How Students Can Be Supported to Apply Geoscientific Knowledge Learned in the Classroom to Phenomena in the Field: An Example From High School Students in Norway

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ABSTRACT

Our study explores how students apply geoscientific knowledge learned in the classroom to phenomena in a field setting. This was investigated by collecting video data from an ordinary high school context in Norway involving one teacher and a class of 17 high school students. We analyzed how the students learned rock identification and relative dating, first during the classroom preparation and then in the field. Supplementary data were collected 1 y after the fieldwork, when six of the students solved two posttasks of rock identification and relative dating. The video analyses of the students' talk and behavior while doing rock identification and relative dating focused on the level of student engagement, their thinking moves, and the extent of their understanding. The findings reveal that students who were able to apply their knowledge of relative dating were not able to do so for rock identification. One reason for this, we suggest, is that the nature of the geoscientific content influenced the students' ability to apply their knowledge in a field environment. Therefore, we identify qualities of relative dating and translate them to what we call "tools for observation and interpretation." The article closes by suggesting how the qualities of relative dating can inform the development of tools for observation and interpretation for rock identification.
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Key words: fieldwork, classroom preparation, high school, rock identification, relative dating

PROBLEM

Fieldwork provides students with the opportunity to apply knowledge learned in the classroom to natural phenomena in the field. This can promote deep understanding of content knowledge and stimulate long-term memory (Orion and Hofstein, 1994; Boyle et al., 2007; Mogk and Goodwin, 2012). However, in the context of our research on geoscience fieldwork involving high school students in Norway, we observed that fieldwork does not always lead to an improvement of students' understanding. When we revisited some high school students 1 y after they had learned geoscience through classroom and fieldwork activities, two observations were made:

- The students were unable to demonstrate a relevant understanding of rock identification.
- The students were able to demonstrate a relevant understanding of relative dating.

Based on these results, the entry point for our research was obvious—why, although they were exposed to fieldwork, did students succeed with relative dating but not with rock identification? In this article, we investigate what happened to these students while they were learning about rock identification and relative dating, first in the classroom and then in the field. Using this approach, the aims are to identify reasons for the preceding results and to discuss how high school students can begin to develop the skill of applying their geoscientific knowledge to phenomena in the field in a way that contributes to their understanding.

THEORETICAL UNDERPINNINGS

Scholars propose that fieldwork can provide students with opportunities to apply knowledge and skills learned in classroom situations and thereby gain deep understanding of geoscientific concepts (Orion and Hofstein, 1994; Dodick and Orion, 2003; Mogk and Goodwin, 2012). This learning potential in fieldwork is comparable to a theoretical definition of understanding offered by Wiske (1997): the application of knowledge and skills in different situations helps students develop understanding. Consequently, we use understanding as a theoretical concept to investigate how students apply the geoscientific content they learn in the classroom to phenomena in the field. This is because knowledge application generally serves two synchronous purposes: it makes students' understanding visible to themselves and others, and it provides an opportunity to improve understanding (Wiske, 1997). The underlying assumption is that knowledge must be learned in a preceding situation before it can be applied. Hence, knowledge application involves two phases: the phase of initial learning and the phase of reusing or applying what was learned (Bransford et al., 1999; Chi and VanLehn, 2012). Similarly, students' learning in the field is usually enhanced by a preceding phase of preparatory activities in the classroom (Orion and Hofstein, 1994). Consequently, classroom preparation can be considered equivalent to the initial learning phase. Subsequent fieldwork activities provide students with the opportunity to reuse and apply what they learned during the classroom preparation.

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Strong knowledge application abilities depend on the high quality of the initial learning (Bransford et al., 1999), which Chi and VanLehn (2012) refer to as deep initial learning. In general, deep learning focuses on grasping the meaning of a new idea through constructive processes, such as making connections and generating ideas beyond the information given. The contrasting concept is surface learning, which results from the unreflective reproduction and memorization of the content presented by the teacher (Entwistle and Smith, 2002; Ritchhart et al., 2011). The process of learning is facilitated by engagement in talk and activity about shared tasks, in which the goal is to promote student learning of mental tools, such as concepts and skills, in the discipline (Vygotsky, 1978; Driver et al., 1994; Solomon and Perkins, 1998). Engagement in talk can reveal the extent to which students learn, and it is more likely to be effective if students make substantive contributions, such as when they listen to and challenge their partners' contributions by asking questions, arguing, and justifying positions (Mercer, 1996; Chi, 2009). This kind of talk appears to be constructive and relates to the concept of deep learning. Researchers have also described talk that is less productive (Mercer, 1996; Chi, 2009). Talk that contains repetition of basic information and skills can be associated with surface learning.

Researchers have investigated how students' initial learning in the classroom can promote subsequent learning during geoscience fieldwork. Specifically, Orion (1993) suggested that students' preparation activities should focus on concepts and concrete materials that are encountered in the field. This could entail, for example, an identification of rock samples. In a later study, Orion and Hofstein (1994) demonstrated that students who are exposed to these types of extensive and tailored preparation activities before doing fieldwork learn more than students with less preparation. There should therefore be a close connection between the content learned during the classroom preparation and the content students should apply in the field.

The phase of applying geoscientific knowledge and skills in the field is a complex process. Kastens and Ishikawa (2006) described the variety of tasks performed by geoscientists, including those typical for fieldwork. These tasks included describing and identifying objects unambiguously, recognizing essential features and patterns in a chaotic environment, and interpreting the geoscientific meaning of these observations. For instance, geoscientists observe landforms and rocks in a complex natural setting and make interpretations about these observations based on knowledge and prior experience. The goal for educational fieldwork is often to introduce students to such geoscience tasks (Mogk and Goodwin, 2012). However, from a student's perspective, observations of objects and structures in nature can cause problems, because students do not necessarily notice the kinds of features that are important to scientists (Ford, 2005; Eberbach and Crowley, 2009). For geoscience in particular, studies have revealed that students do not notice rock properties that are essential in rock identification, and they do not dependably link the observations to geoscientific interpretations, such as the Earth's processes (Happs, 1982; Ford, 2005; Kortz, 2009). While students have difficulty observing features that are geologically relevant when they learn from classroom activities, less is known about how they deal with tasks outside the classroom. Observing geoscientific phenomena in the field could pose further challenges, because these appear in different scales and variables than the representations viewed in classrooms (Kastens and Ishikawa, 2006). For instance, rocks appear in another scale in a field environment compared to hand-size rocks in the classroom. While it can be assumed that deep initial learning through classroom preparation can enable students to apply their knowledge in the field, little research has described how teachers and students do this in practice. Consequently, our study investigates an authentic context involving one class of high school students in Norway. We address two research questions (RQs), which investigate how students learned rock identification and relative dating throughout the first phase of initial learning in the classroom and then the subsequent phase of knowledge application in the field:

1. How was the students' initial learning of rock identification and relative dating during the classroom preparation?
2. How did the students apply and understand their knowledge of rock identification and relative dating in the field?

METHODS

The Participants: Teacher and Students

The study is part of a larger research project on fieldwork in geoscience specialization for high schools[1] in Norway. In this article, we focus on one teacher and his class of high school students. This teacher has been teaching for 15 y, including 3 y of teaching geoscience. The class consisted of 17 students (3 girls and 14 boys, age 17) who were in their first year of specialization in geoscience (grade 12). These students chose to specialize in geoscience as part of their high school education[1] and therefore had a particular interest in learning the subject.

The Classroom and Fieldwork Activities

We asked the teacher to conduct fieldwork in accordance with strategies for fieldwork teaching recommended in the research literature. These strategies were (1) classroom activities that focused on cognitive, geographical, and psychological preparation, to support students' learning in the field (Orion and Hofstein, 1994); (2) fieldwork activities that allowed students social interactions and interactions with the phenomena (adapted from Bamberger and Tal, 2007); and (3) follow-up activities that support further learning (Orion, 1993). Based on these three strategies, the teacher designed and implemented classroom and fieldwork activities for his students. He therefore decided on the learning activities and the geoscientific content. According to the teacher, the fieldwork objective was to provide the students with an opportunity to put the geoscientific

[1] As part of their science specialization before university, students in Norway can choose to "major" in geoscience in grades 12 and 13. The optional geoscience specialization was introduced through the latest Norwegian national curriculum in 2006. Fieldwork is a mandatory part of the curriculum.

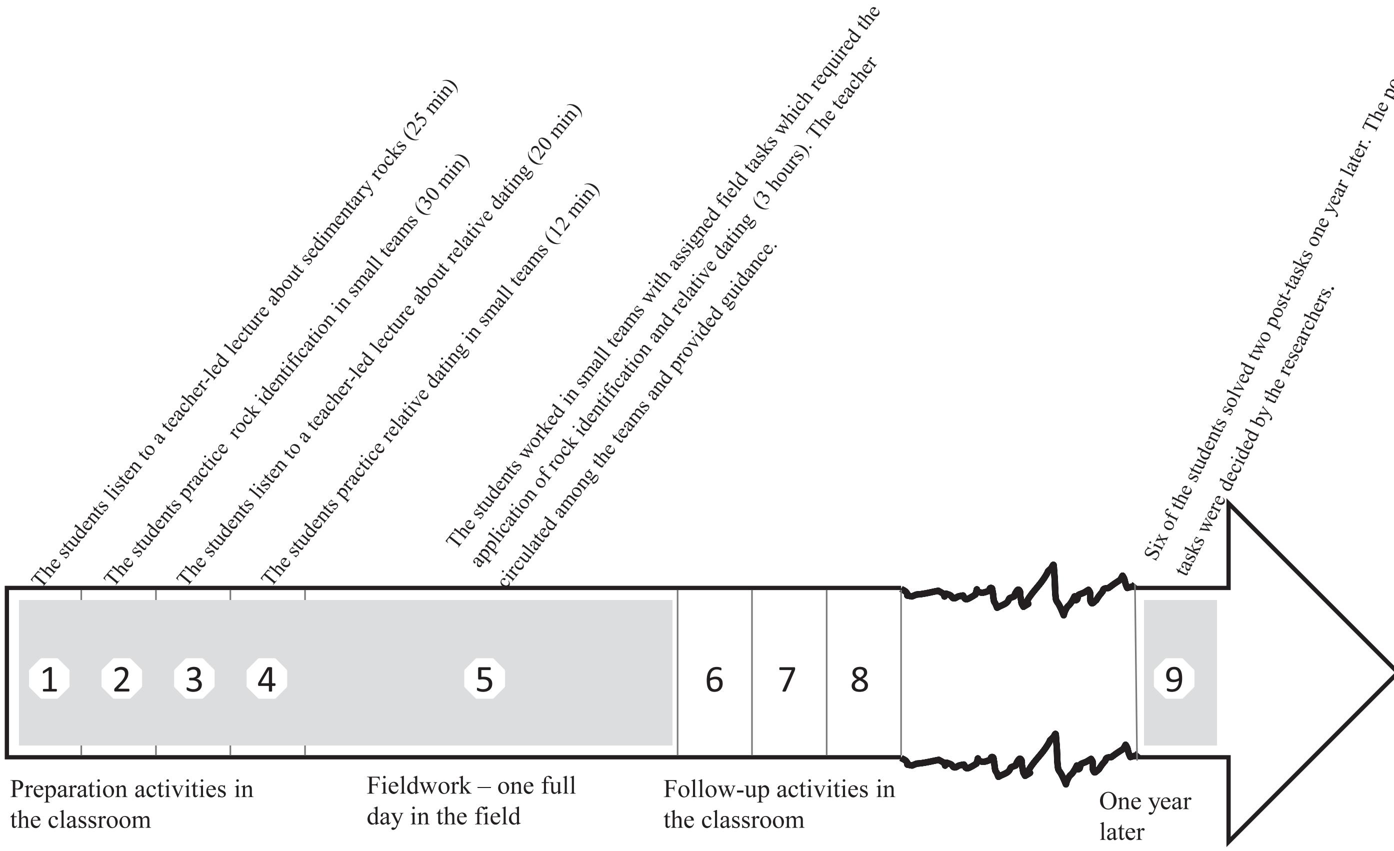


FIGURE 1: Sequential overview of the classroom and fieldwork activities. This article focuses on the learning activities in the classroom preparation (activities 1–4), the fieldwork (activity 5), and the posttask 1 y later (activity 9).

knowledge into practice by applying what they learned in previous classroom lessons. The venue for the field activities was reachable by bus from the school. Figure 1 shows the sequence of the learning activities across time and settings, remaining cognizant that this article focuses on student learning in the classroom preparation, in the field, and in the posttask 1 y later. Our role as researchers was to observe and collect data from these activities (Fig. 1).

Video Observation of the Classroom Activities and the Fieldwork

We used video observation to collect data from all learning activities shown in Figure 1. The video data were recorded by three small video cameras (HD GoPro). The teacher and two students carried the video cameras, which were fastened with a strap around the head. The students with the cameras were placed in two different teams and captured the talk and behavior of the students on their small team (3 students and 4 students for 7 students in total). The teacher's head-mounted camera collected information about the learning activities offered and the talk between the teacher and the students. With this approach, the video data (3 cameras × 9 h of video footage per camera = 27 h) allowed us to observe in depth what kind of learning activities the teacher provided and how the students engaged in these learning activities. Copies of the learning materials (e.g., textbook tasks and field tasks) offered by the teacher were also collected and later used as supplementary information in our analyses of the video data. In addition, our presence as passive observers during the activities ensured that we knew the context well. Our data collection began in the classroom while students learned about sedimentary rocks and relative dating (Fig. 1). Prior to this, the students learned about magmatic and metamorphic rocks. Therefore, the video data collected from the classroom preparation covered the students' initial learning of sedimentary rocks and relative dating, while the video recording in the field captured how the students dealt with sedimentary, magmatic, and metamorphic rocks and relative dating.

Video Observation of the Students' Approach to Posttasks 1 Y After the Fieldwork

Small amounts of follow-up data were collected 1 y after the fieldwork to investigate whether the students had developed their understanding further. We approached this by revisiting the students in their classroom and asked them to solve two posttasks (Fig. 1). The posttasks were designed by us (the teacher was not involved) and allowed the application of rock identification and relative dating. The content of the posttasks is shown in Figures 2 and 3. Six of the 17 students were available for the posttask (due to practicalities, not all 17 students could participate). Four of the students (Lina, Peter, David, and Ola) had been present in all classroom lessons and fieldwork 1 y earlier. The two last students (Tor and Levi) had skipped the fieldwork 1 y earlier and therefore had only learned rock identification and relative dating in the classroom preparation (the phase of initial learning). The

FIGURE 2: Posttask on understanding of rock identification. We gave the students five rock samples (one sedimentary, two metamorphic, and two magmatic). Then, we said to the students "Sort the rocks into the main groups." We did not specify the number of main groups or use geoscientific terms. The purpose was to investigate the students' understanding of rock identification. The still photograph was taken from a head-mounted camera, which recorded the students' reasoning while solving the task.

students solved the posttasks in pairs (6 students = 3 pairs) because we believed that their talk and behavior would provide us with a better insight into their reasoning than would have been possible if they had solved the

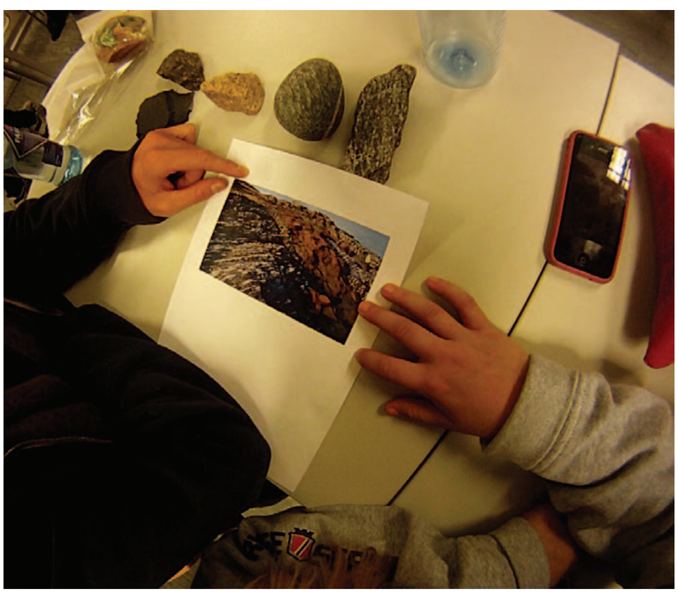


FIGURE 3: Posttask on understanding of relative dating. We gave the students a picture of crosscutting relationships in bedrock. Then, we asked the students, "Which is the oldest, and which is the youngest?" The aim was to illuminate the students' understanding of relative dating. The still photograph was taken from a head-mounted camera, which recorded the students' reasoning while solving the task.

tasks individually. The process of solving the posttasks was recorded on video (3 pairs = 3 head-mounted cameras × 15 min = 45 min of video data). Figure 2 (posttask of rock identification) and Figure 3 (posttask of relative dating) are snapshots from the students' head-mounted cameras while they were solving the posttasks in pairs.

Analysis of the Video Data

Analyses carried out to answer our RQs assumed that talk is an expression of the process of thinking and learning (Vygotsky, 1978; Mercer, 1996). We analyzed the video files of the students' talk and behavior while they engaged in the learning activities for rock identification and relative dating (see Fig. 1). To answer the first RQ addressing the students' initial learning during the classroom preparation, our analyses focused on the level of student engagement and thinking moves. These two analytical foci were also applied to answer our second RQ regarding the students' ability to apply knowledge in the field. In addition, we used a third analytical concept—the extent of student understanding—to illuminate whether the students' knowledge application in the field reflected understanding. Our use of three sets of analytical categories involved the creation of different units of analysis—from longer segments of talk to shorter conversational turns. The connection among the RQs, the units of analysis, and the analytical focus and categories is shown in Table I. Each analytical focus, together with associated categories, is explained in the following sections.

Analysis of the Level of Student Engagement

Our analysis of student engagement while conducting the learning activities assigned by their teacher was based on the ideas of deep and surface learning (e.g., Entwistle and Smith, 2002). Accordingly, we distinguished between two levels of student engagement. Superficial engagement was evident when the students were merely reproducing the content presented by the teacher. Observable features of superficial student engagement were brief talk that contained reproduction of basic information and behaviors such as looking around without paying attention to the learning situation. Deep engagement appeared when the students problematized the content, tried to relate parts, and generated ideas beyond the task requirements. Observable features of deep student engagement included long interactive conversations in which the students gave substantive contributions and explored ideas.

Analysis of Thinking Moves

The episodes of deep student engagement were further analyzed. This is because we considered deep engagement to be associated with deep thinking and to provide opportunities to improve understanding (Wiske, 1997; Ritchhart et al., 2011). Therefore, to analyze the students' ability to use their knowledge of geoscience content, we borrowed the idea of thinking moves from Ritchhart et al. (2011:11–13). They identified eight thinking moves that are particularly useful for developing understanding. We used the thinking moves, described in Table II, as a coding schema for analyzing the students' conversational turns while they talked about rock identification and relative dating. A conversational turn is a line of speech from one student. We transcribed the students' conversations and compared

TABLE I: Overview of the RQs, units of analysis, and analytical focus and categories.

Research Question	Unit of Analysis	Analytical Focus	Codes
How was the students' initial learning of rock identification and relative dating during the classroom preparation?	Segments of students' talk while undertaking learning activities	Level of student engagement	Superficial engagement, deep engagement
	Conversational turns within segments of students' talk, reflecting deeper engagement	Thinking moves	Observing closely and describing what's there, building explanations and interpretations, reasoning with evidence, making connections, considering different viewpoints and perspectives, capturing the heart and forming conclusions, wondering and asking questions, uncovering complexity and going below the surface of things
How did the students apply and understand rock identification and relative dating in the field?	Segments of students' talk while undertaking field tasks in small teams	Level of student engagement	Superficial engagement, deep engagement
	Conversational turns within segments of students' talk, reflecting deeper engagement	Thinking moves	Observing closely and describing what's there, building explanations and interpretations, reasoning with evidence, making connections, considering different viewpoints and perspectives, capturing the heart and forming conclusions, wondering and asking questions, uncovering complexity and going below the surface of things
	Segments of students' talk while applying rock identification and relative dating in the field	Extent of student understanding	Relevant understanding, emerging understanding, little or no understanding
	Students' reasoning during the posttask 1 y after the fieldwork		

each turn with the descriptions of thinking moves in Table II. When determining which kind of thinking move a conversational turn best belonged to, we considered the conversational turn in relation to what was said before and after and whether it occurred in the classroom or later in the field. For instance, if a student said something in the field that contained knowledge learned during the previous classroom preparation, we coded the conservational turn as the thinking move "making connections."

Episodes of superficial student engagement did not allow the coding of thinking moves, because they often consisted of conversational turns that were brief and lacked information. Student turns such as "it's basalt" appeared too simple to fit the thinking moves described in Table II.

Analysis of the Extent of Student Understanding

The first two analyses—the level of student engagement and thinking moves—did not capture whether the students used geoscientific knowledge correctly. Along with the definition of understanding underpinning this study (students demonstrate understanding by applying what they know in a new situation), it was most appropriate to analyze students' understanding in the field and on the posttask 1 y later (see also Table I). We adopted three codes to analyze the extent of student understanding of the geoscientific content, based on Gardner (1999:119): relevant, emerging, and little or no understanding. Relevant understanding showed complete and correct use of knowledge, without activation of irrelevant information. Emerging understanding was evident when the students applied knowledge that was only partially relevant, because it contained errors or lacked details. Little or no understanding reflected either an incorrect use or a lack of knowledge.

Limitations of the Study

Analyzing student learning as manifested by their talk and behavior is has limitations. There will never be a perfect relationship between a student's talk and a student's thinking. Furthermore, our interpretation of student learning processes based on talk and behavior is inevitably subjective.

TABLE II: Thinking moves that help build understanding (Ritchhart et al., 2011).

Thinking Moves	Descriptions
Observing closely and describing what's there	Close observation involves noticing essential parts and features and describing them fully and in detail.
Building explanations and interpretations	Building interpretations of the observations involves drawing on theoretical knowledge.
Reasoning with evidence	Building explanations requires reasoning with evidence to support the position and arrive at a reasonable solution that can be supported.
Making connections	Encountering something new involves making connections between the new and the known to find out where the new ideas fit in. Making connections also includes applying new ideas, comparing and contrasting, and making analogies.
Considering different viewpoints and perspectives	Awareness of different perspectives on an idea supports robust understanding.
Capturing the heart and forming conclusions	Capturing the core of a concept, procedure, event, or work ensures understanding of its essence.
Wondering and asking questions	Wonderment, curiosity, and questioning propel learning. Trying to understand that an idea is driven by questions reflects the depth of understanding.
Uncovering complexity and going below the surface of things	The ability to go below the surface of things aids the ongoing development of understanding. Rather than looking for or accepting easy answers, this ability involves attempting to identify the complexity of an idea.

That said, the opportunity to analyze video files of the same students' talk over time strengthens the interpretations of student learning (Mercer, 2008).

Another limitation is that our analyses report not on individual learning but on learning the students achieve as a team. However, researchers argue that social processes, activities, and tools play an important role in facilitating individual knowledge construction (Driver et al., 1994; Salomon and Perkins, 1998; Chi, 2009).

FINDINGS

Our analysis and findings from the students' talk and behavior while learning from the classroom preparation activities, the field tasks, and the posttasks displayed in Figure 1 are presented in two parts. The first part focuses on the analyses of the students' learning of rock identification. The second part reports on the students' learning of relative dating. The difference between the two parts is the geoscientific content (rock identification and relative dating, respectively). The teacher and the students are the same throughout the activities and analyses.

Rock Identification

The following reports on the analyses of student learning processes while undertaking the activities addressing rock identification, first in the classroom and then in the field. Students' approach to rock identification in the posttask 1 y later is consequently presented.

Rock Identification During the Classroom Preparation

Before presenting the analyses of the learning process on the identification of sedimentary rocks, we describe the nature of the learning activities provided by the teacher, that is, the teacher-led lecture and the practical activity in small teams (see Fig. 1).

Teacher-Led Lecture on Sedimentary Rocks (25 Min)

Using visual displays such as Web animations and sketches, the teacher explained the formation processes of sedimentary rocks in rivers and sediment basins. In the last part of the lecture, he focused on the identification of sedimentary rocks. Typically, the teacher asked the students about geoscientific concepts, definitions, and the names of rocks. The following provides an example:

Teacher: Conglomerate is an example of a coarse-grained sedimentary rock. While a medium-coarse–grained sedimentary rock—Can anyone think of which rock that could be?

Peter: Sandstone.

Teacher: Yes. Ok. Then you can make a note of this one as an example of finer grains than conglomerate.

The excerpt illustrates that the teacher did most of the talking and controlled the interactions by cueing the students as to the correct answer. As seen in Peter's short response, it did not require more from him than recalling the name "sandstone" and what it looked like.

Practical Activity About Rock Identification (30 Min)

After the lecture, students practiced rock identification in small teams. The teacher provided hand-size sedimentary rocks, diluted acid to test calcium carbonate, a handbook about rocks, and a sketch illustrating the sorting of sediments in rivers. The students were required to identify the specimens and connect them to the formation processes.

The students did not talk much during the teacher-led lecture except with brief responses to the teacher's questions. Hence, the teacher-led lecture did not provide much information about the students' initial learning of rock identification. We therefore concentrated our analyses on the students' learning process while undertaking the practical activity of rock identification.

RQ 1: Students' Initial Learning of Rock Identification During Classroom Preparation

The first excerpt that follows illustrates how the students worked on the practical activity of rock identification. The second excerpt shows the interaction between the teacher and a student.

Excerpt 1. Students' Approach to Rock Identification

David: What's this [holding a sample in his hand]?

Tor: It has to be cong-lo-merate.... Let's look at... [searches in the handbook].

David: But it's large grained. No, it's fine grained? I still guess it's clay shale.

Tor: [looking in the handbook] It's definitely not conglomerate.

Excerpt 2. Interaction Between the Teacher and the Students During the Practical Activity

Teacher: Why did you think it could be sandstone?

David: By looking at the pictures [in the handbook].

Level of Student Engagement During the Practical Activity

As seen in Excerpt 1, the students' strategy for accomplishing the rock identification activity consisted of searching for a matching picture of a specimen in the handbook. Their talk contained basic information such as names of rocks and observations of grain size, which was merely a reproduction of what the teacher had told them in the previous lecture. Other common student behaviors were off-task talk and looking around the classroom. Taken together, these observations showed the dominance of superficial engagement with rock identification during the classroom preparation.

Thinking Moves During the Practical Activity

The finding of superficial student engagement with rock identification made it difficult to identify thinking moves in the students' talk. However, in the preceding excerpt, David noticed the observation of grain size. This could be associated with the thinking move "observing closely and describing what's there." The same could also be said about other turns in which the students observed color and reactions to acid tests to compare, identify, and sort specimens. The act of comparing specimens can be coded as the thinking move "making connections." However, the observation of one or two features of the specimens appeared to be superficial engagement rather than a deep level of involvement. This superficial learning is instantiated in Excerpt 2, which showed that the students based their identification of rocks on the pictures in the handbook and not on observation or reasoning. Some students did not find this strategy of rock identification satisfactory:

Student: Are there other methods to identify rocks than just looking at pictures?

In summary, the students' engagement with rock identification during the practical activity showed that the classroom preparation did not promote deep initial learning of rock identification.

Rock Identification in the Field

In the field, the students worked in small teams guided by field tasks (see Fig. 1). Eight field tasks required the identification of rocks—including the connection of rocks to Earth processes. An important reminder about the context is that the students' initial learning of magmatic, metamorphic, and sedimentary rocks during the preparation phase occurred in separate classroom lessons. Therefore, the students had no previous experience with the identification of the three main groups of rocks before they were required to do so in the field.

RQ 2: Students' Application and Understanding of Rock Identification in the Field

In general, students had difficulties with rock identification. Two excerpts illustrate this. Excerpt 3 is a collection of student quotes, representing the best examples, as students identified specimens.

Excerpt 3. Identification of Specimens

Eric: This is conglo-something, because it has big like this [pointing at pebbles in the conglomerate].

Vemund: [pouring acid] This is limestone.

Peter: It's diabase because it's black [referring to basalt].

Excerpt 4 reports how the students tried to connect the observation of rocks to the formation process, as required by the field task. In this situation, the students worked on a field task that required them to identify gneiss (a metamorphic rock) and relate it to the formation process and the theory of plate tectonics.

Excerpt 4. Attempts to Connect Rocks to Formation Processes

Eric: It's called band gneiss when it has such banding.

Peter: But if it has such banding, then it's deposited.

Eric: It's a magmatic rock, yes.

Peter: It's a solidified rock.

Level of Student Engagement in the Field

As exemplified by the two excerpts, the students' talk contained geoscientific terminology without providing further details or reflections about the rocks they were identifying. This observation indicated a level of superficial engagement with rock identification in the field.

Thinking Moves in the Field

The predominance of superficial engagement with rock identification in the field made an analysis of thinking moves complicated, because most of the students' conversational turns lacked information. Both preceding excerpts reveal that the students were able to recall rock specimens and the geoscientific concepts they had learned in the previous classroom preparations. From that perspective, their actions can be assigned the thinking move "making connections." However, the content of the students' turns suggests that these connections were simple, because it merely involved connecting the name of the rock to simple features or geoscientific terminology. In Excerpt 4, Peter tried to interpret the feature of banding as if it were the result of deposition. This might be an emerging sign of the thinking move "building explanations and interpretations." Another hint of a thinking move that could be interpreted from these excerpts is that of "observing closely and describing what's there." That is, the students identified the rocks based on the observation of features such as reactions to acid testing, grain size, color, and banding. In summary, hints of a few thinking moves could possibly be identified in the students' talk, but only on a superficial level.

Extent of Student Understanding of Rock Identification in the Field

The students' talk while solving the field tasks allowed us to analyze the extent of their understanding of rock identification, and Excerpt 4 serves as an example. The students identified a metamorphic rock (gneiss) but connected it to the wrong process (a sedimentary process), which was further connected to the wrong main group of rocks (magmatic rocks). This showed misinterpretation and misapplication of geoscientific terminology to the actual rock. As such, the students' attempts to connect the actual rocks and geological processes lacked details and contained errors, indicating an emerging understanding of rocks.

Taken together, the students showed superficial engagement with rock identification in the field, and their knowledge application was erroneous and fragile. It also appeared that the students felt that their knowledge was insufficient. The quotes that follow reveal that the students called for more knowledge while dealing with rock identification tasks:

Peter: How could we find it [limestone] when we don't know what to look for?

Heidi: I think we have few clues to follow.

David: But what makes gneiss into gneiss? Because something must be in common for all [the gneisses]?

Posttask 1 Y After Fieldwork: Student Understanding of Rock Identification

One year later, we revisited the students and asked them to participate in a posttask in pairs (see Fig. 2). Recall that the two pairs, (1) Lina and Peter and (2) David and Ola, had attended the classroom preparation and the fieldwork. Tor and Levi had been present during the classroom preparation but had skipped the fieldwork. Their reasoning is summarized next, and we analyze the extent of their understanding.

Lina–Peter Pair and David–Ola Pair (Classroom Preparation and Fieldwork)

These two pairs of students had similar discussions. We therefore present one excerpt from the talk between David and Ola as an illustration of their reasoning:

Ola: This is magmatic [holding a metamorphic sample].

David: But these are also magmatic, but it consists of several minerals [pointing at magmatic samples]—and this has one mineral [pointing at a black sedimentary sample].

The students continued to talk about the hardness of the sample; however, they recalled that hardness is a mineral property. The discussion continued with great hesitation about how to group the samples:

Ola: What is the black [pointing at the black-colored part of the metamorphic sample]—is it basalt?

David: But there are layers here [pointing at the stripes in a metamorphic sample]. It's magmatic differentiation.

Ola: Yeah, magmatic differentiation is possible.

David: Then I guess it's a sedimentary rock.

After 10 min, the students decided to sort the samples in two groups: sedimentary and magmatic.

Extent of Student Understanding of Rock Identification 1 Y After Fieldwork

As apparent in the excerpt, the students recalled geoscientific terminology but were unable to apply it to the specimens. The other pair of students, Lina and Peter, observed grain size, color, and layering. However, these features did not enable them to identify the specimens. For instance, as seen in the excerpt, David observed layers in a metamorphic sample, connected these to the process of magmatic differentiation, and then guessed it was a sedimentary sample. Similarly, observing a black sedimentary sample, Peter concluded it was basalt (a magmatic rock) because he remembered that basalt was dark colored. Both pairs of students reached the same conclusion: The samples were sorted as "sedimentary" or "magmatic." David guessed that there was a third group of rocks, but he did not try to apply it to the current rock samples. Taken together, the students had some relevant knowledge but were unable to apply it correctly. Therefore, these students demonstrated an emerging understanding of rock identification.

Tor and Levi (Classroom Preparation but No Fieldwork)

These students began to sort the samples into five groups according to grain size. They tried to memorize the names of the specimens and some geoscientific terms. Finally, they rearranged the samples into three groups with three technical terms for magmatic rocks (corresponding terms in English could be "magmatic," "crystalline," and "eruptive").

Extent of Student Understanding of Rock Identification 1 Y Later

The preceding excerpt revealed limited and erroneous knowledge; thus, it indicated little understanding of rock identification.

Relative Dating

In this section, we report on the students' learning process of relative dating, first in the classroom, then in the field, and finally in the posttask 1 y later (see Fig. 1).

Relative Dating During the Classroom Preparation

To provide the context for our analyses of the students' initial learning of relative dating during the classroom preparation, we first describe the teacher-led lecture and the subsequent textbook activity carried out in small teams (see Fig. 1).

Teacher-Led Lecture of Relative Dating (20 Min)

The teacher used the relative age of individuals as an analogy to the idea of the relative age of rocks and, using a Web-based animation,[2] explained the underlying geological processes and how geological events can be interpreted from the rocks in a geological cross-section. He did not mention that relative dating is carried out by applying established

[2] The Web-based animations are available at http://ansatte.uit.no/kku000/webgeology/webgeology_files/english/geol_time_eng.html.

principles known as stratigraphic principles.[3] An excerpt from the teacher's lecture is provided here:

Teacher: So we can identify the oldest and youngest. If we can see that the dyke cuts through another rock, which was there from before, we can see that there is one young and one older. And sometimes a dyke can cross another dyke.

As seen in the transcript, the teacher explained how the relative age could be interpreted from the observation of a rock layer crossing another rock layer. In this way, he was indirectly referring to the stratigraphic principle of crosscutting relationships. The other stratigraphic principles—horizontal layers and included fragments—were introduced by the teacher in a similar way.

In the last part of the lecture, the teacher began questioning the students:

Teacher: If we look at this example first—which is the oldest here?

Student: The undermost.

Teacher: The undermost yes. Then there is the second oldest here—which is youngest of these examples?

Student: The uppermost.

Textbook Task About Relative Dating (12 Min)

After the lecture, the teacher asked the students to sit in small teams and solve a textbook task about relative dating. The textbook task, replicated in Figure 4, consisted of five graphics of geological cross-sections. It required students to figure out the relative age of the layers (Karlsen, 2007).

The next section presents the analysis and findings from the students' responses, first to the teacher-led lecture and then to the textbook task.

RQ 1: Students' Initial Learning of Relative Dating During Classroom Preparation

At first, the students listened to the teacher lecturing on geological dating and responded to questions, as presented in the preceding transcript. Then, something unexpected happened. Two of the students voluntarily questioned the content in the teacher's lecture. This was not common in this classroom. The nature of the students' questions (eight in total) indicated an interest in trying to understand the underlying geological processes that form layers of different rocks. One of the student-generated questions is given here:

Peter: Is it the same with lava—you can see it [the dykes] goes like this and this—the dykes, is it the same with lava as with water that it always follows the less resistant way?

When the students asked these questions, the teacher changed his explanations, enabling the students to control the content of the activity. Another uncommon observation we made was when the teacher asked, "Which is the youngest, and which is the oldest?" Then, the students who were normally silent in the classroom replied to the teacher's question. Because the students verbalized their thoughts during the lecture, it allowed us to analyze their learning process.

FIGURE 4: Textbook task requiring knowledge of relative dating. Illustration: copyright John Arne Eidsmo (Karlsen, 2007:17).

Level of Student Engagement During the Teacher-Led Lecture

The two observations—that students voluntarily initiated questions and that normally silent students responded to the teacher's questioning—indicated that some students were deeply engaged in relative dating during the teacher-led lecture.

Thinking Moves During the Teacher-Led Lecture

Some questions initiated by the two students allowed an analysis of thinking moves. The originality and depth of the student's question in the preceding example can be coded as the thinking move "wondering and asking questions." It could also be coded as the thinking move "making connections," because Peter was comparing lava and water. This suggested that conversational turns that could allow the coding of more than one thinking move confirmed deep engagement.

After the teacher-led lecture, the next activity was to solve a textbook task addressing relative dating (Fig. 4). Excerpt 5 is extracted from a longer conversation that took place while students were in the process of solving the textbook task. Excerpt 6 depicts the students' responses when the teacher circulated to check their learning.

Excerpt 5. Students' Approach to Relative Dating

Lina: It has to be the undermost, because the oldest rocks lay at the bottom. And which rocks are youngest, the sandstone or the volcanic rock, dyke?

Vemund: It's the volcanic dyke, because it comes through.

Excerpt 6. Interaction Between the Teacher and the Students About Relative Dating

Teacher: Why do you think so [the dyke is youngest]?

Vemund: Because of all these small bites in the magmatic rock.

[3] Readers who are unfamiliar with stratigraphic principles are advised to visit the Earth Learning Idea Web site, available at http://www.earthlearningidea.com/PDF/Laying_down_the_principles.pdf.

TABLE III: Students' talk about relative dating in the field and our analysis of the thinking moves reflected in the conversational turns.

Student	Conversational Turns	Analysis and Coding of Thinking Moves
Peter	I'm not sure which is the youngest, because. . .	Considering different viewpoints and perspectives
Lina	But he [the teacher] talked about before the trip that there were sills in the wall.	Making connections
Peter	Yes, but it's not necessarily youngest. It was those things—mixed in others, you see?	Considering different viewpoints and perspectives Making connections
Lina	Yes, that it was sediments in the upper from. . .	Making connections
Peter	Yes—are there sediments in it? That is dependent on. . .	Considering different viewpoints and perspectives
Lina	Yeah—do you think it [layer] came afterwards? That the layer above has brought bits of the magmatic, so that would be the youngest?	Making connections Building explanations and interpretations
Peter	No, I mean that if we cannot find signs of the uppermost [layer] in the sill, then the uppermost would be youngest because it solidified before the other came.	Building explanations and interpretations Reasoning with (hypothetical) evidence
Vemund	[climbing closer to the cross-section to observe more closely]	Observing closely (and describing what's there)
Lina	I don't think it has. The black spots are just. . .	Considering different viewpoints and perspectives
Peter	If it [the dyke] has solidified first, then it wouldn't carry anything from the other.	Considering different viewpoints and perspectives Building explanations and interpretations
Lina	No, but if it's there from before, then it can't either.	Considering different viewpoints and perspectives
Peter	Yeah, but then the sill melts with something when it comes in.	Building explanations and interpretations
Vemund	[bending closer and pointing on the rock] That's what it's done. If you come and look here.	Observing closely (and describing what's there)
Peter	Ok—then the sill is youngest!	Capturing the heart and forming conclusions

Level of Student Engagement During the Textbook Task

As exemplified in the excerpts, the students' talk contained elaborated turns. They were able to justify their answers upon request from the teacher. Therefore, there was indication of a deeper level of engagement with relative dating compared with rock identification.

Thinking Moves During the Textbook Task

The length of the students' conversational turns allowed the coding of thinking moves. For instance, in Excerpt 5, Lina's turn, "It has to be the undermost, because the oldest rocks lay at the bottom," could be associated with the thinking move "building explanations and interpretations." As evident in Excerpt 6, Vemund justified his interpretation based on an observation of the small bits in the rock. In addition, in the rest of the conversations during the textbook task, we identified the thinking moves "considering different viewpoints and perspectives" and "reasoning with evidence."

To summarize, the students' questions during the teacher-led lecture and the findings on thinking moves while solving the textbook task suggested a deeper initial learning of relative dating compared with rock identification.

Relative Dating in the Field

The students worked in small teams during the fieldwork. The field tasks on relative dating were done alongside the rock identification tasks described earlier. Two field tasks required the identification of the relative age of rock layers in different geological cross-sections. Next, we present the analyses of the students' process in relative dating.

RQ 2: Students' Application and Understanding of Relative Dating in the Field

Of all video data recorded from the learning process in the field (3 h), the most promising episodes appeared when the students engaged in relative dating. An excerpt of the longest and most fruitful conversation is presented in Table III. The students had this conversation away from the teacher.

Level of Student Engagement in the Field

As seen in Table III, the students discussed the relative age of the rock layers. They gave rich contributions, listened to and built on one another's ideas, and moved physically to observe features in the rock layers more closely. This talk and behavior reflected a deeper engagement with relative dating in the field than during the classroom preparation.

Thinking Moves in the Field

The students' conversational turns while doing relative dating were complex enough to allow the coding of thinking moves. The right column in Table III shows that we identified a variety of thinking moves in their talk. The thinking move "making connections" was assigned to the student turns that revealed the reuse of knowledge learned during the classroom preparation. The students conversed back and forth and tried to use their knowledge to interpret relative age; these turns were coded as the thinking move "building explanations and interpretations." Notably, they negotiated the interpretations of their observations, and we interpreted this as consistent with the thinking move "considering different viewpoints and perspectives." As a result of a consideration of different possibilities, Vemund moved closer to the geological cross-section. This indicated that the students created a demand for closer observations of the features. Although Vemund did not verbalize his observation, we coded this behavior as the thinking move "observing closely and describing what's there." Based on the conversation and Vemund's observation of the features, Peter concluded that the sill was youngest. We therefore coded the last turn as the thinking move "capturing the heart and forming conclusions." If we view the conversation as a whole, it appears that the students talked about features (i.e., small bits in the dyke) that they used to reason about the relative age of the layers. Therefore, the whole conversation gave an impression of the thinking move "reasoning with evidence."

Extent of Student Understanding of Relative Dating in the Field

Throughout the discussion in Table III, it appeared that students gained relevant understanding of relative dating.

Posttask 1 Y After the Fieldwork: Student Understanding of Relative Dating

We now report on and analyze how the students solved the posttask of relative dating 1 y after the fieldwork (see Fig. 3). Students are the same as those who solved the posttask of rock identification. Again, the Lina–Peter pair and David–Ola pair had attended the classroom preparation and the fieldwork 1 y earlier. The Tor–Levi pair had been present during the classroom preparation but not the fieldwork.

Lina–Peter Pair and David–Ola Pair (Classroom Preparation and Fieldwork)

The two pairs of students had similar discussions. The dialogue between Ola and David has been selected as an example:

David: This is oldest, because this [pointing at the dyke in the picture] has intruded into it.

Ola: Yeah, it would have been cool if we could see if anything had pressed into it.

David: Yeah, then we could have seen…

Ola: The mixture… you know, something-morphosis.

The discussion continued a few more turns before the researcher entered the conversation.

David: We think this is youngest and this is oldest, because this one [pointing at the dyke in the picture] has intruded into the other.

Researcher: How do you know that?

David: Because it's the same rock on each side [of the dyke].

Extent of Student Understanding of Relative Dating 1 Y Later

As seen in the excerpt, David noted the crosscutting relationship between the two types of rocks to support the identification of the relative age. Furthermore, David and Ola searched for more features than what they could actually see in the picture of the geological cross-section (see Fig. 3). Similar to what transpired in the talk between the other pair (Lina and Peter), David and Ola observed the picture closely and looked for included fragments in the dyke. This showed that the students searched for features and hypothesized interpretations that were relevant to the situation. The excerpt also includes what happened when the researcher asked for the students' solutions. David's reply, "Because it's the same rock on each side," showed that he could use the observation of features to justify his interpretation. The two pairs of students demonstrated a relevant understanding of relative dating 1 y after the fieldwork.

Tor and Levi (Classroom Preparation but No Fieldwork)

When faced with the posttask, these students pointed out the correct answer of the relative age of the rocks without providing any reason. However, when the researcher approached them and asked for their solution, one of the students said the following:

Tor: This has small mineral grains [pointing at the dyke in the picture], so it had a longer solidification time. It's the oldest.

Extent of Student Understanding 1 Y Later

The preceding excerpt revealed incorrect use of knowledge, which signaled little understanding of relative dating.

Summary and Comparison of Findings From Rock Identification and Relative Dating

The key findings are summarized in Table IV to contrast how the students learned rock identification and relative dating while undertaking the sequence of activities displayed in Figure 1. Our analyses revealed that the students who developed relevant understanding of relative dating did not develop such understanding of rock identification.

DISCUSSION

This study built on the assumption that fieldwork provided students with an opportunity to apply theory in practice and thereby improve their understanding of knowledge learned in the classroom (Orion and Hofstein, 1994; Mogk and Goodwin, 2012). However, our findings from an actual case of high school students complicate this picture: the students showed a great ability to apply and understand what they had learned about relative dating but not about rock identification. This occurred even though (1) the students had learned rock identification and relative dating through the kinds of preparation activities that researchers have recommended for promoting learning in the field (Orion and Hofstein, 1994) and (2) the teacher spent more time on rock identification activities than on

TABLE IV: Summary and comparison of findings from the analyses of the students' learning process of rock identification and relative dating.

	RQ 1: How Was the Students' Initial Learning . . . During the Classroom Preparation?		RQ 2: How Did the Students Apply and Understand Their Knowledge . . . in the Field?	
	Rock Identification	Relative Dating	Rock Identification	Relative Dating
Level of Student Engagement	Superficial	Deep	Superficial	Deep
Thinking moves identified in the students' conversational turns	Brief student turns containing simple information that did not allow the coding of thinking moves	Building explanations and interpretations, reasoning with evidence, making connections, considering different viewpoints and perspectives, wondering and asking questions	Observing closely and describing what's there, building explanations and interpretations, making connections	Observing closely and describing what's there, building explanations and interpretations, reasoning with (hypothetical) evidence, making connections, considering different viewpoints and perspectives
Extent of student understanding			Little to emerging	Relevant
Extent of student understanding 1 year later			Emerging	Relevant

those for relative dating, meaning time spent on tasks was not a decisive factor. Taken together, our findings indicate that extensive classroom preparation does not necessarily enable students to apply their knowledge in the field. For instance, a student's quote during the tasks on rock identification ("I think we have few clues to follow") tells us that students experienced a gap in their knowledge and requested more support. The same students did not say such things during relative dating tasks. These findings shed light on what geoscientific content the students were expected to apply and learn in the field. If learning involves internalization of tools in the discipline (Driver et al., 1994), our findings suggest that the students did not have the necessary tools for rock identification. According to Kastens and Ishikawa (2006:59), students and geoscientists keep an appropriate schema—that is, general knowledge structures—that they apply to observe and interpret the concrete phenomena. Our understanding of Kastens and Ishikawa is that theoretical knowledge—or the schema—becomes the mental tool for observing and interpreting geoscientific phenomena in appropriate situations. It follows that students must learn to observe essential features and patterns in the field, as suggested by geoscience educators (Petcovic and Libarkin, 2007). Therefore, the idea of mental tools or structures for carrying out geoscience tasks in a field environment aid our discussion on why the same students were able to do relative dating but not rock identification in the field. By selecting this focus, we aim to illuminate how our findings from one case of high school students can have implications for school-based fieldwork in general.

Why Students Failed to Develop an Understanding of Rock Identification

Our findings regarding the students' confusion during rock identification align with those of previous studies of students' ideas of rocks (Dove, 1998; Ford, 2005; Kortz, 2009). However, our video data extend the earlier studies by allowing an analysis of the students' processes while they were trying to learn rock identification in the classroom and then in the field. At first, the students' difficulties with rock identification in the field can be ascribed to their superficial engagement during the initial learning in the classroom preparation. One explanation for the poor initial learning is that the students learned rock identification by finding a corresponding picture in the handbook. This approach to rock identification is deemed superficial and inappropriate for building disciplinary understanding (Dove, 1998; Hawley, 2002). Our analysis also found that the students occasionally tried to identify rocks based on the features: grain size, color, banding, and reaction to an acid test. These features did not appear to help students identify and sort samples into magmatic, metamorphic, and sedimentary rocks during the fieldwork and on the posttask 1 y later. Color and grain size are ambiguous properties in rock identification. For example, fine-grained sedimentary rocks are easily confused with magmatic rocks (Westerback and Azer, 1991). It is therefore possible that the rock features learned during the classroom preparation, such as color and grain size, were insufficient as mental tools for rock identification in the field. This resulted in a missed opportunity to apply rock identification in a way that developed the students' understanding.

Even though the fieldwork tasks assigned by the teacher required the students to connect rocks to Earth processes, our analysis showed that the students made poor attempts to do so. One explanation of this is that students often regard rocks as unchangeable objects and therefore forget to connect their observations to geological concepts (Ford, 2005). Our findings allow us to discuss other reasons for these kinds of misconnections. We reported one episode in which the students attempted to interpret the rock (gneiss) by connecting it to the formation processes and geoscientific terminology. However, our analysis revealed that the students' connections were simple and erroneous. For example, a student used the term ''magmatic'' about a metamorphic rock without elaborating on the underlying meaning of ''magmatic'' and its relation to the actual rock. We think that this way of using geoscientific terms reveals something about the content in focus of the classroom preparation. The students learned many geoscientific terms, but they did not learn the mental tools for recognizing and applying this knowledge in a field environment. We believe this could explain some of the students' misapplications of geoscientific terminology to actual rocks.

Magmatic, metamorphic, and sedimentary rocks were taught in separate classroom lessons, and students had no initial learning that dealt with samples from the three main groups of rocks at the same time. In this way, the initial learning of rock identification did not equip students with the knowledge and skills required in the subsequent field situation. According to research findings reviewed by Day and Goldstone (2012), a more productive strategy would have been to ask the students to compare samples from the three main groups and then identify the unique features of each group. This may have changed the students' initial learning of rock identification and the subsequent opportunities for identifying rocks in the field, but the approach could not be explored with our data.

In conclusion, the shortcomings in the students' ability to conduct rock identification in the field can be explained by the practical activity during the classroom preparation. The students could carry out rock identification by matching samples with pictures in a handbook. On closer inspection, we suggested that the rock identification lessons learned in the classroom did not provide useful mental tools for identifying rocks in the subsequent field situation. We found the opposite tendency when the students applied relative dating, which we discuss next.

Why Students Developed an Understanding of Relative Dating

Before we proceed to the discussion of why students achieved a relevant understanding of relative dating, a few reminders about the context are necessary. When geoscientists reason about the relative age of rock layers, they apply a set of principles—collectively known as principles of stratigraphy. The teacher in our study did not mention to students that relative dating could be reasoned from such general principles. Despite this, the students were able to solve the tasks of relative dating by applying the underlying meanings of stratigraphic principles. Although the students did not use the term ''stratigraphic principles,'' we use it in our discussion for brevity.

The students' success with relative dating in the field can be ascribed to the findings from the initial learning during the classroom preparation, in which we identified deep levels of student engagement and evidence of thinking moves in the students' talk. However, the interesting question is, Why did the students show deeper engagement with relative dating first in the classroom and then in the field compared with the level of their engagement during rock identification? One answer can be found in the work of Dodick and Orion (2006), who proposed that students have an intuitive talent for doing relative dating. They reasoned that it parallels everyday tasks of organizing events into a logical, temporal order. Therefore, students with little background in geoscience would be able to reconstruct geological layers by applying principles of stratigraphy. Readers may insist that the students developed understanding because relative dating is intuitive and of lower cognitive demand compared to rock identification. Our findings may problematize such assumptions. According to our analysis of the thinking moves (Table III), the students were able to engage in deeper thinking even though relative dating might be considered as a low-order task. In comparison, in the posttask of rock identification, we asked the students to sort five samples into the main groups (Fig. 2). In our view, this had similar cognitive demands as the posttask of relative dating (Fig. 3). Therefore, although the two posttasks posed similar cognitive demands, the students only succeeded with that of relative dating. In comparison, the two students who had skipped the fieldwork showed little understanding of relative dating on the posttask, which indicates that relative dating is not learned instinctively. These findings suggest that there must be something particular about relative dating. We pursue this by unpacking the nature of relative dating to identify possible qualities that can inform how we support students to perform geoscience tasks in a field environment.

The Nature of Relative Dating and the Stratigraphic Principles

As discussed by Dodick and Orion (2006), relative dating appeals to students' natural way of thinking: It is logical that something comes before and something comes after. Hence, there is a short distance between relative dating and students' prior experiences. The integration of disciplinary knowledge and personal experience is critical for deep learning of new knowledge (e.g., Bransford et al., 1999) and suggests that students were more susceptible to learning relative dating than to learning rock identification. By contrast, rock identification concepts might have been more distant from the students' prior knowledge and thinking—and therefore more difficult to learn (Driver et al., 1994). Thus, the closeness to students' prior experience appears to be a particular quality of relative dating and implies that students' initial learning of geoscientific content must begin with their natural way of thinking.

While the students were talking about the relative age of rock layers in the field, our analysis found evidence of several kinds of thinking moves. For example, the student conversational turns coded as ''building explanations and interpretations'' and ''considering different viewpoints and perspectives'' indicated that they applied geoscientific knowledge to make sense of the features they were observing. More specifically, they were talking about whether there could be small bits of alien rock included in the dyke to support their interpretation of the relative age of the layers. This reflected their use of the stratigraphic principle of included fragments, which means that included fragments in alien rock are older than the surrounding rocks. On closer inspection, we see that the stratigraphic principle comprises both the essential features of observation (i.e., included bits of an alien rock) and the geoscientific interpretation (i.e., the alien rock must be older than the rock in which it is included). In this way, the stratigraphic principles functioned as mental tools for the students in the field. It enabled the students to notice essential features, connect them to an interpretation, and then reason about the relative age of rock layers in the field. The connection

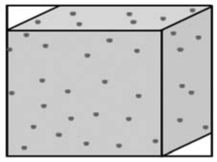
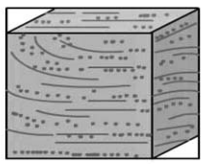
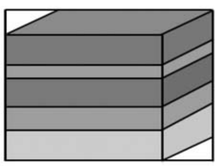
Features and patterns that build on everyday experiences	The features of rocks	Connection of features (observation), and the geoscientific meaning (interpretation)	Geoscience term
		Dotted, angular grains (observation) – Melted rock that has solidified (geological meaning, interpretation).	Magmatic
		Stripes, folds (observation) – Rock that has undergone change due to high pressure and high temperature (geological meaning, interpretation).	Metamorphic
		Layering, fossils (observation) – Collection of sediments over time, often by water (geological meaning, interpretation).	Sedimentary

FIGURE 5: Example of a basic observation and interpretation tool for magmatic, metamorphic, and sedimentary rocks.

between observation and interpretation was also apparent in the results from the posttask 1 y after the fieldwork. The students were able to support their interpretation of relative age with observations of essential features. While the distinction between observations and interpretations is important in science learning (e.g., Lederman, 2006), our findings indicate that it is equally important to help students to reconnect essential features (observation) and geoscientific meaning (interpretation). This was clear in our findings from the students' attempts at rock identification in the field, in which they struggled to connect the rocks to the associated Earth processes and geoscientific terms. In contrast, the students could apply relative dating without being dependent on the recollection of geoscientific terms. We ascribe this to the nature of the stratigraphic principles, which center on features of observation and connections in geoscientific meaning. Educators have also recognized this potential: Stratigraphic principles can be used to help students develop and apply geoscientific meanings before the introduction to new terminology (Hermann and Miranda, 2013). The implication is that students need tools that consist of clues for observation of essential features and connections to geoscientific meaning to apply geoscientific concepts in a field situation. To this end, we suggest "observation and interpretation tools" as a more precise description of the kinds of mental tools we are seeking to develop.

Reflections About the Potential Role of Observation and Interpretation Tools

In this section, we justify our argument that students need tools for observation and interpretation by reflecting upon how these tools can make a difference for their learning processes during fieldwork. The tools for observation and interpretation can provide both an individual and a common platform that enables students to talk with one another about geoscientific phenomena. This is important, because observations are subjective and students do not always notice the same features as geoscientists (Ford, 2005). An example exists in the longer discussion among the students in the field (see Table III). Their ability to negotiate the relative age of the layers can be facilitated by the stratigraphic principles, providing common tools for observation of essential features and interpretations. However, in rock identification, the application merely depended on the individual student's recollection of samples seen in the classroom preparation. We therefore believe that robust tools for observation and interpretation can make geoscientific knowledge more social and accessible for students and thus lower the threshold for engaging in collaborative reasoning about the phenomena in the field.

Observation and interpretation tools may also increase students' motivation for learning in the field. The students' deeper engagement with relative dating indicated a higher motivation for learning compared to their superficial engagement with rock identification. We believe this could have been influenced by students having the appropriate mental tools for the application of relative dating without the teacher's support, thereby facilitating autonomy and motivation. This way, our findings complicate the view of motivation and autonomy as antecedents for cognitive learning during fieldwork (e.g., Boyle et al., 2007; Mogk and Goodwin, 2012). We therefore propose the opposite relationship—that cognitive aspects, such as mental tools for observation and interpretation, precede motivation for knowledge application and learning in the field.

IMPLICATIONS

In the previous discussion, we aimed to identify qualities of stratigraphic principles and suggested that they can be translated into tools for observation and interpretation. Particularly, two qualities of such tools emerged: (1) they should build on students' everyday experiences, for instance, their natural way of thinking and the language with which they are familiar, and (2) they must consist of clues that direct students' observations of essential features and connect these observations to geoscientific interpretations. However, the question remains as to whether the qualities of stratigraphic principles can inform the development of tools for rock identification. We have attempted to do so in Figure 5, based on the work of Frøyland (2010). The first two columns compare the features known from students' everyday experiences and the features of rocks. The third column contains the essential features for observation and the geoscientific meaning of these observations. Connecting observations to the geoscientific meaning (Column 3) is not the same as knowing the geoscientific term (Column 4). Furthermore, the tool indicates that the features of observations and the geoscientific meaning should be applied before the introduction of the geoscientific term. The potential effect of the observation and interpretation tool for rock identification on student understanding needs more empirical research.

CONCLUDING REMARKS

Our study has illuminated some difficulties and opportunities for students in their process of applying what they have learned in the classroom to phenomena in the field and whether their ability to apply this knowledge persisted 1 y later. Essentially, applying classroom learning to phenomena in the field does not always lead to understanding among high school students. One of the greatest challenges for the students in our study appeared to be that they lacked sufficient mental tools for identifying rocks in the field. However, the same students were able to apply relative dating. This showed the importance of researching the students' learning process first in the classroom preparation and then in the field. Using relative dating as a guiding example of how students can perform geoscience tasks such as observing and interpreting phenomena, we have launched the idea that students need tools for observation and interpretation of knowledge application in the field. We hope that teachers and educators can use the findings and the discussion produced in this article to reflect upon how students can be supported to apply geoscientific knowledge outside the classroom.

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