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Swedish 12–13-year-old students' conceptions of the causes and processes forming eskers and erratics

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ABSTRACT
This study investigates students' conceptions of the causes and processes that form eskers and erratics, types of glacial and glaciofluvial landforms which to date have been little researched in geoscience education. The data collected for the study included 134 responses to an assignment completed by 12- to 13-year-old students in the Swedish national geography test in 2013. The responses were sampled and analyzed using qualitative content analysis. The findings show that many of the students held alternative conceptions regarding the causes of these landforms, which included landslides, meteor impacts and human activity. Although some students were able to give a scientific explanation that considered the possible causes and relevant processes involved in the formation of erratics, many students did not give a full account of these processes. Furthermore, only a few students were able to describe the relevant processes involved in the formation of eskers and were more likely to discuss alternative or glacial processes rather than glaciofluvial processes. Given the lack of research on students' understanding of glacial processes and landforms in geoscience and geography education, this study contributes with new knowledge of students' conceptions of eskers and erratics and makes a theoretical contribution to research on students' alternative conceptions and understanding of sequential and emergent processes in geoscience. The findings provide specific insights for teachers and are useful in the design of classroom practices that can change alternative conceptions and strengthen scientific conceptions.

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Alternative conceptions; glacial landforms; causes; processes; educational reconstruction

Introduction

The Northern European landscape is made up of different landforms dating back to the last ice age. The question of how these landforms were formed have caused a number of interesting theories throughout history. In Scandinavia, Norse mythology contain tales of powerful giants throwing stones over the countryside, as a result creating these landforms. More recently, naturalists tried to explain the origin of these landforms using natural causes, such as stones falling from the sky or other catastrophic events (Carozzi, 1984). In general, the ice age, and glacial and glaciofluvial processes and phenomena are included in the national curriculum or standards of many countries, yet very little is known regarding students' conceptions of glacial systems and of glacial landforms in particular (Francek, 2013; Reinfried & Schuler, 2009). Knowledge about erratics and eskers is important as it provides students with a deeper understanding of the origin of the natural landscape of Northern Europe as well as other parts of the world whilst also showing how these landforms serve as important resources for humans. The aim of this study is to investigate students' conceptions of the causes and processes forming erratics and eskers, and the results provide useful insights for teachers in designing instruction for students 12–13 years of age. Findings in geoscience education research have shown that students bring their own conceptions into the classroom and use these to organize and interpret scientific knowledge (Sexton, 2012). In this study, students' conceptions of the causes and processes were investigated from a conceptual change perspective focusing specifically on students' alternative conceptions related to entities and processes in science, as described by Chi (2013). Knowledge about students' alternative conceptions of the causes and processes involved in glacial and glaciofluvial landforms is useful in designing teaching aiming to address alternative conceptions and strengthen scientific conceptions. The present investigation can contribute with new knowledge for improving science teaching as described in the Model of Educational Reconstruction (MER) (Duit et al., 2012). The model is inspired by the European continental tradition of *Didaktik* emphasizes that science content, seen as educationally significant, and students' conceptions are equally important in relation to learning and teaching and can also promote an interplay between research and educational practice. Earlier studies involving educational reconstruction

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has mainly focused on science content, but later it has become clear that inquiry processes in science also need to undergo educational reconstruction in order to facilitate learning and teaching of science (Duit et al., 2012). The model has previously been used as a framework to develop and design teaching of geoscience topics such as plate tectonics, wind systems, glaciers and the ice age (Felzmann, 2017).

Aim of the study

The aim of this study was to investigate 12 to 13-year-old students' conceptions of the causes and processes concerning the formation of eskers and erratics. The following questions directed the present study:

1. What are students' conceptions of the causes for the formation of eskers and erratics?
2. How do students understand the processes involved in the formation of eskers and erratics?
3. What are the implications of the results for teaching and learning?

Geoscience education in Sweden

School-level geoscience is a minor compulsory part of the national science curriculum in the UK, Japan, New Zealand and other southern European countries, or taught as part of the national geography curriculum in Germany and Sweden (King, 2008). For many decades, geography has been the only subject in the Swedish education system that covers geology and geomorphology as a science. The curriculum states that geography education "should give pupils the opportunity to develop knowledge about different human activities and processes produced in nature that have an impact on the forms and patterns of the Earth's surface" (Swedish National Agency for Education [Skolverket], 2011). In the current curriculum, the learning objectives regarding the processes that shape and change the landscape have mostly been set for students in year 4 to 6. Furthermore, the curriculum concentrates on glacial and glaciofluvial processes, which are integral to understanding and interpreting the Swedish landscape and how it was formed. The present study concentrates on the two following landforms in particular that act as important resources for humans: eskers, which are used as water storage, water filtration and as a source of gravel and sand (Gruszka et al., 2016; Jokela et al., 2017), and erratics, which are used for tracking valuable mineral deposits and determining the age of landforms, or ice-covered bedrock (Veevers & Saeed, 2013). Furthermore, glacial and glaciofluvial processes are important indicators of global warming and climate change.

Previous research

Students understanding of glacial processes in geoscience education

An early study involving 11- to 17-year-old students in New Zealand concluded that students were experiencing difficulties in understanding glacial processes (Happs, 1982). Dove (1997) further investigated 16- to 19-year-old students' understanding of erosion and weathering and for example one finding regarding abrasion showed that students believed that the ice in glaciers caused the underlying rocks to wear down and not that glaciers are laden with debris. Furthermore, Reinfried and Hug (2008) found that students in secondary high school were experiencing several problems in their conceptualisations, including relating glaciers to the aggregate states of water, understanding the dynamic nature of glaciers (i.e. seeing them as static objects), and being able to relate glaciers to climate. Felzmann (2014) further investigated the contexts in which 13- to 14-year-old students used different conceptual metaphors to construct concepts about glaciers and found that the students' conceptual metaphors were different to those used by scientists. Moreover, Felzmann (2017) also found that the students tended to have conceptions of glacial processes as one-time processes rather than cyclical processes, e.g. large volumes of water becoming glaciers when suddenly freezing rather than a continuous transformation of snow to ice. In addition, the students were also found to lack conceptions about continuous sedimentation.

Eskers, erratics and the processes involved in their formation

Definition of eskers and erratics

The term esker originating from the Irish word *eiscir*, meaning ridge, is commonly used to describe long, sinuous ridges of glaciofluvial sand and/or gravel sediments which have been deposited by a stream of meltwater, confined on both sides by the glacier ice (Banerjee & McDonald, 1975; Benn & Evans, 2010; Newton & Huuse, 2017). In general, the size and form of eskers varies in different places of the world, for example, some of the largest eskers in Canada are several hundred kilometers long and over 50 m high (Benn & Evans, 2010), while some other eskers found in southern Sweden are smaller (Gruszka et al., 2016). Glacier and ice sheet processes are the main causes of esker formation. Although eskers are formed today by ice sheets in Greenland and Antarctica, the eskers that are most commonly found were once formed by Pleistocene ice sheets, which existed during the last ice age and formed much larger esker systems (Brennand, 1994).

The term erratic originates from the Latin word *erraticus,* meaning wandering. Parry (2007) concludes that there are many definitions of erratics, but the term glacial erratics specifically refer to clasts of different sizes which have been eroded, transported and deposited by moving ice and are often of a different origin compared to the bedrock in the vicinity (Colgan, 2008). The processes involved in the formation of erratics are complex since the reconstruction of transportation routes can involve several glacial cycles with shifting glacier flow directions (Bouchard & Salonen, 2008; Evans, 2013).

Processes involved in their formation

In physical geography, events such as *erosion (E), transport (T)* and *deposition (D) of material* are hierarchal metaconcepts concerning processes at a superordinate level (Gregory & Lewin, 2018). These concepts are used for describing processes involved in the formation of many landforms, including glacial and glaciofluvial landforms. Concerning eskers, erosion (E) of material means that particles (i.e. gravel and sand) are originally imbedded in ice. As for transport (T), melting water acts as a transporting agent for sand and gravel to move down channels or below glaciers in tunnels. Finally, deposition (D) means that eskers can be seen as the infillings of material in these channels and tunnels (Benn & Evans, 2010) and occurs when the speed of the melting water decreases. The size, shape and composition of eskers thus depend on the material available in the glaciers and ice sheets, the transport capacity of the meltwater rivers, and how tunnels and channels are able to contain the sediments (i.e. particles) during deposition. Ice tunnels/channels are not static but change with seasonal conditions, and processes such as mechanical excavation and frictional melting need to be considered (Burke et al., 2015). In addition, sediments in eskers formed under the ice will usually show a well stratified pattern compared to eskers formed in or on the ice where sediments often become disturbed in the process when the underlying ice melts (Benn & Evans, 2010).

As with eskers, the metaconcepts *erosion (E), transport (T)* and *deposition (D) of material* are also used in describing the process of formation of erratics. Concerning erosion (E), erratics are presented as being part of the initial bedrock and ending up as large isolated boulders in the surrounding landscape. Most erratics are a result of glacial-erosional processes such as plucking and quarrying (Parry, 2007), meaning the ice erodes the material from the bedrock. However, erratics may also result from rock avalanches (Evenson et al., 2009), which means rocks falling down on ice sheet/glaciers from cliffs on a higher elevation. As for transport (T), erratics have long been considered as evidence of glacial transportation, due to glacial flow within, on or under the ice (Evans, 2013). In addition, erratics may also be transported by ice rafting (Larkin et al., 2011; Paduan et al., 2007), a process which occurs when glaciers and their incorporated debris reach sea level and icebergs calve off (Bischof, 2000). Although many erratics are deposited continuously by active glaciers and ice-sheets today, most erratics found in the landscape are the results of Pleistocene ice sheets.

Theoretical framework

Students' alternative conceptions

In conceptual change research there are many terms for describing students' "incorrect ideas" such as misconceptions, naive beliefs, pre-conceptions and everyday ideas. However, some of these terms have been used inconsistently and there is no widely agreed meaning (Taber, 2017). Alternative conception is a similar, but wider term describing conceptions which differ from what is accepted by current science (Sexton, 2012), and are conceptions that are not viewed as merely obstacles but instead as starting points to depart from in further learning (Duit et al., 2012). Alternative conceptions result from a diverse set of personal experiences such as observations of natural objects, everyday language, media and teachers' explanations and instruction (Mintzes et al., 1997). This means that learners use their experience to construct explanations of natural phenomena to make them intelligible. In this sense, the term alternative conception represents an overarching term encompassing a wide range of conceptions (e.g. preconceptions and misconceptions) formed by either direct or inferred experience (Arthurs, 2011), while simultaneously conveying intellectual respect to the learners holding these ideas (Thorn et al., 2016). In this study, alternative conception includes conceptions held by students which are more or less scientifically correct, but lack important components. These are seen as incomplete scientific conceptions (Sexton, 2012), in this study labeled *partial* scientific conceptions as described by Ignell et al. (2017).

The model of educational reconstruction (MER)

The model of educational reconstruction (MER) includes three major aspects: 1) the analysis and clarification of the science subject matter, 2) investigation into students' and teachers' perspectives on the chosen subject, and 3) design and evaluation of teaching and learning environments. In this study our focus is mainly on the two first aspects of the model but we discuss implications of the study in line with the third aspect. According to Duit et al. (2012), science content should not be viewed as given but needs to undergo a reconstructional process, where it is transformed into a content structure for instruction. In this process *elementary ideas* (basic phenomena, principles, processes) have to be detected in regards to aims of instruction while also taking in to account students' perspectives (e.g. alternative conceptions). This elementarization process should thus not be interpreted as a way of merely "simplifying" science but instead as a way of introducing students to the elementary content, hence finding a balance between the scientific point of view and what is accessible for students to learn. In our context the ETD-model discussed previously can be seen as containing basic principles for an understanding of glaciofluvial and glacial processes and phenomena, cf. encyclopedia of quaternary science (Carrivick & Russel, 2013; Evans, 2013), and basic textbooks in physical geography (Strahler & Strahler, 2013). We will therefore use this model in structuring the analyses of students' understanding of those processes and phenomena.

Conceptual change, causality and processes

Conceptual change research focuses on students' alternative conceptions, the ways they change, and how students gain their scientific understanding. Vosniadou (2013) describes this process in terms of students' initial "framework theory," which is not explicitly scientific, but rather theory-like thinking about how the world works, "They are called 'theories' because they are relatively coherent and principle-based systems characterized by a distinct ontology and causality and are generative in that they can give rise to prediction and explanation" (pp. 13–14). Lundholm (2018) describes the process of conceptual change as an activity where students come to a scientific understanding by relating a meta-level of the discipline — that is, relating and understanding scientific theories and causality at a meta level — to concepts that are to be learnt, and, to phenomena or empirical data. Causality is thus important as it is central in science and scientific explanation, which not only describes *what* the world looks like but *why*. It is therefore of great interest to investigate students' conceptions of *processes* and *causality*.

However, identifying students' alternative conceptions/misconceptions in relation to a scientific content is important, but it does not explain why some conceptions are very difficult to change. Conceptual change research conducted by Chi (2013) shows a need to make a *shift in categories* of science concepts and describes the existence of two different types of misconceived knowledge, either *inaccurate* (e.g. false beliefs/flawed model) or *incommensurate* (e.g. category mistakes, missing schemas). Whereas inaccurate knowledge, in statements such as "a whale has the same size as a salmon" often is successfully revised in the process of refutation, this procedure does not work with incommensurate knowledge, in statements such as "a whale is a fish" which instead requires an ontological category shift (from fish to mammal). As students very rarely make category mistakes in everyday life, it is difficult for them to understand the source of their misunderstanding. This is particularly relevant for young children, who are reluctant to undergo category shifts, for example from the category of "entities" to the category of "processes" (Chi, 2013).

Furthermore, Chi (2013) describes the importance of understanding *processes* in science in contrast to *entities* as the two do not share common dimensions. Whilst entities have dimensions such as having color, volume or being contained, processes lack all of these dimensions but instead incorporate a dimension of time which entities do not possess. Previous research in science education has found many robust misconceptions that are related to category mistakes between entities and processes, but more recently research has also shown that some category mistakes can only be explained in the way students understand processes in science (Chi, 2013). Chi et al. (2012) describe processes as either sequential (an event causing another event; A→B→C) or non-sequential, which are known as emergent. When children enter middle school, they tend to use sequential thinking, which they have developed to understand everyday life processes, and use this to try to understand and interpret processes in science classes. In many cases, this works well if students for instance are learning about the human circulatory system, which is made up of sequential processes and requires direct causal explanations. But many other processes in science such as diffusion, natural selection and erosion are not sequential but emergent processes, which require an emergent kind of causal explanation (Chi et al., 2012; Chi, 2013). Emergent processes are different from sequential concerning inter-level causal explanations, meaning the way agents' interactions (at a micro-level) relate to a larger pattern (at a macro-level). Emergent and sequential processes are also different in the way that agents interact (second order interaction features). While sequential processes have identifiable agents, dependent on/restricting each other, and act sequentially, agents in emergent processes are difficult to identify, not dependent on/restricting each other, and may act simultaneously. Furthermore, research in geoscience education has shown that students often presume natural phenomena is the result of a unique cause, or chains of cause and effect (Raia, 2005), thus applying a sequential thinking. Although this is true concerning many landforms, this is not the case for all of them. This distinction is thus relevant when students conceptualize how eskers and erratics are formed.

Methods and material

The data collected included 134 responses from a written assignment in the Swedish national geography test for students aged 12 to 13 years old in 2013. The national tests in the social sciences (geography, social science, religion, history) were divided equally by the Swedish National Agency for Education, among all students in Sweden 12–13 years of age, meaning the students were tested in only one out of the four subjects of social science during year 4–6. Which test the students in a particular school were given, was announced to the teachers two weeks in advance. During a 4-year period every middle school in Sweden was supposed to have administered all tests in all four subjects.

The test in geography was taken by 23,969 students in 2013, approximately one quarter of all students in this age group. The purpose of the national test in geography was both to support equal and fair assessment and grading in geography, and to generate data for analysis regarding to what extent the knowledge requirements (grade criteria) in geography are fulfilled in a school, mandator (e.g. municipality) and national level. The test was administrated by the social science teachers in each school, which means the teachers were responsible for conducting the test with their students, grading the test, as well as reporting the results to the Swedish National Agency for Education/national test unit in geography. The national test in geography year 2013 contained 28 items related to four different geographical capabilities; sustainable development, knowledge and skills of maps, geographical relationships, and natural processes and landforms. All items in the tests were intended to measure one of these capabilities and together cover the syllabus in geography year 4–6. One item focused on eskers and erratics, and a question in the assignment asked the students to describe:

"Why are eskers and erratics found in the Nordic region? Explain how they were formed?" The students written answers to these questions provide the basis for this study.

The assignment also contained two images, described in Figure 1.

Figure 1. Images in the assignment in the national test. (a) The image to the left shows a cross-section of an esker (Geological Survey of Sweden/Esko. D), (b) the image to the right an erratic (Geological Survey of Sweden/Damberg. A).

Sampling process

In order to conduct statistical analysis concerning the national tests in geography (as well as in other national tests in schools in Sweden), the Swedish National Agency for Education and the national test unit in geography gather the results from a preselected sample of the complete national test based on students' birth dates. The teachers administrating the test were instructed to report the result online (administrated by the test unit of national test in geography) of students who were born on the 10th, 20th, and 30th of every month. In addition, the teachers were also instructed to send a copy of the complete paper test of the students born on the 10th, thus containing both student responses and results. In total, the results from 1944 students were reported to the Swedish National Agency for Education, including 578 complete paper tests sent in by the teachers in 2013. These 578 complete tests represent the "larger sample" and from where data were sampled for this study.

As we were interested in students' conceptions of eskers and erratics on a national level, a randomized sampling procedure was undertaken as described by Krippendorff (2004). Every third response on the assignment on eskers and erratics from the 578 national tests was thus extracted until saturation was reached (134 responses), meaning that no additional categories and themes could be identified (Feig, 2011). The characteristics of the smaller sample were made up of 50% boys and 50% girls, and it also represented different schools and grades and came from different geographical areas in Sweden, similar to the larger sample.

Analysis

The written responses were analyzed by using qualitative content analysis for the *causes* (Elo & Kyngäs, 2008) and thematic analysis for the *processes* (Braun & Clarke, 2006). Thematic analysis is similar to qualitative content analysis (Drisko & Maschi, 2015) and uses similar techniques in terms of coding procedures. Both approaches are suitable for analyzing qualitative data on a descriptive level involving a relatively low level of interpretation. However, while qualitative content analysis allows data to be analyzed both qualitatively and quantitatively, focusing on the manifest content, data in thematic analysis is analyzed in a more purely qualitative way, focusing on contextual understanding of both latent and manifest content (Vaismoradi et al., 2013).

Causes

The main categories found in causes were the following: *natural, human and mythological causes*. These categories were derived from previous research studies on other natural phenomena in earth science education, including volcanoes, erosion and earthquakes (Blake, 2005; Sexton, 2012; Tsai, 2001). Thus, because the categories chosen existed before the data were collected (Kuckartz, 2014), the present analysis can be defined as deductive. In regards to the content analysis, a choice had to be made to focus either on the *latent* or the *manifest* content, choosing between the level of depth and repeatability (Downe-Wamboldt, 1992). According to Graneheim and Lundman (2004) a category refers mainly to a descriptive level of the content in a text, while the creation of themes may link together latent meanings in categories. In the analysis of causes in the present research, there was a focus on the manifest meanings of concepts such as meteors and landslides when describing causes. In addition, as some students used everyday words such as "space-stones" or "rocks rolling downhill," latent meanings were also analyzed. After completing the coding procedure, the frequency was also calculated.

Processes

Responses that described a scientific cause for either eskers or erratics (e.g. glaciers and ice sheets as basic agents) were extracted and analyzed to focus on the processes mentioned. As with causes, processes for each landform were analyzed separately. In the thematic analysis, both latent and manifest meanings were considered to give a rich description. The following two main themes were identified: A) students who described partial scientific processes or scientific processes, and B) students who described what was labeled as alternative processes. In the second phase, subthemes within these two themes were further identified. In regards to theme A, responses were analyzed in relation to *Erosion-Transportation-Deposition* (EDT) (see Background) and then sorted into the following subthemes: *one, two or three processes*. Visual representations of students' conceptions were created by the authors in order to aid in sorting the responses into the three given subthemes. An inductive approach was taken in regards to theme B and the material

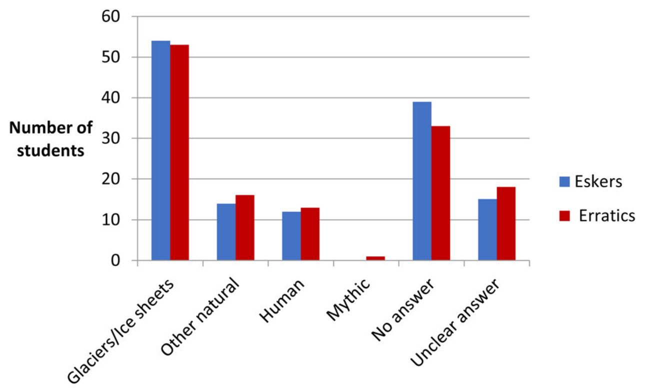


Figure 2. Students' conceptions of the causes forming eskers and erratics (N = 134).

was analyzed in terms of alternative conceptions of processes for each landform. Braun and Clarke (2006) state that researchers may have to be flexible when it comes to deciding themes, given that a theme might have considerable space in some data sets and little space in others. In the present case, both major and minor patterns were identified for each landform and were assigned a subtheme giving a richer description of the whole dataset.

Trustworthiness

A way to ensure reliability and trustworthiness is by having each researcher in a team code the same material and compare the results (Drisko & Maschi, 2015). To ensure high reliability, the coders should also have a similar educational/professional background (Krippendorff, 2004). The categories described in the tables in the results (e.g. human causes) and themes/subthemes (e.g. one process, two processes) represent the general instruction in the codebook used by the two coders. Concerning the analysis of the causes, Cohen's Kappa interrater reliability test was conducted after half of the responses were coded showing a good match (0, 82), a score considered a strong and desired level of agreement (Downe-Wamboldt, 1992; McHugh, 2012). As for the analysis of processes, the coders discussed their individual coding and potential themes and subthemes together. Discussions concerned deviant interpretations, for instance, the meaning of the terms erosion, transport and deposition when applying the ETD-model, but also whether conceptions were deemed as alternative or not. This discussion led to the conclusion that the two main themes and subthemes were representative in describing students' understanding of the processes.

The researchers/coders have experience of teaching geography at both high school and university level and also share experience and knowledge of working with the school geography curriculum at a national level. One of the researchers is a professor holding a PhD in geography and the other researcher holds a licentiate degree in geography and currently works as a PhD student in geography education. The researchers conduct research on conceptual change theory in geoscience and geography education and have used content and thematic analysis in previous work.

Results

This section presents students' conceptions of causes forming erratics and eskers, and students' conceptions of processes. Interpretations of students' conceptions by the authors are illustrated and presented in Tables 1–5. The bar chart in Figure 2 together with the illustrations in Table 1 are intended to describe students' conceptions of causes. Excerpts from students' written responses, together with illustrations in Tables 2–5 are intended to describe students' conceptions of processes.

Students' conceptions of causes forming erratics and eskers

Scientific causes

Scientific natural causes (glaciers/ice sheets as agents): The results in Figure 2 shows that students most frequently described glaciers/ice sheets as a cause of the formation of eskers (54) and erratics (53).

Alternative causes

The results in Figure 2 and Table 1 shows that many of the students described several alternative causes (other natural, human, mythic).

Natural causes. As illustrated in Table 1, A–C, these conceptions included earthquakes, landslides/crumbling ground and meteor impact. Some students also described different unspecified natural causes such as "there are lots of mountains or forests" or it being "very cold." However, these students did not specify what caused the mountains, forests or the cold to create these landforms.

Human causes. As illustrated in Table 1, D–E, some students selected human activity as the cause for the formation of eskers and erratics. For instance, one cause for both these landforms related to people in the past (Vikings) having used eskers as defence structures or erratics for transporting longships. Another cause was attributed to the activities of modern man with eskers and erratics being the end material from detonations of explosives when building roads.

Mythological causes. Table 1, F, shows that only one student selected a mythological cause in the case of erratics, with giants throwing rocks. The tale about giants was also given by three other students. However, these students had mentioned it as an additional "mythological reason" and had given the correct response by identifying glaciers/ice sheets as the real cause.

No answer or unclear answer

As described in Figure 2, many of the students did not describe a cause for any of these landforms (i.e. left a blank space) or only described a cause for one of the landforms. 39 of the responses concerning eskers and 33 of the responses concerning erratics did not provide any answer. In addition, there were also a total of 15 responses on eskers and 18 responses on erratics that were not possible to interpret and categorize (unclear answer).

Table 1. Alternative causes for the formation of erratics and eskers described in terms of natural, human and mythological causes.

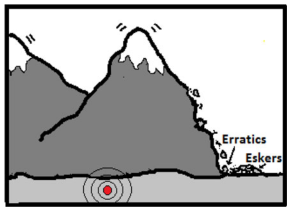
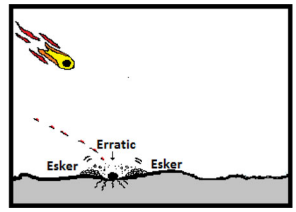
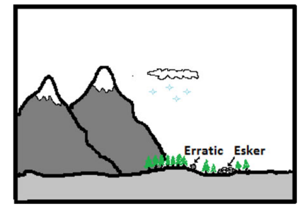
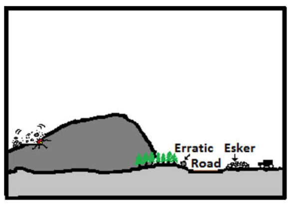
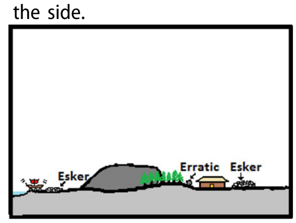
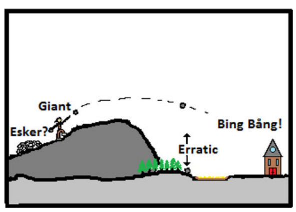
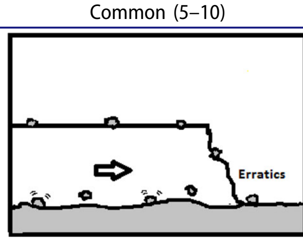
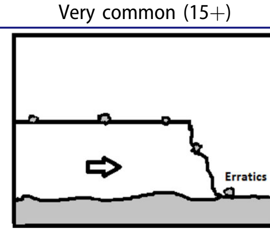
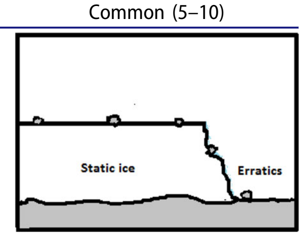
Alternative causes			
Natural causes			
Examples	(A) Earthquakes & landslides: e.g. accumulated material in shapes of eskers and erratics	(B) Meteors: e.g. impact leaves erratics in the crater, and eskers as displaced material or as marks on the side.	(C) Unspecific natural: e.g. cold climate, mountains and forests create eskers and erratics.
Human causes			
Examples	(D) Road construction: e.g. residual material from explosions form eskers and erratics.	(E) Viking tools/defence structures: e.g. eskers used as defence structures and erratics for transporting longships.	
Mythological causes			
Example	(F) Giants: e.g. picking up and throwing erratics.		

Table 2. Illustrations of students' conceptions of EDT processes related to erratics and theme A. The numbers refer to student responses.

Theme A			
Occurrence	Common (5–10)	Very common (15+)	Common (5–10)
Erratics *Erosion (E)* *Transport (T)* *Deposition (D)*			
Subthemes (processes)	(G) Three processes: **E&T&D**	(H) Two processes: E&D/ **T&D**/ E&D	(I) One process: E/T/**D**

Students' conceptions of processes involved in the formation of erratics and eskers

Specific answers were selected from the 134 responses for the analysis of processes, which identified glaciers/ice sheets as the cause of erratics and eskers (54 on eskers and 53 on erratics). These responses contained an explanation of processes involving either: a) eskers, b) erratics, c) both landforms or d) none of the landforms (i.e. students only identified glaciers/ice sheet as the cause for these landforms but did not explain the processes involved).

Theme A: Scientific cause and scientific conceptions of processes

Erratics. Depending on whether students gave a full account of these processes or not, the conceptions were labeled scientific or partially scientific. These conceptions suggest that sequential thinking was employed when describing different causal events in the process such as erosion, transport and deposition of material.

When students' explanations contained all three processes, it was labeled a scientific conception (see Table 2, G).

Table 3. Illustrations of students' conceptions of EDT processes related to eskers and theme A. The numbers refer to student responses.

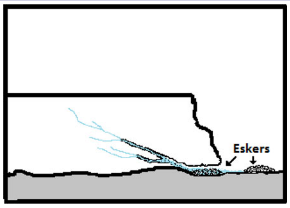
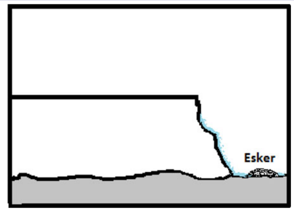
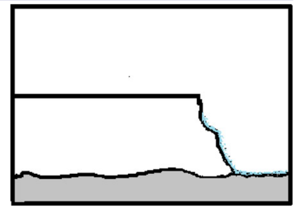
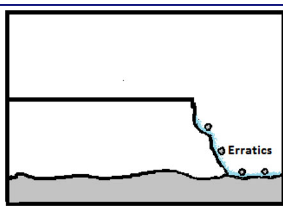
Theme A			
Occurrence	Very rare (1)	Rare (3 or less)	Rare (3 or less)
Eskers *Erosion (E)* *Transport (T)* *Deposition (D)*			
Subthemes (processes)	(J) Three processes: **E&T&D**	(K) Two processes: E&D/ **T&D**/ E&D	(L) One process: E/**T**/D

Table 4. Illustration of students' conceptions of erratics and Theme B. The number refers to student responses.

Theme B			
Occurrence	Rare (3 or less)		
Erratics			
Subthemes (processes)	(M) Meltwater transports erratics	–	–

An example of E&T&D: "*During the ice age there was a thick layer of ice over the Nordic region. But when the ice started to move/melted, the ice moved over the bedrock/mountains. Then large pieces of rocks fell off and were transported with the ice. But when the ice melted, then the stones landed, well, kind of everywhere.*"

When students' explanations contained two processes, it was labeled a partial scientific conception (see Table 2, H). The most common conception in this group was the combination of the processes transport and deposition. An example of T&D: "*There was an ice age long ago, and then they were formed. The ice brought them, and when the ice melted, the stones were left. Now they are kind of everywhere.*"

When students' explanations contained only one process, it was labeled a partial scientific conception (see Table 2, I). The most common conception in this group involved the process of deposition. An example of deposition (D): "*The ice was very high and there were large stones lying on the ice. When the ice melted, the stones landed on the ground and remain there today.*"

Eskers. Students that were found to hold a partial scientific or scientific conception mainly used short-term sequential thinking when describing processes such as erosion, transport and deposition of material. These conceptions were labeled as partially scientific when students only provided relevant explanations for one or two of the processes. Furthermore, the students' conceptions were labeled as scientific only if students gave a full account of all three processes and were able to identify other important non-dominant agents in the formation of eskers (e.g. meltwater, ice tunnels or bedrock) rather than only glaciers, which took into account an emergent process.

Students' explanations which contained all three processes and other important non-dominating agents participating in the formation of eskers were categorized as EDT (see Table 3, J). This was labeled a scientific conception and only one of the students' answers was categorized as such. An example of three processes (E&T&D): "*The ice began to melt and water from the melting ice flowed in a tunnel in the ice. When the water flowed rapidly it brought stones. The ice melted and the stones remained on the spot.*"

When the students' explanations contained only two processes, it was labeled a partial scientific conception (see Table 3, K). Only two students were found to hold these conceptions. Furthermore, these processes were not always explained in detail by the students (i.e. did not provide information regarding where the material originated from and did not mention the process of erosion of the material in glaciers transported by meltwater). An example of two processes (T&D): "*Eskers were made when rivers or streams brought stones, gravel and sand. In the end, eskers were formed, containing stones, gravel and sand.*"

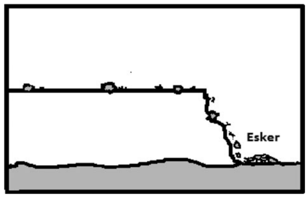
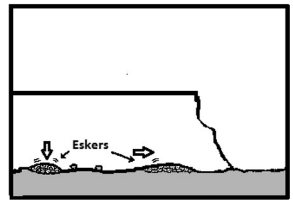
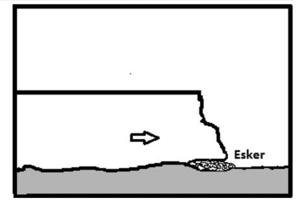
When students' explanations contained only one process, it was labeled a partial scientific conception (see Table 3, L). For example, identifying meltwater as an agent for transporting the material without explaining where the material came from, although providing an explanation as to why material is rounded in eskers (T). An example of one process (T): "*Eskers are due to the melting of the ice sheets. The water brought stones which were grinded against each other.*"

Theme B: Scientific causes and alternative conceptions of processes

Erratics. When students used nonscientific processes or scientific processes which were not relevant in the formation of erratics, these conceptions were labeled as alternative.

Only one type of alternative conception was held by students concerning the processes involved in the formation of erratics, stating that large erratics are transported by meltwater (see Table 4, M). This conception shows similarities with other conceptions regarding how material in eskers are transported in that students also discussed how erratics

Table 5. Illustration of students' conceptions of eskers and Theme B. The numbers refer to student responses.

Theme B			
Occurrence	Very common (15+)	Common (5-10)	Rare (3 or less)
Eskers			
Subthemes (processes)	(N) Ice melts and dumps material	(O) Ice crushes/hones bedrock	(P) Ice tunnels collect material

became smooth as they were transported by meltwater. An example: "*During the ice age, the ice was very thick and many kilometers long. When all the ice melted there were many stones with the water. That is why erratic stones are smooth. They went with the water and it made them smooth. That's why we have so many erratic stones in the Nordic region, the water brought them.*"

Eskers. When students used nonscientific processes or scientific processes which were not relevant in the formation of eskers, these conceptions were labeled as alternative.

The subtheme of "Ice melts and dumps material," included student descriptions of the ice as the agent forming eskers (similar to how moraine ridges are formed) (see Table 5, N). This was the most common alternative conception regarding the processes in esker formation (more than 15 students). An example: "*When ice melted the stones fell down. The eskers were made when the ice moved over a place and stones fell down to form an esker.*"

Students conceptions of the ice as the only agent which crushes or grinds/hones the bedrock or material by force into eskers (see, Table 5, O), were labeled "Ice crushes/hones bedrock" (subtheme). This conception was the second most common alternative conception of the processes in esker formation, held by five to 10 students. For example, "*Eskers were probably large stones crushed by the ice,*" and "*When the ice moved, it honed the ground and rocks. The ground became valleys and the rocks eskers.*"

Finally, a subtheme labeled "Ice tunnels collect material" included students' descriptions where ice tunnels are the dominating agent forming eskers by collecting material from the ground as the ice moves (see Table 5, P). This conception shares characteristics with the conceptions of subtheme (O) *crush and honed*. An example: "*There was a hole in front of the ice mountain. The ice just went on and on and collected stones, soil, trees, shrubs and so on.*"

Discussion

Students' conception of causes concerning erratics and eskers

The results shows that students most frequently described glaciers and ice sheets as the cause of formation of eskers and erratics. Students' conceptions also included other natural, human and mythological causes, although only a minority of the students mentioned the latter in contrast to findings on earthquakes as reported by Tsai (2001). As for other natural causes, many students related these to landslides, earthquakes and meteors similar to Sexton's (2012) findings regarding canyon erosion. However, similar to Blake's (2005) findings regarding the causes for volcanic eruptions, humans were also described by students as the cause for the formation of erratics and eskers; for example, activities by Vikings and those of modern man.

Students' conceptions of the processes concerning erratics and eskers

The results of the present research are similar to findings described in previous research regarding problems in understanding glacial processes (Felzmann, 2014, 2017; Happs, 1982; Reinfried & Hug, 2008). It is evident that many students did not understand the transport of erratics, and the dynamic nature of glaciers and ice sheets in general, which is a similar conclusion as that made by Felzmann (2014, 2017) and Reinfried and Hug (2008). The results indicate that many students hold conceptions that erratics somehow get lodged firmly in glaciers and ice sheets and are then either transported with the ice-sheet moving in one direction as a solid block of ice sliding on the bedrock, or as a result of a growing/expanding glacier due to water freezing. Many students also associated the movement of the glaciers and ice sheets with the term *melting*, suggesting a conception of an immobile ice that is absent of equilibrium flow. The concept of equilibrium flow was not used by any of the students, which is worrying as it is a fundamental element in understanding glaciers (Felzmann, 2017). Overall, a small number of alternative conceptions were found regarding the processes related to the formation of erratics, and the majority of answers were categorized as partial scientific conceptions. The results also indicate that students may have difficulties understanding the timescale required for ice sheets to transport material, describing the process in terms of years rather than hundreds or thousands of years. This implies that students' understanding of timescales related to glacial processes need further research, especially as past research has found that students aged 10 to 11 experienced difficulties in determining the relative timing of the ice age in relation to other global events (Trend, 1998).

Furthermore, the results show that many students held alternative conceptions of the processes involved in the formation of eskers, indicating that students may have problems understanding the aggregate states of water in relation to glaciers, a finding which was also reported by Reinfried and Hug (2008). The idea that meltwater runs through channels in the ice sheets even as the ice sheets, from an external perspective, seems to be intact may be inconceivable or challenging for students to understand. Instead many of them held conceptions of ice being like a bulldozer, that is, pushing or dropping material as it melts along the ice front forming the shapes of eskers. In this sense, the majority of the students did not describe esker formation as a *glaciofluvial* process, but rather as a *glacial* process similar to how moraine ridges are formed. These alternative conceptions may be explained by drawing on theories of conceptual change described by Chi (2013). It is plausible that these students have assigned all "ice-related landforms" into the same ontological category and have difficulties making a shift in category (or schema shift) when moving from learning about processes involved in formation of glacial landforms to glaciofluvial landforms. In that sense, students will focus on ice as the dominant and only agent, using sequential thinking when explaining the formation of both erratics and eskers.

Apart from the complexity of multiple transportations routes, the processes involved in the formation of erratics during a short timespan can be described more or less as a sequential process (A→B→C). However, processes in the formation of eskers are more complex as they possess attributes of both sequential and emergent processes.

In the formation of eskers, there are sequential features (described as second order interaction features), e.g., some agents interact sequentially in distinct ways and are dependent/restricted by the interaction of other agents (e.g. transport of material is dependent on/restricted by meltwater flow). However, all features in the formation of eskers are not sequential; agents can act simultaneously and independently, hence emerging (e.g., meltwater flow suddenly increases, available material decreases, ice tunnels collapse, glacial flow changes, and parts of underlying bedrocks become deformed). Furthermore, eskers also share some attributes characterizing emergent inter-level causal explanations (Chi, 2013). The way eskers vary in shape and size is the result of the sum of interactions among all agents (e.g., ice tunnels, available material, meltwater flow and the shape of underlying bedrock), rather than result of one dominant agent (e.g. glaciers/ice-sheets). In addition, local events and larger patterns behave in disjointed rather than corresponding ways (Chi, 2013), which is evident as eskers both look and are formed in different ways around the world.

This might explain why such a small number of students provided scientific explanations of formation of eskers; emergent processes do not follow the same logic as sequential processes, and the latter are often used when explaining a plethora of phenomena in science. It is thus no surprise that sequential thinking was found to be common when interpreting glaciofluvial processes in the sample and could be indicative of how many students in geography education fail to understand these processes.

Limitations

The national test in Sweden is a unique piece of material as it contains students' responses from a wide range of schools and geographical locations. The nature of this study is qualitative which means it is not to be generalized beyond the sample population. However, as the study includes a representative sample of Swedish students within this age group, we believe that results can be generalized to students in Sweden of similar age, which provides a solid ground for future intervention studies. A limitation in the study is related to time, as four years had already passed after the national test was taken by the students in 2013 until the time the study was initiated in 2017. Consequently, the possibility of further investigating students' conceptions using interviews was no longer feasible. However, focus group interviews with students in year 6 and interviews with their teachers were conducted in 2017 to further investigate these conceptions.

Implications for practice

The results are important for teachers as they provide new insights on students' understanding of erratics and eskers which may help teachers improve their instruction on the causes and processes involved in the formation of these specific landforms.

Causes

As for students holding alternative conceptions of the causes of formation, the findings indicate that it is necessary to help students understand that these landforms are caused by ice sheet and glaciers and not by other natural forces, humans or mythological beings. However, knowledge about these alternative causes is helpful for teachers and can be used as a point of departure in tuition before introducing students to scientific explanations, and thus relates to the MER-model.

Processes

A more difficult challenge concerns alternative conceptions of processes and the common conceptions of glaciers and ice-sheets pushing material like bulldozers or dropping material to form eskers. The ETD-model can be understood as building an elementary structure for interpreting the basic processes involved in glacial and glaciofluvial processes. However, to support student learning and conceptual change, that is, to sustain a shift from sequential to emergent thinking, students need help to distinguish between different casual mechanisms typical of these processes (Chi et al., 2012). In regards to eskers, students 12–13 years of age need at least to recognize that the formation is complex, with many agents which are not so easy to identify, behaving differently from agents involved in the formation of glacial landforms (e.g. erratics, moraine ridges). Consequently, some of the agents in esker formation need to be much more in focus and discussed with students. One example is ice tunnels, which some students may have noticed in textbook images and interpret as static holes in the ice which collect particles as the ice sheet moves, rather than as dynamic tunnels continuously changing and determining the shape of the eskers in the long run.

Visualizations

Students partial scientific conceptions of the processes related to erratics can be interpreted as a lack of understanding of the multiple processes involved in their formation. For example, one process concerns the erosion (E) of material which many students did not include when explaining the formation of erratics. Thus, glacial-erosional processes such as plucking and quarrying need to be better visualized for students. In addition, very few visual tools such as images and animations currently exist that could help explain the processes in formation of eskers, such as how meltwater transports and sorts material. Similar problems have been discussed by Cheek (2010), who proposes that the use of 3 D images and computer animations should be further researched in schools, considering that students' main problem in geoscience is understanding concepts that they have no direct experience with.

Intervention studies

Although these findings and recommendations can support teachers in the design of instruction, we also encourage further research on this topic. We believe it is important to conduct intervention studies focusing on model-based reasoning and argumentation as means of developing students' scientific thinking and reasoning, thus applying the final step described in the model of educational reconstruction described earlier which concerns *design and evaluation of teaching and learning environments* aiming at changing students' alternative conceptions (Duit et al., 2012). Since glaciers and ice sheets are melting rapidly today due to climate change, and erratics and eskers continue to be utilized by humans in many different ways, we also suggest further research on students understanding of these landforms as resources for humans.

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