The results show eight different conceptions of processes causing earthquakes, represented by different subthemes (see, Table 1). Most of these conceptions were labelled as partial scientific conceptions as they included a relevant plate boundary as the cause of earthquakes but did not describe the processes to a full account, such as build up and release of tension (see, Table 1A, B, F, G, and H). One of the conceptions was labelled scientific as it included a relevant plate boundary and described processes causing earthquakes together with relevant geological events (e.g., tsunamis) (see Table 1C). Two conceptions were labelled alternative conceptions as students did not relate earthquakes to any relevant plate boundary, or describe the processes involved (see Table 1D and E).

Table 1. Students' conceptions of processes of earthquakes.

Category/ theme	Convergent (67)	Unclear (30)	Multiple (13)	Divergent (6)	Transform (5)
Subtheme	A) Two plates colliding.  B) One plate pushes over another plate.  C) One plate sliding under the other. 	D) Plates moving or vibrating.  E) Plates move under the earth. 	F) Plates colliding, spreading, or sliding along each other. 	G) Plates spreading apart. 	H) Two plates sliding along each other. 

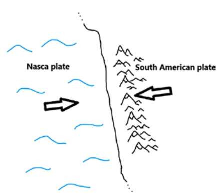
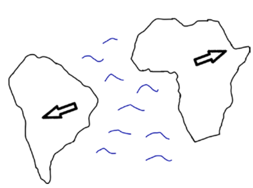
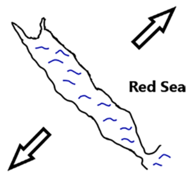
Students' understanding of earthquakes and their consequences in terms of spatial and societal-nature relations

National test

Spatial relations – scale, distribution and location. The scale and distribution of earthquakes were mainly described in implicit ways by the students, and not to a full account. Statements such as "*a plate moves*", "*plates collide*", "*plates diverge*" *or* *"plates slide along each other"*, were considered as local or regional understanding of scale and distribution of earthquakes. Statements including earthquakes occurring at two or all three main boundaries were considered a global understanding. Examples: *"Earthquakes can occur in many ways. One is when two plates collide, and the ground shakes"*, *"Earthquakes can also occur when two plates slide past each other. But also, when two plates diverge, earthquakes occur"*.

Most students did not refer to any specific location where earthquakes occur (see, Table 2A). Some students provided a relevant example of a location such as Sweden where few earthquakes occur and explained that this country is situated on the middle of a plate, far away from any plate boundary (see, Table 2B). Finally, some students provided a relevant example of a location where earthquakes occur in relation to a relevant plate boundary (see, Table 2C1, C2, and C3). In one example, a student related an earthquake to a convergent boundary, in this case, where the Nazca plate collides with the South American plate forming the Andes (see, Table 2C1). In a second example, a student related an earthquake to a divergent boundary; South America and Africa in the break-up of Pangea (see Table 2C2). In a third example, a student also related an earthquake to a divergent boundary; the break-up of the Red Sea in the past, although it is recognized as a transform boundary today, where the African plate and Arabian plate slide past each other (see Table 2C3).

Table 2. Students' spatial understanding of earthquakes – location.

Theme:	Location	Student examples
No location, relevant plate boundary	None (A)	*"Plates collide and earthquakes happen".*
Relevant location, no plate boundary	Sweden (B)	*"In Sweden there can hardly be any earthquakes since we do not have two plates that can touch each other".*
Relevant location and plate boundary	The Andes (C1): the Nazca plate collides with the South American plate. 	*"I think it occurs when two different plates smash together, for instance, the South American plate and the Nazca plate. So, it shakes because they smashed together, and the plates shake and of course the countries situated on these plates as well".*
	Pangea (C2): Africa and South America split up. 	*"Sometimes the lithospheric plates move, and when they do, it may shake on what is above the plates, which is the land and then an earthquake occurs. All land-islands were once together as one, which you can see on South America and Africa. They have all slowly been pushed, and sometimes earthquakes have occurred".*
	The Red Sea (C3): Asia and Africa split up. 	*"It is when two plates which are stuck together separate, and become different plates. For instance, when the African and Arabic plate were together and then diverged, there was a massive earthquake".*

Societal-nature relations – interaction

In question b) in the national test, students were asked to explain why consequences of earthquakes are more severe in poor countries than in rich countries. From a geographical perspective this highlights *interaction* between nature and society. Understanding societal effects of hazards like earthquakes has to be understood in the context of vulnerability and adaptive capability. Here we categorized students' answers by using different capitals as an indicator of community capability. Most of the students used a combination of societal aspects and societal explanations when responding to question b) which already in the question picked out financial capital. Financial and physical capitals were the most common combination, whilst some students combined financial capital with other capitals (e.g., human, social) (see, Table 3A–C). However, a small number of students stated that poor countries are more vulnerable due to natural conditions (e.g., location at plate boundaries, climate, soil/bedrock conditions) and thus held alternative conceptions. Examples *"Earthquakes do not occur in rich countries since they are not situated at the boundaries on earth"*, *"In poor countries (…) it is often very warm and earthquakes can happen easier"*, *"(…) in poor countries the ground is often uneven or bad"*.

Table 3. Societal aspects and societal explanations.

Forms of capitals:	Subthemes:	Examples of students' explanations
Financial/Physical (A)	***Rebuilding***: Poor countries have instable constructions, and lack money to rebuild houses/ cities, and in time.	*"People in poor countries cannot afford to build stable houses, so these fall apart/over more easily. And poor countries cannot afford to rebuild either".*
Financial/ Social (B)	***Healthcare & Education:*** Poor countries lack proper healthcare/ rescue service and education. **Migration:** Poor people do not have options to move to a safe country.	*"It is because the poor countries do not have money to rebuild everything again and these countries do not have as good healthcare". "The house is almost the only thing the poor have. When the houses collapse, they have nowhere to go as they have no money. The rich can settle in another country as they can afford it".*
Financial/Human (C)	***Human resources***: Poor countries lack qualified construction workers and tools, and scientist with equipment that can predict earthquakes. ***Natural resources***: Poor countries lack providers of vital natural resources (e.g., food, water).	*"In poor countries they cannot afford to remove everything that has been destroyed. The poor countries cannot afford machines which can build houses. There are not so many who can build in poor countries either". "If there is an earthquake in a poor country, they cannot afford to rebuild the city or village as it costs too much money. If they rebuild the village/city again they will have to work hard and maybe be without access to food and clean water. It is unfair here on earth".*

Focus group interviews

Causes and processes

Similar to the national test, most students referred to a convergent boundary when describing causes of earthquakes, whilst some students stated that earthquakes can occur at divergent or transform boundaries as well. However, most of the students mimicked the three main types of plate boundaries by using hand gestures but without discussing how earthquakes and plate boundaries are related. Similar to responses in the national test, earthquake processes at the plate boundaries were often described as sudden onetime events, such as when a plate is breaking up or collides with another plate. Additionally, some students provided a general scientific description of an earthquake process (e.g., tension and release of tension) but did not relate this process to a specific plate boundary. Similar to responses in the national test, many students in the focus groups used everyday words such as "land plates" and "water plates" when describing the plates.

Spatial relations - scale, distribution and location

Similar to responses in the national test, most of the students in the focus groups described scale and spatial distribution of earthquakes in an implicit way, with statements such as "*plates colliding*" and rarely providing examples of locations. During the interviews some of the students explored the plate boundary map in more detail and were surprised that earthquakes for example occur in US, and the San Andreas Fault was unknown to them. Furthermore, few students described earthquakes occurring in the oceans, and those who did, mainly related earthquakes to subduction zones. Although the plate boundary map in the assignment was not used to a high extent by the students, they described that it guided them to understand the context of question a) in the assignment.

Societal-nature relations - interaction

Students in the focus groups discussed similar societal aspects as students in the national test (e.g., financial and physical) when responding to question b). However, students did not mention any alternative natural factors (e.g., climate/heat). Other types of physical interactions such as mountain building, volcanoes, tsunamis and ocean trenches were discussed by some students, but rarely in relation to societal aspects.

Discussion

Students' conceptions of causes and processes of earthquakes

The majority of the students described that causes of earthquakes are due to plates interacting in a convergent boundary rather than in a divergent or transform. This may be explained in relation to students' everyday experiences, where they can relate to the term collision, e.g., car accidents, but less to divergence and transform.

Consistent with findings by Licona et al. (2013) and Mills et al. (2017) most of the students held partial scientific or alternative conceptions, and very few held scientific conceptions of the processes. The results indicate that many students do not understand the processes of earthquakes at plate boundaries to a full account.

Students geographical understanding of earthquakes and their consequences in terms of spatial and societal-nature relations

Spatial relations - scale, distribution and location

Students' understanding of scale and distribution of earthquakes seemed restricted to a local/regional scale and distribution (one boundary, or no boundary) rather than to a global scale and distribution (multiple boundaries). Few students described specific locations where earthquakes occur at plate boundaries, which suggest that students have acquired a general knowledge of earthquakes in relation to plate boundaries, but do not know exactly where these occur on earth. These findings are similar to Licona et al. (2013) in the way that many students related the location of earthquakes to plates and plate boundaries in general, but differ from our study where few students held alternative conceptions of locations.

Societal-nature relations - interaction

A majority of the students explained the reason why consequences of earthquakes are more severe in poor countries by drawing on at least two different capitals. Many of the explanations (e.g., financial/physical capital) are in line with the scientific literature, but did not further elaborate as to how and why. Other explanations were more elaborated, in particular when students combined multiple capitals (e.g., financial, social and human) in a chain of cause and effect. Furthermore, we note that a small number of students' attribute causes and consequences of earthquakes in developing countries to natural factors. These alternative conceptions included explanations such as; plate boundaries are mainly located in developing countries; earthquakes occur in a warm climate; developing countries have poor bedrock/soil conditions. Similar alternative conceptions have been reported by Licona et al. (2013) and Mills et al. (2017), which implies that students have difficulties understanding natural processes, as well as difficulties distinguishing between different causes; natural or socioeconomic.

Limitations

The national test in Sweden is a unique material comprising of student responses from a wide range of schools and geographical areas. As the study includes a representative sample of Swedish students within this age group, we believe that the results can be generalised to students in Sweden of similar age and therefore provide a solid ground for future intervention studies. A limitation of the study is related to time as four years had already passed after the national test was taken by students in 2013 until the interviews were conducted in 2017 (cf. Arrhenius et al., 2022). However, findings from the focus groups indicate similar problems of understanding earthquakes as those identified in the national test.

Implications for instruction

Results show that students lack an understanding of *processes*, which we have addressed earlier in a study on students' conceptions of glacial and glaciofluvial processes in geoscience education (cf. Arrhenius et al., 2021). In order to support learning we propose the use of computer animations in instruction and research (Mills et al., 2017), as it can show *multiple* changes over time, for example that earthquakes involve slow processes where tension builds up and is released between rocks at plate boundaries.

Furthermore, instruction can support the development of students' understanding of earthquakes and *spatial relations*, by focusing more on students' map-reasoning skills. Using earthquake and plate boundary maps in instruction can help students understand both the global scale of earthquakes as well as distribution of earthquake at plate boundaries and map-quizzes may also improve students' understanding of concepts such as location (Dunn, 2011). In addition, highlighting examples of historic events at plate boundaries, for example Nepal in 2015, can provide students with a more contextual understanding of earthquakes. Finally, concerning students' understanding of earthquakes and their effects in terms of *societal-nature relations*, the results show that students need support in explaining as to how and why poor societies face more problems than rich societies in coping with earthquakes. In order to develop students' geographical relational thinking and support an understanding that integrates society and nature, instruction can utilise the concept of "capital". Instruction also needs to highlight, and differentiate, between causality in nature and society/human world, and support students thinking and differentiating on this. Furthermore, teaching needs to take in to account and design instruction to meet students' alternative conceptions of societal consequences of earthquakes being solely predetermined by natural factors such as climate or heat.

Finally, while the study contributes with new knowledge for improving teaching that supports conceptual change (cf. Lane & Coutts, 2012; Mills et al., 2017; Reinfried, Aeschbacher, Kienzler, & Tempelmann, 2015), we propose further design- and intervention studies through teacher-researcher collaborations (e.g., using the Model of Educational Reconstruction (MER)) (Duit, Gropengiesser, Kattmann, Komorek, & Parchmann, 2012; Reinfried et al., 2015; Arrhenius et al., 2022), that target students' alternative conceptions of earthquakes from a geographical point of view.

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