A Phenomenographic Analysis Of Students' Experience Of Geological Time

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ABSTRACT

Geological time is by many geoscience instructors considered a threshold concept for geoscience students, being a central concept for how we experience geosceince phenomena that takes place on a spatio-temporal scale ranging from micro (e.g. cloud formation) to macro (e.g. plate tectonics). If one wishes to understand geoscience phenomena that goes beyond human perception, one must move from the concrete toward the abstract—from experiencing a phenomenon with one's senses toward an experience of the phenomenon that is based on an mind construct; we refer to such competency as disciplinary spatio-temporal competency (DSTC). The purpose of this study is to gain an understanding of how first-year students in a geoscience program in Sweden experience and represent the phenomenon of geological time, i.e. to capture their DSTC. Analyazing data from three semi-structured group interviews using a phenomenographic approach revealed how the students express geological time through their language, their gestures, and their visualizations. From the result in this study, including four qualitatively different themes, or categories of description, it is possible to conclude that the students' way of expressing geological time give rise to exciting interpretations and we believe that these expressions can provide information also about how students experience (and learn about) geological time. We report that through students' illustrations and discussions, students experience geological time as something more than a static one-dimensional *straight line. The data analysis shows that students connect geological time with spatio-temporal aspects from various geosientific phenomena, one example of such an dynamic description of geological time is "One simply fills it with more information" indicating that the students experience geological time as two-dimensional (space and time).*

Keywords: Discipline-Based Education Research; Geoscience Education Research; Geological Time; Spatio-Temporal Scales; Competency; Phenomenography; Multimodality

Space and Time are defining aspects in the study of geoscience. In the education of students in geoscience (including geology and Earth science) the teaching of geoscience processes and their relation to space and time is fundamental and requires a very special competency; we refer to such competency as a disciplinary spatio-temporal competency (DSTC). Several studies have shown both the importance of, in particular, geological time for students' understanding of geoscience and the difficulty students encounter when it comes to interpret, understand, and learn the temporal aspects in geoscience (Burton & Mattietti, 2011; Cheek, 2013; Cheek, LaDue & Shipley, 2017; Czajka & McConnell, 2018; Guffey, Slater & Slater, 2017; Kastens, et al. 2009; Kastens & Manduca, 2012). Hence, geological time is considered a threshold concept (Truscott, Boyle, Burkill, Libarkin & Lonsdale, 2006; Cheek, 2010). A threshold concept is a disciplinary concept that is vital for mastering of a subject and that students often experience as difficult to grasp (Meyer & Land, 2006).

In this paper we report on a case study of Swedish first-year university geology students' experience of geological time. In the study we applied a phenomenographic approach to the data-analysis and were able to identify qualitatively different categories describing students' experience of geological time. The categories express a broad range of different ways of experiencing geological time, such as the students' narrative time descriptions of geological time, how they define geological time and how they represent it.

To be able to talk about students' experience of geological time we must first define what we mean by geological time. Geological time, as we use it in this paper, is not just the strict linear timeline as expressed for example in the geological timeline (Figure 1), but also encompasses an understanding of different processes, their timescales, and how to think about different time scales. Within geoscience, timescales of processes range from "very fast", for example a seismic wave traveling with a velocity of 800 m/s through Earth's interior, to "very slow" such as plate tectonics moving continents over billions of years. Most geoscience processes follow a linear progression (with a beginning and an end), while others often are described as cyclical, one example of this is plate tectonics. Viewed from one perspective plate tectonics is described as linear, it begins, and it ends, but from another perspective it is described as cyclical where crust is being created and recycled. To fully understand geological time, one must develop an understanding of all timescales (small and large) as well as how different processes come together to create a whole. For example, to fully understand the formation of a section of sedimentary rocks one must understand the different processes that have formed the section. These processes include the deposition of the sediments, conditions in the depositional environment, the forces that have transformed the loose sediments into sedimentary rocks, and the ongoing weathering and erosion that transforms the exposed rocks. To understand the processes at work in creating and shaping a section of sedimentary rock a geoscientist must not only read the order of events but must also be able to identify what type of event and what type of processes that caused each different layer in the section. To identify different layers requires knowledge about geoscience processes, and perhaps also knowledge from other disciplines, such as chemistry or physics. Thus, to gain a full understanding of the concept of geological time, students need a solid understanding of different geoscience processes, how they interact with each other, and when they occur. In other words, to fully understand geological time, students must move beyond the common linear diagram shown in Figure 1. We will begin this paper by describing our aim and research questions. We then move on to, in more detail, introduce the theoretical frameworks (phenomenography and social semiotics) that we used to analyze the data and to interpret the results. Following this we describe the data collection and the analysis process in detail. Finally, we present our results and discuss the results in relation to our research questions. We conclude by giving suggestions for how these results have implications for teaching and learning geoscience and other disciplines with similar challenges.

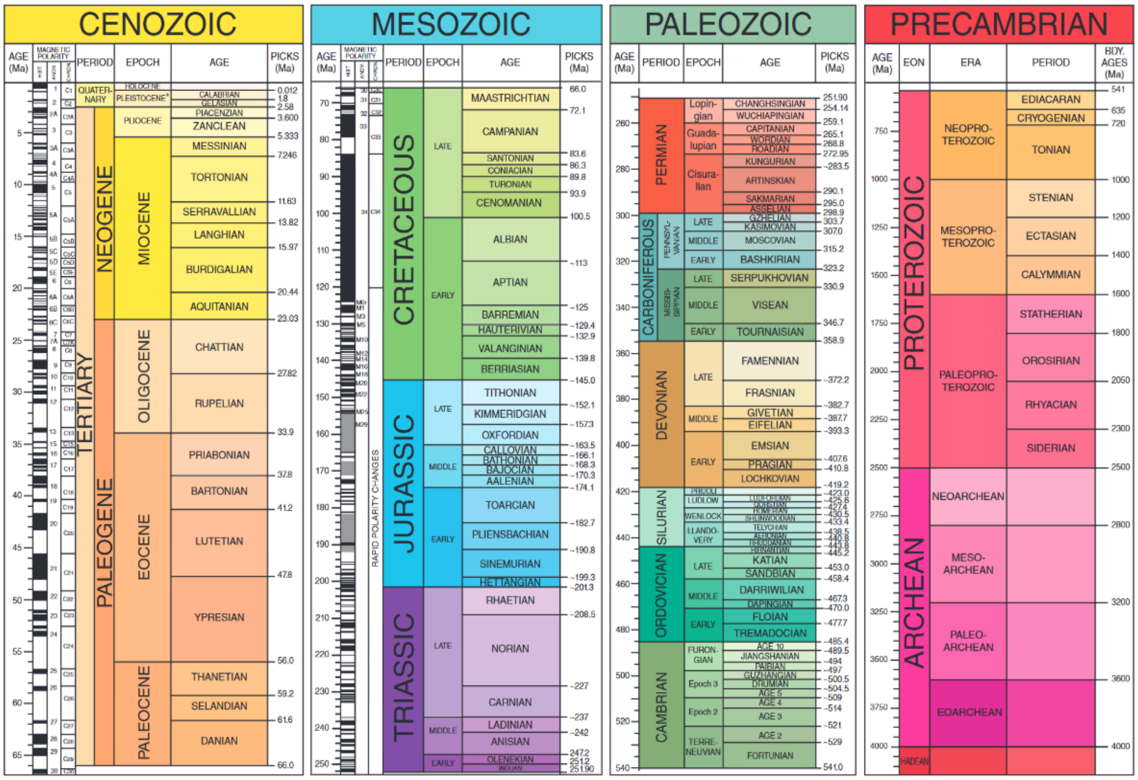
The aim of the research presented in this paper was to investigate Swedish first year university geology students' experience of geological time. From this, we formulated the following research question(s) to guide this study:

1. How do first year university geology students experience geological time?

    a) How do these students' reason while solving tasks that involve geological time and geoscience processes?
    b) How do these students discuss geological time and geoscience processes?
    c) How do these students represent geological time and geoscience processes?

The main question is subdivided into other questions that must be investigated before an answer can be obtained. This subdivision was necessary so that the construction of the data collection considered a wide range of student experiences.

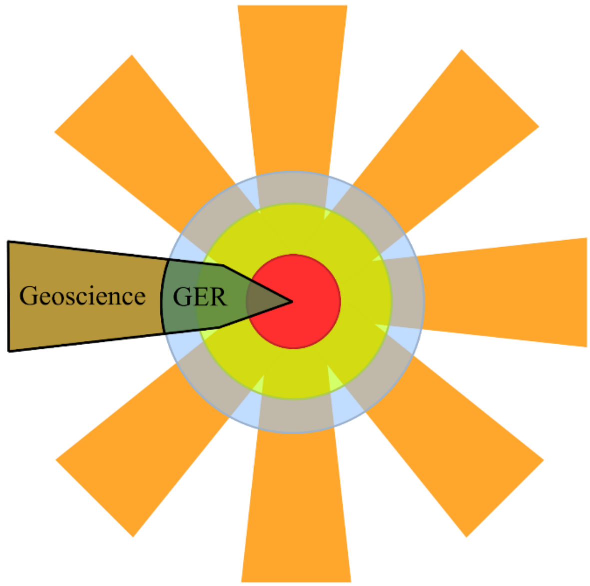
Figure 1. The geological timetable (the GSA Geologic Time Scale version 5.0). The table shows geological time divided into progressively smaller time units with clearly defined ages. The time units are based on geological features, such as occurrence of specific fossils or rock types. In the table, geological time is a linear, ordered series of periods or events. This representation of geological time is often one of the first that geoscience students encounter. Adapted with permission from https://www.geosociety.org/GSA/Education_Careers/Geologic_Time_Scale/GSA/timescale/home.aspx.



BACKGROUND AND CONTEXT

Disciplinary Based Education Research, or DBER, is a relatively new area of research that focuses on education research based within the knowledge of a discipline, such as geoscience or physics (Henderson et. al., 2017; Slater, Slater, Heyer & Bailey, 2015). The research focuses on problems and ideas that exist within the discipline and applies the ideas from general education research and cognition to construct an evidence-based ground. Each discipline deals with its own concepts and ideas that introduce their own unique problems for learning. The challenge of understanding geological timescales is unique to geoscience and must be studied from a disciplinary point of view by researchers that are experts on both geoscience and education research. See the DBER-flower in Figure 2.

Figure 2. The DBER-flower. Each petal is a discipline that dips into education research and related disciplines to address their own problems that are unique to their discipline. Geoscience Education Research (GER) is part of both the Geoscience discipline but also located within the education research discipline. Image based on Fig. 2 by Henderson et. al (2017).



Moreover, multimodality (Jewitt, Bezemer & O'Halloran, 2016; Kress, 2009; Bezemer & Kress, 2008) is a guiding theoretical framework for this study, designed to study how the use of different modes affect learning and communication. A mode is vaguely defined as a different way to represent something, such as an image or a text. The multimodal aspect enters when several modes are used together to enhance or support the meaning-making potential of each other. A text may be written so that an equation is easier to understand or vice versa. Several modes working together provide opportunity for meaning-making and for better transfer of knowledge. In the study described in this paper, Multimodality has been used to get a more holistic perspective of the communication taking place between the participants by taking into account, not just their speech, but also their drawn representations, gestures and body language.

Finally, to guide the analyzes and discussion, Variation Theory of Learning (VTL) (Marton, 2015; Marton & Booth, 1997) was used. VTL was developed from the idea of critical aspects of a phenomenon. In VTL an object of learning is all the critical aspects of a phenomenon, and to be able to learn, you must first discern the object of learning critical aspects. Marton and Trigwell (2000) describes discernment as a necessary step in the learning process as: "There is no learning without discernment and there is no discernment without variation" (p.387). Thus, to discern a critical aspect, the learner must experience variation within that critical aspect to discern it, such as varying the density of a floating object to discern when it sinks in a liquid. The variation of a critical aspect is called; the opening up and exploration of a dimension of variation (Lo, 2012) and is required when learning a new phenomenon. Thus, when learning geological time, it must be experienced through variation and the exploration of dimensions of variation. The students' experience of geological time is thus coupled to how they explore and vary critical aspects through the use of multimodal representations and communication.

METHODS & ANALYSIS

The underlying methodological framework used in this study is inspired by the qualitative research approach phenomenography (Marton, 1992; Marton & Booth, 1997), which is closely related to VTL. Phenomenography is defined as "the empirical study of the limited number of qualitatively different ways in which we experience, conceptualize, understand, perceive, apprehend etc., various phenomena in and aspects of the world around us" (Trigwell, 2000, p.77), for example, geological time. Different experiences, understandings, etc., are characterized by themes, or categories of descriptions, logically related to each other, and often forming hierarchies in relation to certain given criteria. Data is usually acquired in different types of interviews, probing previously unthematized aspects of the phenomenon in question—here geological time—recorded either by audio or video recording, and then transcribed verbatim and/or multimodally (Eriksson, M., Eriksson, U., & Linder, 2020). The analysis is then carried out in an iterative manner (Guba & Lincoln, 1982) and distinctly different ways of experiencing a phenomenon are identified rather than single individuals. This is an important distinction to make; what is found is thus the different ways of experiencing something, or understanding it, not each person's way of experiencing a phenomenon, or understanding it. It is important to mention that a phenomenographic research approach takes a relational (or non-dualist) qualitative second-order perspective. This means that it 1) describes the key aspects of the variation of the experience of a phenomenon rather than the richness of individual experiences, and 2) that it yields a limited number of internally related, hierarchical categories of description of the variation (Trigwell, 2000). Usually, the number of identified categories of descriptions are few, only a handful, regardless of how many interviewees one has. The identified categories of description corresponding to those different understandings, and the logical relations between them, constitute the main results of a phenomenographic study (Marton, 1992; Marton & Booth, 1997). The practical approach to analysis that we have chosen for this study is thus inspired by phenomenography and in the following we describe the steps, or stages, that underpin our analysis methodology.

In the first stage relevant data were identified by reading the transcriptions and listening/watching the video-recordings multiple times by all authors individually and in groups, and the selected data were then coded into different "nodes". See Figure 3 for an illustrated overview of the process. A node is a piece of data with relevant information for the study; it can be a short individual quote, discussions in various lengths, gestures with an adherent quote or illustration with adherent quotes. The most important part of the first stage is to work through the material each time with an open mind. When keeping an open mind, it is more likely that one discerns sections in the material that are important for understanding of the experience of geologic time. By maintaining an open mind, it is also possible to avoid prejudice from the researchers that can lead to potential loss of important data or misinterpretations of the experience. Furthermore, it is important to acknowledge that one is not evaluating the participants' knowledge level; one is searching for how they experience time.

In the second stage of the analysis nodes with similar content were merged into coherent working categories, e.g., 'use of numbers', 'perspective', 'gestures' or 'reasoning'. From this process categories could be merged into larger themes. Because of the recurring coding process during the analysis, new nodes could emerge, old nodes could be re-coded and working categories could be changed, added or deleted. This sorting and resorting of the nodes and working categories continued until all relevant data was coded and placed in a working category, a process referred to as saturation (Guba & Lincoln, 1982). After saturation was reached no more coding or re-coding was done.

The working categories and themes were then clearly described and organized into their final saturated categories and themes, with hierarchical structures. Each saturated theme now describes qualitative different ways of experiencing or understanding some phenomenon, like geological time.

The chosen research design for this project is a case study. The research question lends itself to a case study because it is a 'How' question, best answered by qualitative means as described by Baxter and Jack (2008). The question necessitates a situation where students can express themselves in several different ways and we use multiple data sources to capture all the different ways of experiencing geological time. In a case-study, the multiple sources of data are used together to construct a holistic picture of the situation. In this study, video, still images, audio, student-created representations, questionnaires and notes from the interviewer are all used together to obtain a well-grounded foundation for the analytical process.

Nine students answered the questionnaire and six of them decided to participate in the interviews. The attendance at the interviews varied between 4-6 students and two students attended all three interviews. To collect useful data for a phenomenographic study, a semi-structured task-based interview method (Kvale, 1996) was chosen because the interview could be used to ask predetermined questions but also questions about specific spur-of-the-moment subjects that the students were discussing. Since the intent of the data collection was to obtain a wide range of answers (i.e., "rich data"), which was used in the analysis, it was necessary to construct an environment that allowed the students to express themselves using several different means or modes. The interview space was a calm conference room with a large table in the middle and with easy access to a large whiteboard for the students. The students had access to standard geological representations, such as printed images, fossils and different geological samples. To encourage discussion and to capture a variety of experiences, the interviews were done in groups of students that all knew each other from the courses they had taken together. This ensured a rich dataset that could be used in a comprehensive phenomenographic analysis.

Three interviews were conducted and recorded using 2-3 cameras (GoPro Hero 6) and several microphones (WS-852). The full interviews were video recorded from several angles to capture the whole discussion as well as the students' gestures and drawings. The drawings and other representations that the students created during the interviews were also gathered and used in the multimodal analysis. The interviews were conducted at a university in southern Sweden on first year geology students during the period fall 2019 and winter 2020. The students had used 'Earth: Portrait of a Planet' by Marshak (2019), in their first and only course in geology. In their course, one of the first representations of geological time they encountered was the GSA timeline seen in Figure 1.

Questionnaire

The main aim of the questionnaire was to gain preliminary guidance regarding the students' understanding of geological time before the interviews. In order to collect this information a questionnaire with open-ended questions was constructed based on general literature regarding construction of questionnaires and questions (Carlström & Carlström-Hagman, 2006; Teorell & Svensson, 2007) and subject specific literature such as, for example, Dodick and Orion (2006), Teed and Slattery (2011), Burton and Mattietti (2011) and Czajka and McConell (2018). All questions in the questionnaire were developed by the research group, except the first two questions which were adopted from previous studies by Dodick and Orion (2006) and Czajka and McConell (2018). The questions developed for this questionnaire aimed to elicit information regarding how the students experience geologic time through both disciplinary and philosophical perspectives, see the excerpt below for a question based on a more philosophical aspect:

Line	Excerpt 1
1	Explain, with your own words, how you experience a million years. You are welcome to use examples and analogies.

Before the questionnaire was used it was sent to the two main lecturers on the course the students attended to receive a second opinion on the questions. The questionnaire also served as a recruitment tool, where interested students could volunteer for the following interviews. The answers from the questionnaire were used as a guide for the construction of the questions for the interviews, but the answers were also used as part of the analytical process.

Semi-Structured Interviews

The semi-structured interviews were constructed around several problem-based tasks where the students had to discuss, and construct, representations of different aspects of the concept of geological time. The diversity of tasks and room for open discussion ensured that a wide range of ways of experiencing geologic time was captured. In total, three interview sessions were carried out.

The first session started with an 'association' exercise where the students were asked to choose and discuss different images in relation to geological time in whatever way they saw fit. In the second exercise (the main exercise) the focus lay on creating a geological timeline, where the students had to insert different geological events, such as the oxidation of the oceans or the formation of Bohus-granite (Schouenborg & Eliasson, 2015) on a timeline, see Figure 3. At their disposal they had physical samples that represented a specific time on the timeline, notes with events, pens and a very large piece of paper where they could construct their timeline. This session ended with a mind-map exercise where the students were asked to construct a mind-map with the instruction to answer the question: "How do you experience geological time?"

Figure 3. Part of the timeline constructed by the students using different props and representations.

The second session started with an exercise that encouraged the students to both discuss both different time scales in geoscience, such as, for example, cloud formation and the formation of a galaxy but also to discuss different representations from, for example, a textbook or a published article. In the second exercise the students were asked to discuss cyclic e.g., the rock cycle or linear processes in geoscience e.g., the evolution of horses. In both these exercise the students were given a set of A4 seized prints of the different phenomena. The session ended with the students being asked to create their own representation of geological time.

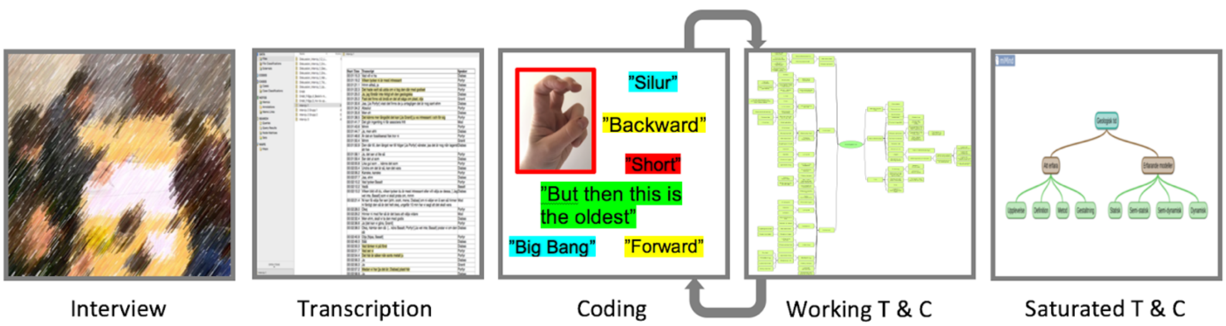
The third session dealt with the concept of the future and geological time. The theme was chosen because of an interesting phenomenon observed in sessions 1 and 2. The observations indicated that the students only discussed geological time in the past tense and ended the geological timescale at the present day. The final session was thus designed to help the students expand their perception of geological time and experience it in a new context: the future. The session began with a five-minute contemplative period where each student had to think about what the future of the Earth would look like, from their own point of view, but also in geological terms. They were then asked to present their ideas and thoughts. As a final task, they had to discuss and create different scenarios of Earth's future on the whiteboard. The students were prompted to envision the Earth in a hundred, thousand, tens of thousands, hundreds of thousands, millions or even billion years in the future.

The combination of data obtained from the three sessions provides a diverse and rich dataset that represents a wide range of student experiences. Each session was open ended, and the interviewers would ask the students questions about different ideas that they presented, either to get a clarification or to prompt a new discussion around the question. The questions themselves were not pre-written but emerged as the interviewers observed the situation.

In order to assure quality issues in this research, the methodologies and theories used are well established and the researchers conducting the interviews and doing the analysis are well versed in the concepts and ideas. Each interview session was planned and discussed with experts and practitioners in geology education and physics education research. This methodology ensured that each interview session was designed and prepared to capture different student experiences regarding geological time. It should also be noted that the types of experiences that the method was looking for pertains to the disciplinary notion of geological time and the student's own notion of geological time. Each interview used examples and representations from geoscience to spark discussions and allowed the students to express themselves. At the start of the second and third interviews, the students had an opportunity to ask questions and discuss the last session, to ensure that they could complement the collected data with clarifications or expansions of their own thoughts. This recall ensured that the student had time to reflect on their thoughts, and the questions, to come up with new and interesting answers. Together with the analytical methods, the case study structure and the qualitative methods, we fulfill Guba & Lincoln (1982) categories for naturalistic research. The high-quality data collection, the competency of the researchers and extensive literature and analytical work ensures that the results are robust and honest.

The collected audio- and video recordings were used both as a source for transcription but also as a vital support during the phenomenographic analysis. With well covered recordings it was possible to place the student's discussions and statements in the right setting ergo it was possible to connect things like speech and gesture or posture and facial expressions. This made it possible to fully experience the atmosphere when the students discussed their experience of time, which in turn makes it possible to reduce the risk of misinterpreting the students' expressions of time. We could also cross-reference the audio file with the video file if there were words that were hard to hear, and it was possible to ensure that we captured the conversations correctly.

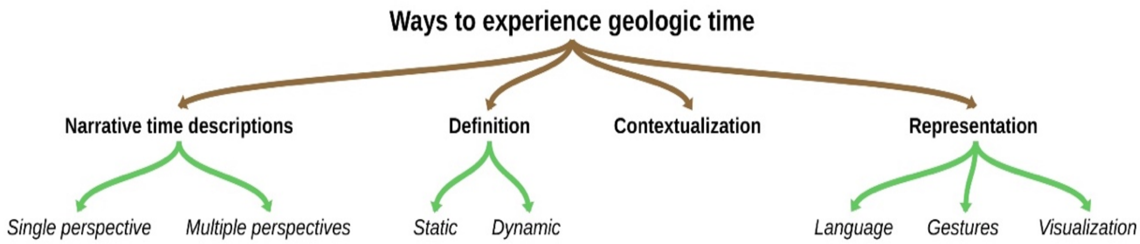
Figure 4. The phenomenographic analysis process uses the transcription from the interviews to construct temporary categories. Through iterations and discussions, the temporary categories are modified until all the data can fit into a small number of themes (T) and categories (C). The result of the analysis is the saturated themes and categories that fully captures the experiences of the phenomenon.



The written questionnaire and transcribed interviews were analyzed simultaneously as the combined pool of data.The analysis process began concurrently with the data collection and involved an initial analysis of the obtained data. In this stage, each questionnaire was summarized in relation to students' understanding of earth science phenomena in general (e.g., sedimentation or plate tectonics) and geological time, as well as their experience of time in general. The analysis of the interviews began with two of the authors listening to the recordings from the first interview several times, paying special attention to how the students had interpreted the assignment they had been given, as well as how well we had been able to capture the students' speech, gestures and other resources which they used during their discussions. This was used to improve the second interview and the process was repeated for the third and last interview session. In the second step of the analysis, we transcribed the recorded interviews using the qualitative analysis software NVivo 12.

The final step involved a phenomenographic analysis described in the methodology section of the paper. This iterative analytical categorization process was performed by the first author, however with close communication and support of the other authors. This iterative process was designed to exhaust the dataset through a detailed and holistic approach of looking at the data.

Figure 5. The experience of geologic time is divided into four different categories: ’Narrative time description’, ’Definition’, ’Contextualization’, and ’Representation. Each category may also have a number of sub-categories that further details the experience



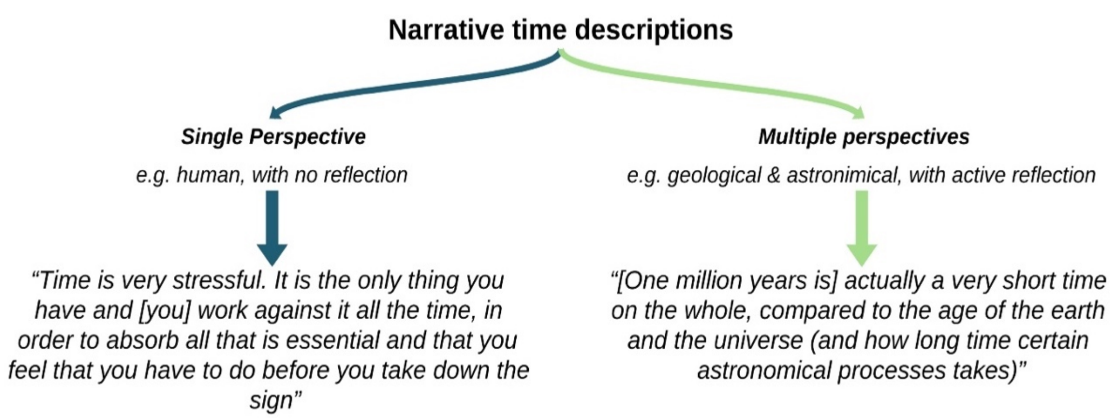
RESULTS

The iterative coding and categorization process resulted in four qualitatively distinct categories of description of how students experience geological time: ‘Narrative time descriptions’, ‘Definition’, ‘Contextualization’ and ‘Representation’. For some of these categories we identified two to three sub-categories, see Figure 5. Below we will present the descriptions of the categories and their subcategories and exemplify their meaning by providing excerpts from our rich data, some categories are also based on student-created illustrations and/or diagrams. All excerpts from interviews and the survey have been translated from the Swedish original into English.

Narrative Time Descriptions

This category with its two sub-categories (‘Single-’ and ‘Multiple’ perspectives), describe how geological time can be narrated. The category is characterized by two characters first, the number of perspectives used in the description of geological time and second, whether active contrasting where present or absent, within or between varying perspectives, see Figure 6 for examples of these sub-categories.

Figure 6. The ’Narrative time description’-category is subdivided into two sub-categories: ’Single Perspective’ and ’Multiple Perspectives’. Each sub-category explains a facet of the experience of geological time.



Single Perspective

This subcategory is characterized by a single perspective and an absence of active contrasting within the perspective or with other perspectives.

Line	Excerpt 2
1	Time is a human invention. Time is actually not something that exists, we have decided that time shall exist - which we benefit from nowadays with studies and work.
2	[...] geologic time is only as we ourselves have divided and identified and sort of interpreted it [earth's history]. It is not objective, any of it, actually.

In the excerpts above the descriptions of geological time emanate from and revolve around a human perspective. Time and geological time are something humans have created: “Time is a human invention" or “...geological time is only as we ourselves have divided...”. In both excerpts there is an absence of active contrasting i.e., no depiction of alternative description, either within the perspective (e.g., other individuals) or from other perspectives (e.g., other disciplines such as astronomy). In the following excerpts, the single perspective can also be observed in temporal reasoning.

Line	Excerpt 3
1	Yes, it leads to us, plus [...] it leads to more resources, that are perhaps more important, than a plain diabase.
2	Yes, it shows, that the closer to us [humans] we come, the more important, the more zooming in is required, because we think it is more important.

In both excerpts above, geological time and events in the past are valued and connected to the present through a single perspective. Geological time and events in the past are connected to the present through the evolution of modern humans and to the resources we claim. The significance of geological time and an event in the past are valued based on their relation to human evolution and to the proximity to human interests. The closer to an event that influences human evolution, or an event that in the future will yield human resources, the more significant it becomes and the more “zooming in” is needed. As for the descriptions of geological time, there are no active contrasts present in the temporal reasoning where one considers other perspectives.

Multiple Perspectives

This subcategory is characterized by multiple perspectives with active contrasting i.e., descriptions of geological time emanate from and revolve around two or more perspectives with contrasts either within a perspective or between different perspectives.

Line	Excerpt 4
1	If you talk geologically, it is significant that there are many who [are], for example, if you are a religious person, you might not [share] the perception that the earth is 4.6 billion years. So, it is something that not all humans have in common, it might be a bit polarizing.

The excerpt above shows an example of a multiple perspective revolving around variations within a perspective, in this example a human perspective on geological time. This description emanates from a human perspective, but within this perspective it is acknowledged that different individuals may perceive the age of the earth differently, depending on their previous experience. This is an exploratory description of geological time with active contrasting over what geological time means to different individuals. The excerpt below shows an example of a multiple narrative with active contrasting between three different perspectives.

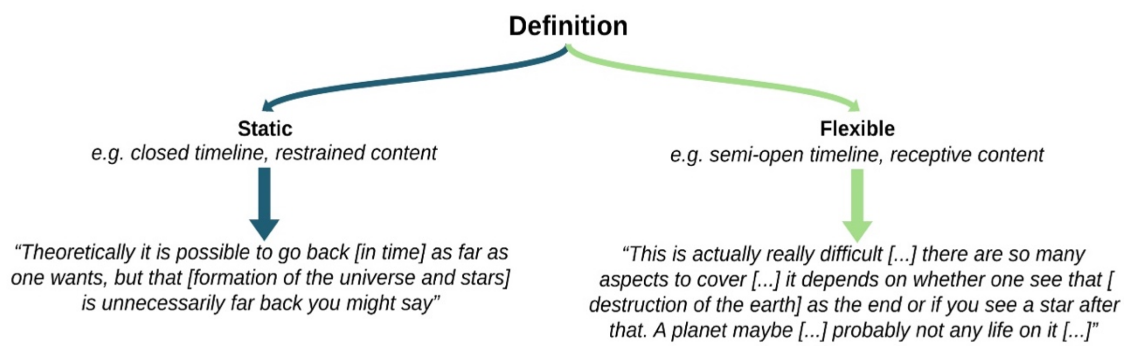
Line	Excerpt 5
1	[One million years is] actually a very short time in the whole compared to the age of the earth and the universe (and how long time certain astronomical processes takes). It is hard to really grasp the number. It is something that is unfathomably long for humans but short from a larger perspective

This description of time contains three perspectives –human, geological and astronomical– in order to describe something that is "...hard to really grasp...". The single (human) perspective on time is challenged by the awareness of two other ways to describe time, namely geological time and astronomical time. Instead of discarding the conflicting perspectives, the three perspectives, human, geological and astronomical, are contrasted against each other in order to, in this case, compare the limitations of a human perspective of time with the infinity of geological and astronomical perspective of time.

Definition

This category with its two subcategories ('Static' and 'Flexible') describes how geological time can be defined and is characterized by when geological time begins or ends and which phenomena e.g., events or processes, are included (or excluded) into the definition of geological time, i.e., restrained content or receptive content.

Figure 7. The category 'Definition' is subdivided into 'Static' and 'Flexible'. Each sub-category captures a different aspect of 'Definition'. 'Static' captures the idea of a concept that is set in stone with well defined borders. 'Flexible' describes a relative perspective where definitions are more fluid.

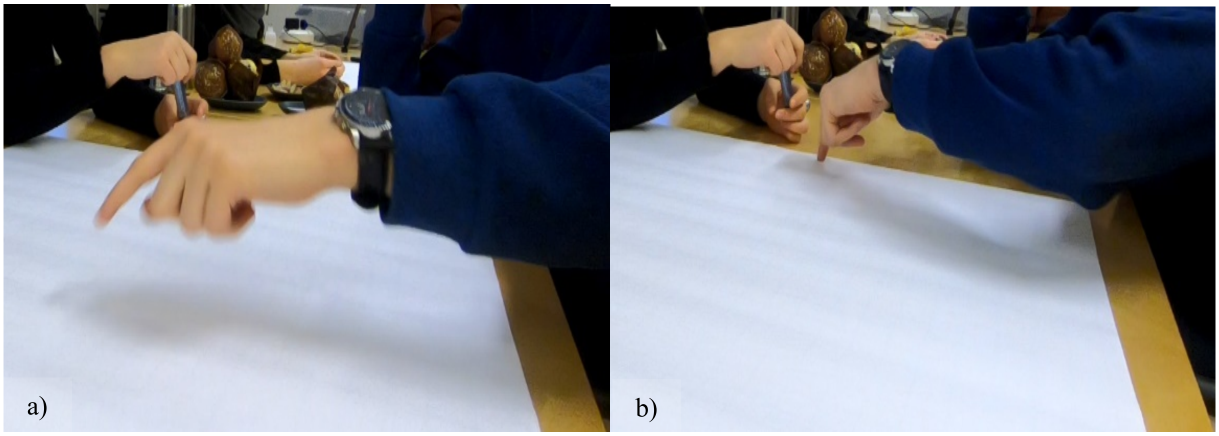


Static

A static definition of geological time is characterized by a closed timeline with a pronounced beginning, a distinct end and a restrained view of which phenomena (e.g., events or processes) are included. The following multimodal transcription (Excerpt 6 and Figure 8) from one of the interviews demonstrates an example of how a closed timeline is expressed through both language and gestures.

Line	Excerpt 6
1	It begins there [Figure 8a] and ends here [Figure 8b] [points from one end of the paper to the other]

Figure 8. The student indicates where geological time starts (a) and ends (b), implying that the timeline has a definite start and end.



In the excerpt above geological time is defined by pointing from one end of the paper to the other and emphasizing the gesture with language, through the words "begins there" and "ends here". There is no further reasoning to whether or not geological time can exist outside this definition. The next example includes two important aspects of a static definition of geological time. The first is the use of fixed reference points and the second is the strong association between geological time and the age of the earth.

Line	Excerpt 7
1	There is not a lot geology left of the earth after it has been devoured by the sun, so to speak.

In this excerpt, geological time ends when the earth ceases to exist. This fixed reference point of the end of time leads to an indirect reference point for the beginning of geological time, namely the creation of the earth. This static definition of geological time depicts a strong connection between geological time and the earth, where the beginning and end of geological time is linked to the creation and destruction of the earth. This connection between geological time and the earth can also be seen in which phenomena are included or excluded in the description, which the below excerpt shows.

Line	Excerpt 8
1	S1: There are theories that say that there is a possibility that the universe could be cyclical.
2	S2: Sort of like Big Bang and then together?
3	S1: Yes, and then it will end in a Big Crunch.
4	S3: But is that geological time?
5	S1: No.
6	S3: It is astronomical.

In this excerpt, the suggestion that geological time could be viewed as part of a larger whole, and possibly become cyclical, is challenged ("...is that geological time?") and then dismissed ("No.", "It is astronomical."). A static definition of geological time is strongly connected with the age of the earth. Phenomena, such as for example: the Big Crunch, is not seen as being part of earth's timeline hence not regarded as vital and is thereby excluded from the definition, i.e., a closed timeline. In a static definition of geological time there is no active reflection over the possibility that a different context (intra-disciplinary or disciplinary) can change the definition or the phenomenon's included (or excluded) in the definition.

Dynamic

A dynamic definition of geological time is characterized by an open timeline where the beginning, end and the phenomena e.g., events or processes included (or excluded), are open for reflection and can vary depending on the perspective.

Line	Excerpt 9
1	[When does geological time end] Or when humanity dies. Where you end is entirely subjective.

The above excerpt shows an awareness of the possibility of several plausible definitions of the end of geological time. Instead of excluding any definition that is not seen as valid, the question is left open to reflection through a dynamic reference point. Another excerpt further shows the use of plausible definitions of geological time.

Line	Excerpt 10
1	S1: No, but what would then end, when the universe [...] only consists of black holes and nothing else.
2	S2: That is when it ends.
3	S1: And [...] everything just goes around with Hawking radiation and eventually they will disappear too, kind of [...]
4	S2: Yes, it [...] depends on the perspective.
5	S1: Then it is a few googol mil [ions], kind of, years if you can say that.

In this discussion, the end of geological time is associated with the end of the universe. In a flexible definition of geological time there is a receptive view on which phenomena one could include in the definition. This was exemplified during one of the interviews where timescales were discussed in relation to geological time.

Line	Excerpt 11
1	And, I am thinking about another thing when we are talking geological time, most timespans take a very long time and are enormous, that is, they have an enormous timescale, but there are also [...] geoscience processes, such as impact structures and, like, meteor impacts, they go very fast I say. So, you can imagine that geological time can be very short as well.

This example shows how an awareness of the different timescales in geoscience affects the definition of geological time. In this dynamic definition of geological time, impact structures with short timescales are included and adds a new dimension to the definition of geological time with an awareness that geological time can contain both long and short timescales. This opens the possibility of including a myriad of plausible phenomena that can be included in the definition of geological time.

Contextualization

This category describes how temporal context is experienced and explored. The category is characterized by the identification of ‘reference points’, the process of connecting the ‘reference points’ to various concepts and how these are seen as associated with each other. One example of this can be seen in the following excerpt from the exercise (‘association’) where the following discussion arose around a picture of a candy shelf.

Line	Excerpt 12
1	S1: What is the first that comes to mind?
2	S2: What do we see, this is probably some kind of metal.
3	S3: Yes
4	S2: While we have plastic here
5	S1: Yes. If you are going to think about how old, when raw material is formed or should you...
6	S2: But that can we [...] talk about
7	S1: Because I think that this is probably aluminum or something like that simple. So yes, it doesn't form naturally on Earth, so that happend some [Billions ... ; S2] some billion years ago. Yes, and it didn't really formed by, it probably didn't form in the solarsystem at all.
8	[...]
9	S2: Mmm, but what we have to say about aluminum, then it is kinda, it was [...] When meteorites, and similar, collided, the Earth formed and it wasn't one of the first ones because of high atomic number [Yes; S1]. So, very far back but it probably didn't form on Earth but arrived here.
10	S2: Yes

In the first four lines in the excerpt above, two 'reference points' are identified, metal and plastic. In line five the contextualization continues by connecting the 'reference points' to two concepts 'how old the material is' and 'when a material is created'. In lines seven and nine the exploration of the temporal context regarding the 'reference point', metal, is expanded. This is done through a connection of the 'reference point', it's two initial concepts and new unexplored 'reference points and concepts such as the formation of aluminum, impact events and atomic numbers. One important aspect of contextualization is that it provides temporal scaffolding in a discussion, as seen in the excerpt below.

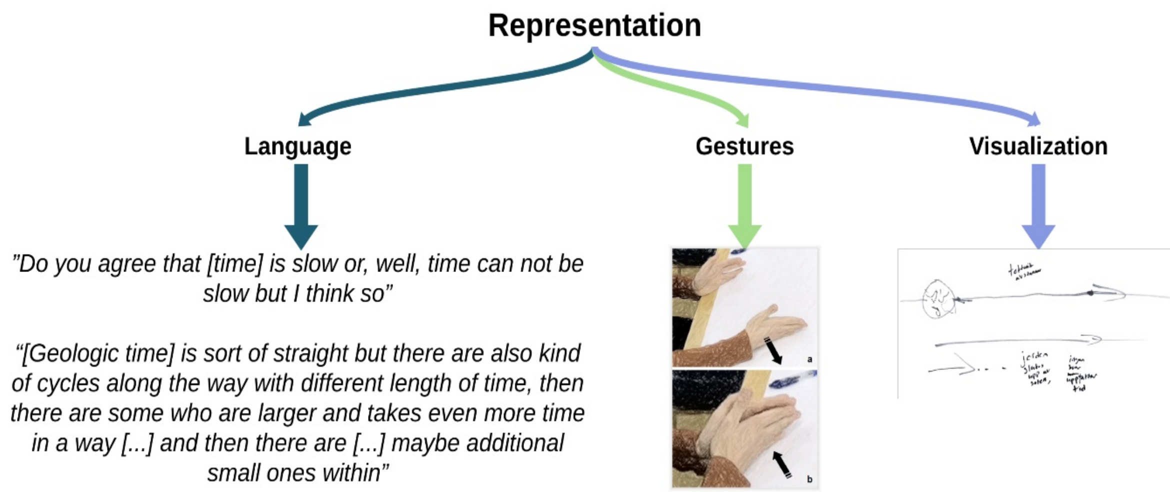
Line	Excerpt 13
1	S1: We could write on Cambrian also, like 550.
2	S2: Yes.
3	S3: Cambrian explosion.
4	S2: Shall I write 250, no, what did you say, 550?
5	S1: Yes, it's something like that.
6	S3: Isn't it 5...20 or something?
7	S1: Okay, but I think.
8	S2: It is probably a bit unclear, perhaps, how long it lasted.
9	S3: Yes, maybe. Everything is unclear.
10	S1: 540
11	S3: 520

In the excerpt above regarding the occurrence of the Cambrian explosion the temporal scaffolding facilitates a heuristic discussion of temporal aspects where only the scale, e.g., 550 is provided during the discussion. The dimension is completely depending on the context, in this case Ma (million years).

Representation

This category with its three subcategories ('language', 'gestures', and 'visualizations') describes how geological time can be communicated. The category is categorized by how verbal ('language') and non-verbal communication ('gestures', 'visualizations') are used to mediate temporal aspects in geoscience.

Figure 9. Geological time is represented using different modes, such as 'Language', 'Gestures', and 'Visualization'. Together they make up a multimodal representation of geological time.



Language

'Language' is characterized by two central parts, the usage of conceptual metaphors e.g., far back, not long ago and the usage of a disciplinary vocabulary e.g., Cambrian explosion or Thermohaline circulation. Examples of how temporal information is mediated through conceptual metaphors can be seen in the excerpts below.

Line	Excerpt 14
1	So, very far back.
2	That time can go both back and forth.

In the excerpts above, conceptual metaphors are used to communicate the direction and scale of time through spatial references. Another way to use conceptual metaphors is to describe events and/or organize the relationships between temporal events, see Excerpt 14.1 for an example of this.

Line	Excerpt 15
1	[Time is] a room/gap/window where I live. By me, experienced as large. Time before and after is perceived as small and less significant, which in a way is contradictory.

In the excerpt above there are two spatial metaphors for time, the first one is where time is described as a defined space, "a room", "a gap", "a window" and the second spatial metaphor is where time is described as a dimension "large" or "small". Time is also described through sequential temporal reasoning where the temporal relationship between the three events 'a lifetime' ("where I live"), "time before" and "time after" are related independently of the present (i.e., no deictic center). There is also a conceptual metaphor that describes the experienced value of time, where events in time are experienced as more or "less" significant depending on their proximity to a specific event, in this example a lifetime. The experience of time is also described through spatial action metaphors where time is experienced as an active motion in space, as seen in the following quote where time is described as moving "fast" through space. This also indicates a time moving, observational metaphor.

Line	Excerpt 16
1	But I think the experienced time is quite fast

There are also descriptions that relate the experience of time with the amount of information one can elicit from the surroundings or a dataset, in this example the geologic time scale. In time spans where it is possible to perceive that there are plenty of data points e.g., the present, time is experienced as "fast" but in time spans where it is possible to perceive that there are few data points e.g., Archean, time is "tranquil".

Line	Excerpt 17
1	[Time] here and now [is] definitely, [...] fast would I say
2	In a way it is a rather tranquil time

In the following quote there is another example of the connection between the amount of information and the experience of time. In this case the spatial description of time depends on the amount of available data. Time is described as a defined space with boundaries "you fill" but the boundary is adaptable and can increase in "width" to be able to accommodate more data (information) i.e., more time.

Line	Excerpt 18
1	[And] then you fill all this with, with, like events and time. So that's why you need, width, more [...] space

Finally, it is possible to use disciplinary vocabulary to mediate temporal information, examples of this can be seen in the excerpts below.

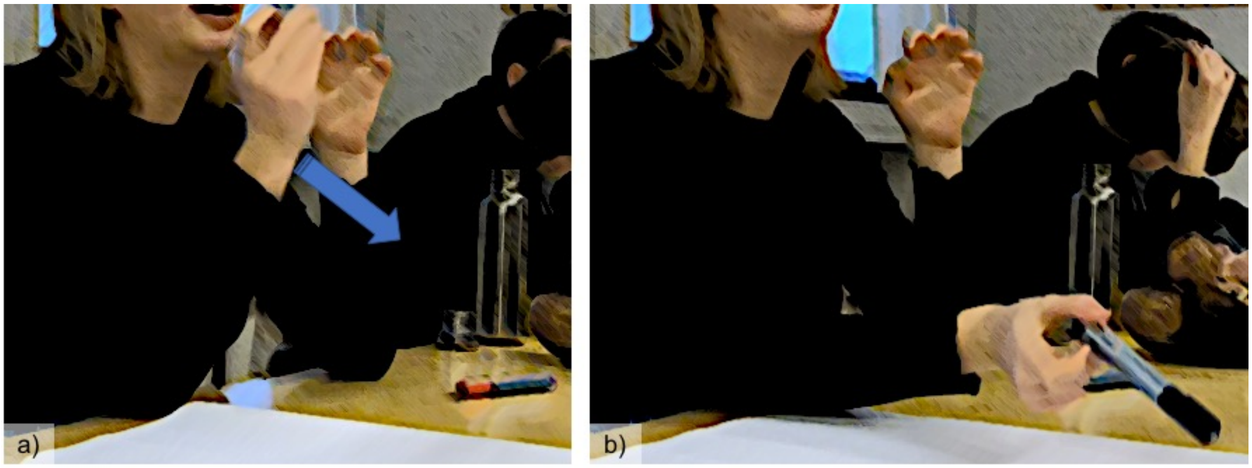
Line	Excerpt 19
1	Yes, you can even see a clear layer sequence.

In the excerpt above disciplinary vocabulary is used to mediate temporal information incorporated into disciplinary concepts such as, for example, layer sequence.

Gestures

We identified four types of gestures used to communicate temporal information in geoscience. The first type of gesture and the most common, are gestures that occur along the lateral plane (movements towards the left indicate old, and movements to the right indicate young). The second type of gestures related to time are movements in the sagittal plane, where gestures that are directed forward indicate future and gestures that are directed backwards are indications of the past. The third type is disciplinary tied gesture where time is linked to a vertical orientation, see the following multimodal transcription (Excerpt 20 and Figure 10) for an example. The fourth type of gestures identified in this study are "complementary" gestures that cannot be "linked" directly to time, but they are used to emphasize time, this can be air quotes, hand waving (approximately), pointing (exact) or the place directions of the notes used in the time-line exercise.

Figure 10. The student indicates how geological time is visualized in an vertical line (a) the gesture starts from a high position (b and moves to a low position, implying that the timeline is visualized linear and vertical.

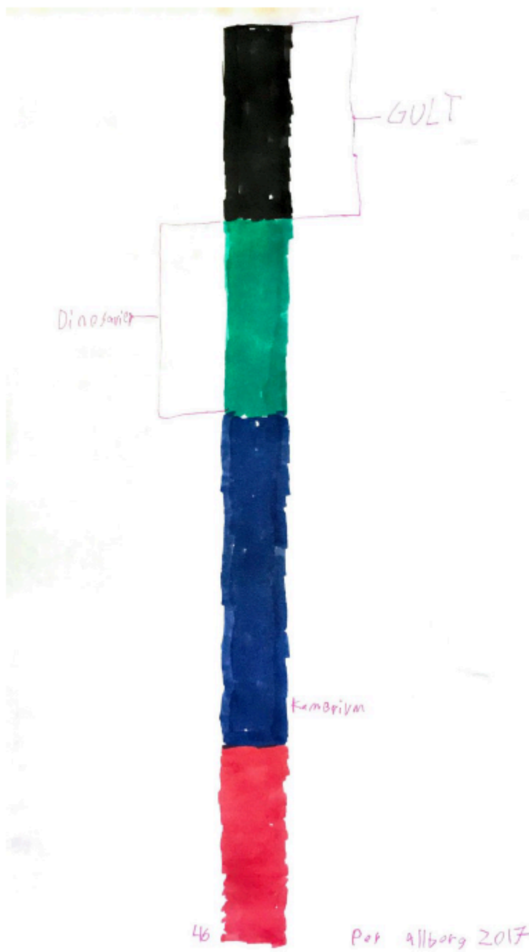


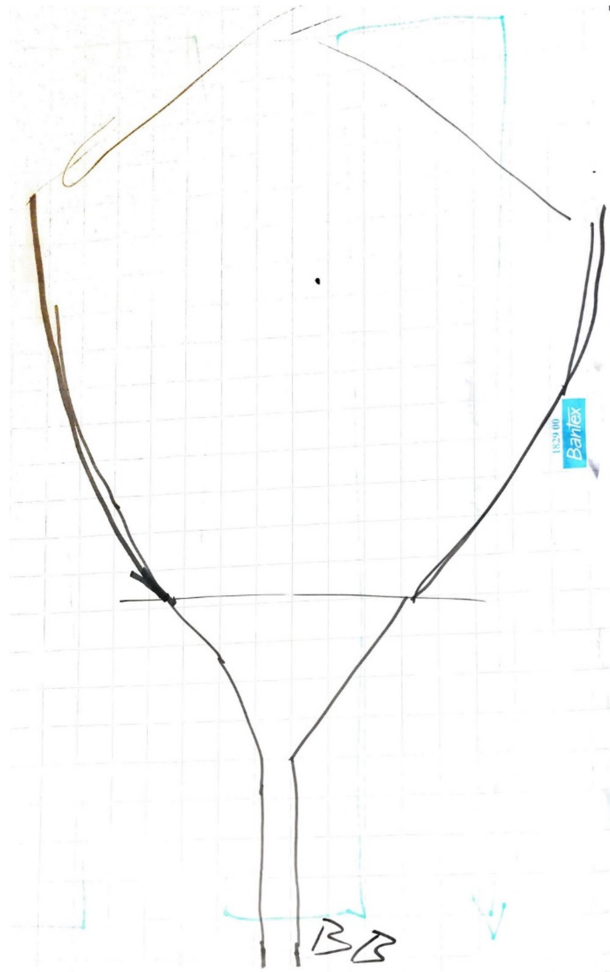
Line	Excerpt 20
1	I probably see it as more linear. When I think of geologic time, I think of this *gestures up and down* that scale

Visualizations

The different types of visualizations used to communicate geologic time can be divided into three groups 'one dimensional', 'two dimensional' and 'duality'. In the one-dimensional representation of time, time is visualized as either a single vertical or a single horizontal line. The horizontal line is visualized as an arrow with a clear beginning and an open end whilst the vertical is defined through a clear beginning and a definite end (today), see Figure 11a for an example of a vertical visualization. Both scales can be segmented but the segmentation is most prominent in the vertical representation. In the two-dimensional representation of time, see Figure 10b, time is visualized as a function of something, it can be between time as a function of information frequency e.g., more information equals more time or time as a function of processes e.g., geological time is a collection of individual phenomena such as plate tectonics or time as a function of scale e.g., long time scales (geologic time) are experienced as linear and short time spans (a year) can be visualized as cyclical. In the dualistic representation of time, time can be represented in several different ways. One example of this can be that there is a disciplinary way to represent time such as the geological time scale and simultaneously there is an individualistic way to experience time such as the meandering historic time and vertical geologic time.

Figure 11. a) A linear representation of geological time with sharp distinct borders between different parts of Earth's history. b) The geological timeline since the Big Bang (BB at the bottom). It expands as more information is obtained about the time. The horizontal line near the middle represents the Cambrian explosion.





DISCUSSION

In the sections above we presented our results from the phenomenographic analysis, in this chapter we will discuss our findings. Through our analysis we have found that there are four qualitatively different ways to experience geological time: 'narrative time descriptions', 'definition', 'contextualization' and 'representations. In this chapter we will discuss our findings. We will do this by placing the categories into context and contrast them against previous research in different disciplines such as, for example, disciplinary based education research and cognition.

In this study we aim to gain a deeper understanding of 'temporal aspects in geoscience'. In its most basic form humans' ability to experience spatio-temporal aspects in their environment is formed by evolutionary processes (Ladyman, Ross & Collier, 2007; Dawkins, 2016). Humans have the ability to "naturally" experience a spatial scale from approximately a tenth of a millimeter to a few kilometers and to experience a temporal scale from approximately a tenth of a second to a few decades (Klemeš, 1983). Within this human spatio-temporal environment, the individual also has a personal sphere with a diameter of approximately two meters (Cutting & Vishton, 1995). This contrasts with the spatio-temporal scales one needs to grasp many phenomena in geoscience, and it is not surprising that geologic time is a threshold concept. In our data we observe the collision between the human way of experiencing time and the experience of geoscience phenomena that goes beyond human perception. We also see that there are different ways to handle the varying temporal aspects in geoscience. In the category 'narrative time descriptions' the 'single perspective" describes how the students use, for example, their human experience of time to try to grasp the temporal aspect in geoscience. Here we see that it is easier to associate and talk about familiar concepts rather than unfamiliar concepts, “it is much easier to talk about shorter time perspectives, I do not have so much to say about, well, about this long time [perspective]”. In the ‘multiple perspective’ they use another approach here the human experience of time is percent, but it is contrasted against the geoscientific to ‘make sense’ of the unimaginable timescales encountered in geoscience, “It is hard to really grasp the number. It is something that is unfathomably long for humans but short in a larger perspective”. In ‘multiple perspective’ we see how the students use an environment that they are familiar with (human space and time) to describe and grasp an environment that they feel unfamiliar with (geoscience space and time). Marton and Booth (2000) describe that in order to experience a phenomenon in a complex world an individual must be able to discern what is important and what is not important to discern the context. Marton and Booth (2000) compare an individual's ability to experience something with the analogy of being in a room filled with details such as walls, roof, tables, chairs, bookcases, books and so on. An individual that has grown up in such an environment knows what the different parts are called, what they mean, how they are connected and how they work. For example, they know that it is possible to open a window to let in fresh air and that books are filled with images and words. Now, let us use the room metaphor from Marton and Booth (2000) but change the context to a kitchen and view it from a spatio-temporal perspective. In a kitchen an individual will feel familiar with the spatio-temporal scale incorporated into the context. If you describe the kitchen to another individual and say that the kitchen table is small and that the kitchen widows are large, they are likely to be able to give accurate estimates of the absolute scales of these descriptions. The power of familiarity is also evident for our perception of time. If you describe that it takes four minutes to soft boil an egg on your stove, the individual has an approximate estimate of this description. When you are familiar with an environment, it is possible to accurately estimate time, size and relation between events and objects. You know what will fit the spatio-temporal scale for example, if someone tells you that a soft-boiled egg takes one hour to prepare or that they keep an elephant in the kitchen you know something is off.

So how do students handle spatio-temporal aspects in new environments that they have no prior knowledge of, or in environments where the scales are far beyond what they can have direct experience of? One way is to try and define the new concept; for novices in geoscience this means that they must define the concept of geologic time. This is no small challenge novices in geosciences are faced with. They must define the unfamiliar concept of geologic time without a framework or language to accurately describe the objects or phenomena they encounter. In ‘Definition’ we describe how this challenge is handled by the students through the example of the discussion regarding how aluminum is formed. Is aluminum a part of geologic time, or is it astronomical time? In a static way of defining the concept of geological time the formation of aluminum is not a part of the concept, the formation of aluminum belongs to astronomical time. It appears as if when you are unfamiliar with the concept of geological time it is more manageable to handle clear definitions. This is also something that the students themselves are aware off “[...] when you have to explain something for [...], someone the first time, it is better to make it simple and [to] have fewer details but, if you only, if you already understand it, it is actually better if you can read more stuff out of it [...]”. One possible explanation for the need to find clear definitions is that it might be easier for a novice to describe and handle an unfamiliar phenomenon, such as, spatio-temporal aspects in geoscience, if it is well defined (cf. Reed, 2016). This explanation can also find support in the subcategory ‘dynamic’ definition. When you are familiar with the concept of geological time it is easier to move beyond the initial restrained definition and to redefine its borders to include more information, or to imagine geologic time to be, for example, cyclical. "There are theories that the universe could be cyclical".

In both categories so far, we can see that the students' experience of the concept of geological time is in some way, or another influenced by familiarity. This shows that it is important to remember that the categories we present in this article does not describe knowledge levels. When a novice is introduced to an unfamiliar concept such as geological time, they must create ways of processing and handle this new way of experiencing the world. Zacks and Tversky (2012) write that it is first when individuals have common reference frames that they can use the connection between established spatio-temporal scales and the spatio-temporal expectations, because it is first when a spatio-temporal scale is established they can process information in relation to the background of this spatio-temporal scale. We can also see that familiarity with the concept of geological time also is important in the contextualization process. Here the familiarity is used in order to orient oneself in an unfamiliar context by identifying familiar ‘reference points’ “"But it feels like, we have more of a connection to the fossil [a bonefish], because we just [read about them]". In this example the choice of photograph for the ‘association’ exercise was made based on the familiarity with the concept of fossilization. In another example from the association exercise, we can see that the process of contextualizing was richer if the concept was familiar, but more modest when the concept was unfamiliar. This example builds on the excerpt from the ‘contextualization’ category, where we could observe a rich contextualization around the ‘reference point' metal. In the same discussion the 'reference point' plastic was also discussed; the formation and development of the contextualization process and it were similar to the one about metal. The students draw references not only to personal experiences from childhood, but also tie the contextualization to recent laboratory work. In the contextualization around metal and plastic, we can see that it is the connection between 'reference points' and familiar concepts that drives the process. This becomes clear when we add the final 'reference point' identified by the students during the final part of their discussion, namely wood. In the discussion the 'reference point' 'wood' did not spark any contextualization process, there was only a short statement concluding "Yes, let's talk about, here are a few, this is probably wood, from kind of, barley, something like twe[nty], [they have] let them grow for about twenty to thirty years maybe and then chopped down [...] probably cheap wood". This is interesting because this shows that familiarity towards different concepts is important in the contextualization process. Imagine if you gave a piece of wood to an individual who is working with dendrochronology or tree-ring dating as it is also called. Dendrochronology is an important dating method in geoscience especially for phenomena concerning particularly paleoclimates and climatic trends. We interpret this finding in the following way, in order to spark a contextualization process like the one described for the reference point metal or plastic it is important that the student can identify a 'reference point' and that they are familiar with one or several concept in order to develop a connection between them. If there are no familiar concepts associated with the 'reference point' the contextualization process will not take place and the student is left with only the identified 'reference point'.

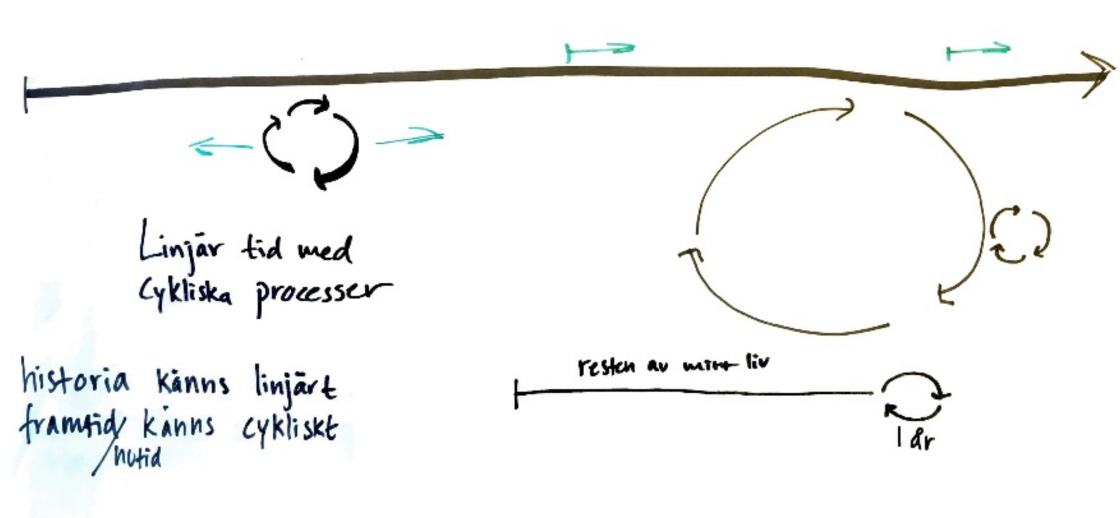
Another important aspect of the contextualization process is the importance of a common temporal scale. In order to be able to communicate temporal information it is vital to have a common spatio-temporal scale. This common scale enables the speaker and listener to share an understanding for which scale one is referring to (Zacks & Tversky, 2012). One simple example of this from geoscience is the difference in temporal scale between the concept of the related concepts of climate and weather. Climate refers to large-scale spatio-temporal changes, while weather refers to small-scale spatio-temporal changes. If you are unfamiliar with the common spatio-temporal scales used to describe weather and climate there is a risk for misconceptions and misinterpretations of climate and weather phenomena. According to Zakcs and Tversky (2012) the formation of common reference frames, that are used in discussions, are dependent not only on the scale of the phenomenon but also on the context they refer to.

Common reference frames are also important in geoscience (e.g., Gleeson & Paszkowski, 2014). They flow like a red thread through our categories, but they become extra noticeable in the contextualization process through the phenomena of heuristic estimation. In excerpt 13 ('contextualization') it is assumed, perhaps unconsciously, that the fellow participants in the discussion will understand the meaning of the scale "550", based on the context (Cambrian explosion). We argue that there can be two reasons why this heuristic estimation is used as a tool to handle temporal aspects in geoscience. The first one is to create a way to reduce the cognitive load when dealing with unfamiliar temporal scales by placing the dimension of the phenomena (Ma, Mega annum, "millions of years") into the context, in this case, the Cambrian explosion. In this way the students can reduce their internal visualization of the scale into more manageable chunks i.e., it is easier to visualize 550 than it is to visualize 550 000 000. Let us take another example, if the discussion is about the formation and evolution of mountains, the scale 'million years' becomes implicit in the context and the students need only to use the smaller numbers to discuss the phenomenon. The ability to off-load the dimension on to the context allows the student to essentially ignore the problem of visualizing large numbers. The other reason for using temporal heuristic estimation is to create flow in a discussion. This strategy is used when one is familiar with the scales used, and by placing the dimension of the scale in the context it is possible to speed up the discussion and come to a conclusion faster than if you must end every scale statement with a dimension i.e., it is faster to say 550 instead of 550 million years. So, by creating common reference frames it is possible to drop the dimension of the scale and rely on context to provide dimension, in order to either reduce cognitive load if you are unfamiliar with the concept or to speed up the discussion if you are familiar with the concept. And in both ways, this allows the student to discuss processes that take place over millions or billions of years without having the difficulty of obtaining a direct understanding of large scales.

We would like to call this strategy of handling scales temporal heuristic estimation. In a temporal heuristic estimation, it is the context that sets the dimension, and the temporal awareness sets the scale. We argue that in order to experience the concept of geological time an individual must develop a geoscientific temporal awareness based on the varying spatio-temporal scales in geoscience and combine this with the dimension aspect provided by the context i.e., disciplinary knowledge. In a temporal heuristic discussion, it is vital to be able to associate a specific spatio-temporal scale to a context or process in the discussion. Together the temporal awareness and the disciplinary context form the common reference frames for geoscience, and they show that in order to extract the implicit dimension from a context, disciplinary relevant knowledge is required. To be able to communicate without dimension in discussions is an indication of the acquisition of disciplinary understanding related to the concept of geological time. However, one must bear in mind that the perceived disciplinary understanding caused by temporal heuristic estimation may only be an indication of a shallow learning, or even just disciplinary imitation, where a number have been associated with an event without any understanding of why.

The capacity to narrate, define and contextualize the concept of geological time are all important when it comes to how the concept of geologic time is represented. In our data we can see that there is not only a "human way" to speak about time, where words like long and short are used. There is also a "disciplinary way" where the context decides the dimension and where concepts such as relative time and absolute time form the way individuals think about the concept of geologic time. When geologic time is discussed through an absolute perspective the descriptions and reasoning become short and concise and events are referred to in years or "period names". This contrasts with when geologic time is discussed through a relative perspective. Here the discussion focuses on finding the logical order of events and how the timescale of an event can be relative depending on which perspective it is viewed from. Both perspectives are similar to the 'event based' and 'logic based' structures found in Dodick and Orion (2006). A division in the way individuals represent the concept of geologic time can also be identified in the gesture's geoscientists used to communicate temporal information. In our work it is possible to conclude that the two main characteristics of the gestures used to communicate temporal aspects are gestures in the sagittal plane (forward-future and backward-past) and gestures in the lateral plane (left-older and right-younger). These two ways of using gestures to communicate temporal aspects in geoscience agrees well with the result from Cooperrider and Núñez (2009). Even the observation that the predominating gestures used to communicate time were performed in the lateral plane agrees well with the results from Casasanto (2016). In a more general term, the importance of gestures for communicating and experiencing geoscience knowledge is "well" known (Kastens, Agrawal & Liben, 2008; Liben, Christensen & Kastens, 2010; Herrera & Riggs, 2013; Van Boening & Riggs, 2020).

Figure 12. A representation that captures a linear time but with cyclic processes. Translated text: "Linear time with cyclic processes", "History feels linear, future/present feels cyclic", and "The rest of my life.



Finally, familiarity or unfamiliarity with the concept of geologic time also can be seen in the way the concept of geological time is visualized, the more familiar one becomes with the concept of geological time the more "detailed and complex" the visualizations of the concept of geological time becomes, see Figure 12.

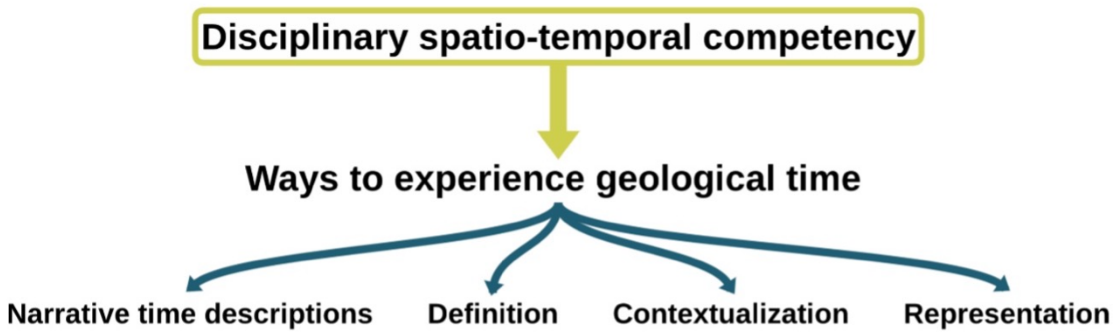
When the representations of the concept of geological time were constructed, it became apparent that one individual could use two separate ways of visualizing time. One was tied to personal time together with human historical time. We choose to call this 'personal time' and it focuses on humans, human knowledge and events that have shaped history with the addition of current time and the near history (~100 years into the future). The other way was a more disciplinary way where the geological perspective was focused around how the discipline represents geological time. The personal time is more fluid and focuses on the 'now' and the representation of time is not linear. The lifetime of the individual was expanded and took up as much space as 1000 years in the historical timeline, indicating a strong bias in how they choose to represent time. However, the disciplinary representation was approximately linear. The disciplinary representation was also very reminiscent of the geological time presented to the students through the geology literature. The students commented on the disparity between the two ways of representing the geological timeline by stating that they knew that both timelines represent the same thing, but that they thought about them in different ways. The personal time encapsulated things outside of geology but the disciplinary depiction was used to understand the order of geological events. This indicates that the student enters a 'geological-mindset' when they are talking about geological time or geological events and that this 'geological-mindset' is somehow separate from their personal experience. The idea that the student separates their mindset into geology and personal may provide insight into how students learn and why some aspects are harder to understand, or how different geoscience processes may affect them personally. Another way to visualize geologic time is in a two-dimensional representation, where time is visualized as a product of something. One student made a representation where time was related to the amount of information (Figure 10b). The reason the student expressed was that 'time gets bigger' when it is '...filled with more information'. This student had coupled linear time with information density. It is likely that this concept emanates from their studies, where they have the impression that a lot happened after the Cambrian explosion and time must get bigger/wider/larger to accompany everything. This is an indication that the student's perception of time may not only concern time itself, but that time itself is coupled to other variables and that they think about time in relation to something else. A further expansion on this is the possibility of affecting the student's perception of geological time by changing their perspective of the density of information. This is not tested, but it is a distinct possibility based on the observation that the two concepts are coupled. As the student learns more about a single concept, their perception of something seemingly unrelated may change. The observation that students may perceive geological time and information to be coupled together is a new observation that has yet to be seen in other studies. This is probably because this is the first phenomenographic study of students' experience of geological time which allows us to capture a wider range of qualitatively different ways of experiencing the phenomenon itself.

From our four categories we can see that it is important for a novice to create a connection to an unfamiliar concept, such as, the concept of geological time, in order to be able to experience it. This connection to a new way to experience the world can be drawn from a variation of contexts. Which context(s) an individual have to their disposal is partly individual and depends on, for example, interests, education, upbringing environment, but it can also be tied to social and cultural differences. Contexts can be used both to increase the complexity and understanding of a phenomenon, but also to reduce the complexity and make a problem more manageable. When you feel insecure, you often turn to a context that is familiar to you and with which you feel safe. You return to the context that forms the basis of your worldview. When you delimit the world as you experience, you reduce the cognitive load, but you also lose important knowledge. An example of this is when the students during a discussion about the age of aluminum are confronted with the information that aluminum was not formed on earth but long before the earth was created. Their reaction is that they want to limit "time and space" in order to reduce the "cognitive burden" that arises when complexity increases. In this case, they feel more comfortable discussing the age of the oil in relation to aluminum, as oil is formed on earth, unlike aluminum, which was formed "unnecessarily far back" in time, out in infinite space. What makes this example extra interesting is the way they limit the geological space-time scale as it also shows what information the students can discern. They choose to discuss oil and coal instead of aluminum but really it makes no difference in fact because it is not known exactly how coal is formed or when it came to earth.

CONCLUSION AND IMPLICATIONS

There is no question of the importance of spatio-temporal aspects in geoscience; it is truly a "threshold concept" in geoscience teaching. The question is rather how students learn to discern, understand and reason about spatio-temporal aspects in geoscience. We consider this to be a disciplinary spatio-temporal competency (DSTC), or ways to experience geological time. This competency is described and characterized by the four qualitatively differnet categories of descriptions identified in this study, see Figure 13. In our data we can see how DSTC impact students expereince of the concept of geolgocal time in several ways, such as, for example, disciplinary language, temporal awareness and temporal heuristic estimation. The development of DSTC is important not only in order to build the fluency around the concept of geologic time from a disciplinary perspectiv (i.e., "reading" representations, cf. Eriksson, 2019) but also how to fluently communicate the disciplinary knowledge, using many types of representations (Airey & Linder, 2009).

Figure 13. This illustration shows how the qualitativeley different ways to expereince geological time outlines the base of disciplinary spatio-temproal competency.



In this study we set out to answer the research question 'How do first year university geology students experience geological time?', and the three sub-questions relating to how students' reason, discuss and represent geological time and geoscience processes. First, when it comes to how students' reasons about the concept of geological time, we can see that they do so by using narrative time descriptions and definitions, as described by our categories. Second, on how the students discuss the concept of geological time, we can see how they do so by using the process described by the 'Contextualization' category. Finally, on how students represent the concept of geological time, we can see that they use three distinct ways to describe and communicate their experience, referred to by our categories: 'language', 'gestures' and 'visualizations'. In conclusion, we see that in the beginning of a geoscience career novices in geoscience experience the concept of geological time from a "human perspective". Through the exposure to varying spatio-temporal aspects in geoscience this initial human perspective change into a dualistic way of experience the concept of geological time. In this dualistic way the novices' contrast their experience of "human time" with their experience of geological time in order to develop their understanding of the concept, hence building and improving their disciplinary spatio-temporal competency.

The different ways students experience geological time, as shown in this study, can be used as a way to understand the difficulties students encounter when they are faced with the varying spatio-temproal aspects in geoscience. It can also be used as a tool to find effective teaching activities to teach the concept of geological time. An instructor may want to construct different contexts so that students can experience variation in how geological time is contextualized and represented, or the teacher may present geological time using different modes in parallell to create a multimodal learning situation. Each of the identified categories can be explored and from using them in the teaching allow the students to experience the phenomenon of geological time in a qualitatively different way, thus expanding their DSTC.

It is clear, from the representations of geological time the students produced in this study, that the simplistic form of representing geological time (see Figure 1) as a column is not fully capturing the different ways they are understanding time. One way to handle this in teaching situations is to use more diverse sets of representations of the concept of geological time to not lock in the students to one way of seeing geological time. Using more diverse sets of representations of geological time will also expand the students connections between time and geological processes. Since our understanding of time and space is so strongly linked to our own experience of time it could be useful for students to actively reflect on their own experience of geological time. In our exercises it appears that the students also learned things about their own experiences of time during the exercises and that this helped them in their understanding of geological time. Reflective exercises could therefore be a helpful additional tool in teaching geological time to geoscience students. Reflective elements can for example be incorporated in exercises where students work with problems related to geological time. This can for example be done with a basis from the exercises used in our interviews. The tasks can be as simple as letting the students discuss the aspect of geological time in photographs and representations of different features, like our exercise with association to pictures. Mapping exercises, that most if not all geoscience students are exposed to, could also be an excellent basis for time-reflective additional exercises. Mapping exercises can be very complex and include diverse elements of geology features and processes, and based on translating field-observations into a map format and then into a coherent geological history. In the mapping process, many different representations can be utilized to move from the field-observations to the coherent geological history. The movement between different representations, and its implication for learning, is explored elsewhere (Svensson & Eriksson, 2020).

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