Chapter 7
Doing Geoscience: Negotiations of Science Identity Among University Students When Learning in the Field

Lene Møller Madsen and Rie Hjørnegaard Malm

7.1 Introduction

Waiting for the bus to take us on a field trip, a first-year geology student wearing sneakers said: 'I can see that I don't have the right shoes today' as an opening phrase when joining a group of fellow students and me [the first author] at the parking lot. The other students smiled; they were all wearing various types of hiking boots. I participated in the field trip as a pedagogical supervisor of the teacher taking the students on the field trip. I had also been with the students at lectures and in the classroom, observing them in learning situations, for example, classifying rock samples and producing geological profiles. Unlike those situations, it was striking that from the first instance I joined the students in the field, issues of how to look and perform as a geology student came to the foreground (Fieldnotes, first author).

This observation points to interesting considerations about disciplinary culture, belonging and tacit knowledge if we are to understand how students engage in identity work and negotiate their belonging in relation to the geoscience cultural community. How do you know what shoes to wear on a geology field trip? What happens if you have the 'wrong' shoes on? Does the type of shoes you wear influence how you are perceived in the geology community? Can you succeed in geology with sneakers?

In this chapter, we unfold the relations and intersections between science identity, disciplinary culture, belonging and tacit knowledge as they are produced and negotiated in learning situations within the discipline of geology in higher education. With this approach, we aim to explore what is at stake when becoming a geologist and negotiating a geoscience identity in relation to the process of establishing disciplinary knowledge. Science identity, disciplinary culture,

L. M. Madsen (✉) · R. H. Malm
University of Copenhagen, Copenhagen, Denmark
e-mail: lmmadsen@ind.ku.dk

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belonging and tacit knowledge are not easily separated entities when analysing students' negotiation processes. Our intention is not to use the empirical data to make such a distinction or to provide a framework for analysis. Instead, we draw attention to how analysis of the relations and intersections between these, in concrete learning situations, can unfold the process of becoming a geoscience person. We do this by using our empirical material to show how students continuously engage in identity work and negotiate their belonging within the disciplinary culture of geology in relation to their experiences in the field. Hence, we add to the literature in science identity by providing thick descriptions of how disciplinary knowledge occurs, is negotiated and contested.

7.2 Science Identity and the Doing of Geoscience

We place this chapter within the research field of science identity and use the construct of science identity to investigate learning processes and negotiations in the becoming of a geoscience person. Carlone and Johnson (2007) presented the now seminal model of science identity, with three dimensions of science identity: competence, performance and recognition as well as their intersections. The construct of science identity has been used and developed in a range of studies of both students', teachers' and faculty's science identities. For a review, see, for example, Lee (2012), Varelas (2012), and Hazari et al. (2010). We situate our work in line with studies of science identity that draw on identity not as something one has but as something that one negotiates and performs in cultural settings (Avraamidou, 2020; Carlone & Johnson, 2007; Holmegaard et al., 2014; Malm, 2020).

By conducting science identity research in a disciplinary setting, we wish to contribute with knowledge on both "how science identity might serve in making science learning meaningful and purposeful" (Avraamidou, 2020, p. 4) and explore which "Kinds of people [are] promoted and marginalized by science teaching and learning practices" (Carlone & Johnson, 2007, p. 1189). In the conceptual paper 'Science identity as a Landscape of Becoming', Avraamidou (2020), as others before her, departs from science identity as an individual and isolated project. Instead, she argues for seeing identity as part of a social practice as she links the construction of identities to 'the process of becoming' developed in the theory of communities of practice (Lave & Wenger, 1991; Wenger, 1998). We adapt this approach to science identity, but place the discipline in the foreground by investigating 'the process of becoming a geoscience person' in the context of disciplinary culture. As such, the chapter does not adopt an explicit and critical intersectionality lens to science identity as advocated and discussed by Avraamidou (2020) and Gonsalves (2020), but situates itself within the studies that Avraamidou (2020) describes as studies of science engagement through the construct of identity. Examples are Gonsalves (2014), Johansson et al. (2018) and Danielsson (2012), who study the doing of physics and its intersection with gender and gender performance.

In Danielsson's (2012) study of four women studying physics at university, she argues that: "A more complete understanding of students' learning of physics must expand the meaning of learning (…) [and] needs to be understood in a broader personal and societal context" (p. 26). In line with this approach, we argue for a discipline-specific investigation of science identity in higher education, focusing on how the tacit and embodied practices within a discipline as well as the forms of knowledge intersect with science identity and the process of becoming in specific learning situations. By taking the disciplinary context into account, we follow up on the call by Enyedy et al. (2006) to foreground practice as a missing component in the construct of identity. In their study of middle school teachers, Enyedy et al. (2006) argue that: "A person's identity is shaped and negotiated through everyday activities" (p. 71). To address this, we focus our study on fieldwork as an important practice for learning and developing a disciplinary science identity within geology.

In geology, fieldwork is historically linked to the exploration of the Earth and scientific knowledge production. The practice of fieldwork is perceived to be integrated in a geologist's identity and thereby important when students negotiate their belonging in a higher education geoscience programme (Malm, 2020). Working in the field include a series of embodied, implied notions and practices (Raab & Frodeman, 2002) such as observations, measurements, drawings as well as creating interpretations in the field. The embodied practice of fieldwork includes developing an intuitive selection strategy and learn to make judgements based on both knowledge and direct experiences in the field. Stories of fieldwork are produced in the context of geology as an exploration-centred discipline (Nielsen et al., 2012), where both historical and current discoveries are told as personal stories of overcoming difficulties or dangerous situations in order to retrieve data from the field. These stories are central in the disciplinary culture, as they reproduce fieldwork as central to the identity performance. Thus, the practice of fieldwork ties together the idea about 'who' a geologist is and 'how' geology is performed within a strong disciplinary culture focusing on performance in the field (Malm, 2020).

A cultural practice includes a learning community with shared practices that are accepted through shared language, signs and recognition (Hastrup, 2004; Lave & Wenger, 1991). As the disciplinary culture and the fieldwork practice of geology include a physical element and the use of instruments, we expand our exploration of students' identity work by paying attention to tacit and embodied knowledge in fieldwork. As described by Polanyi (1966), knowledge is both practical and theoretical: "I shall always speak of "knowing", therefore, to cover both practical and theoretical knowledge" (Polanyi, 1966, p. 7). In addition, he argues that to know something includes more than you are capable of expressing, that some of our knowledge within disciplines is tacit and often strongly linked to the practices within the discipline.

The use of instruments is central in understanding tacit knowledge as it is related to "The art of knowing" (Polanyi, 1966, p. 7) with an embodied dimension to knowing. Hence, one also understands and knows things through one's use of the instrument through a bodily knowledge. Particularly the tacit use of instruments is important when collecting geological data in nature. Here, a bodily physical task

becomes interwoven with an intellectual reasoning task. Competence is therefore both shown by being able to physically perform the task or handle an instrument and being able to scientifically reason and argue for the choices made in the field. Both tasks are perceived as including a tacit and embodied dimension.

Gaining access to the fieldwork practice, being and feeling competent and receiving recognition in relation to fieldwork are important for students to become part of the disciplinary culture, and at the same time problematic when structural or physical barriers hinder participation (Malm et al., 2020; Núñez et al., 2020; Posselt & Nuñez, 2021). Students in higher education geoscience programmes in Scandinavia often participate in field courses, excursions and fieldwork throughout their studies to learn the practice of fieldwork, as it is believed that these experiences strengthen their engagement and retention in the geosciences (Boyle et al., 2007; Streule & Craig, 2016). The students' engagement with the field and development of a fieldwork practice to be included in the disciplinary culture all start with entering the space of the field, and entering with the wrong shoes is not insignificant when one's appearance and performance in the field is linked to recognition, culture and identity.

7.3 Methodology

The methodology applied in this chapter is eclectic in the sense that we draw on a range of empirical material produced in different research projects with different purposes and teaching situations. The empirical material includes a variety of aspects of fieldwork within the discipline of geology: from looking at minerals in the classroom to practising measurements and discussing geological structures in the field. The multitude of the different types of empirical material as well as various learning situations allow for studying different facets of becoming a geologist.

We organised the analysis in three portraits of learning situations named 'how to make sense of disciplinary knowledge', 'tacit and embodied practice with instruments' and 'being a geologist'. We use the term portraits to denote that we unfold the analysis more extensively in selected parts of the large empirical material. In all three portraits, the point of departure is analysing how science identity intersects with the concepts of sense of belonging, disciplinary culture and tacit knowledge. Hence the main concept in all three portraits is science identity and then the additional concepts are foregrounded in different ways in the different portraits, as shown in Table 7.1. We perceive science identity as a dynamic and social practice that is negotiated and re-negotiated in a continuous process in relation to the learning situations the students are engaged in (Pozzer & Jackson, 2015).

The interviews used in all three portraits were conducted in either Danish or Norwegian, the interactions observed (when verbal) were likewise in these two languages. For this chapter, we have made the translations into English as close to the meaning in the original language as possible. Throughout the chapter we have used they/them, and when using names in portrait 1 and 3, we have used gender-neutral names approved for official use in Denmark.

Table 7.1 The three portraits of learning situations

Portraits of learning situations	Main concept	Additional concepts	Empirical material
How to make sense of disciplinary knowledge	Science identity: Competence, performance and recognition	Belonging Disciplinary culture	First-year student doing coursework and fieldwork
Tacit and embodied practice with instruments		Tacit knowledge Disciplinary culture	Two BSc students doing fieldwork
Being a geologist		Belonging Disciplinary culture Tacit knowledge	MSc student doing fieldwork as part of an MSc thesis

Note. The table shows how the analytical constructs are foregrounded in the portraits and outlines the empirical material used

We provide an outline of the methodologies and materials used in each of the portraits in the following sub-sections.

7.3.1 Methodologies and Materials for Portrait 1: How to Make Sense of Disciplinary Knowledge

In the academic year 2012–2013, the second author researched how first-year students in a BSc study programme of geology negotiated and made sense of geoscience knowledge and developed a geological identity (Malm, 2014). Six students were interviewed individually five times during the first year of their studies (one student was interviewed only twice). The first interviews took place in August, 2 weeks before semester start. The next interviews took place in October and one in December at the end of the first semester. Another round of interviews was held in March and the final interviews were held in June just before the summer break. The interviews lasted between 40-min and 2.5 h and were transcribed verbatim and anonymised. A narrative approach was applied where the students' personal stories were explored (Polkinghorne, 1988; Webster & Mertova, 2007). The analysis of the interviews used a thematic analysis approach (Braun & Clarke, 2006) to find the main themes for each student at each point in time. Then, each interview was analysed using the analytical questions: (1) What influences the students' understanding of the content? and; (2) How do the students negotiate and make sense of the content? Hence, both the development of an understanding of the content as well as the students' negotiations during this process were unfolded. Additionally, the students' narratives were analysed across time using the concept of turning points (Holmegaard et al., 2014). This allowed for analysis of changes in the narratives and the students' negotiations and re-negotiations in relation to their making sense of the content.

In this chapter, we focus on one of the students, Ada, and how they negotiate knowledge production in different learning situations during their first year of studies and how the lens of identity brings new knowledge to our understanding of these processes.

7.3.2 Methodologies and Materials for Portrait 2: Tacit and Embodied Practice with Instruments

In 2019, the first author had been assigned as a pedagogical supervisor of an assistant professor teaching BSc geology students. As a pedagogical supervisor, she discussed and observed teaching practice with the assistant professor in various teaching settings. The teaching settings included lectures, classroom teaching and a field trip to a number of geological sites. At the beginning of the supervision, there were no plans to make any parts of the supervision into research. However, as the observations and interactions with the students intensified during the field trip, it became clear that insights for research could be made by analysing the observations. For purposes of formative feedback to the assistant professor, comprehensive notes were taken by the first author during all observations of teaching in the lecture hall, the classroom and in the field. Notes were taken in relation to students' engagement with the teaching activities and mastering of the geoscience content. These notes serve as the empirical material for the analysis.

In this portrait, we focus on one of the many practises that students are urged to master in order be part of the discipline of geology and become a geologist – the learning of tacit and embodied practices with instruments, in this case using a compass to take measurements.

7.3.3 Methodologies and Materials for Portrait 3: Being a Geologist

From 2016 to 2020, the second author conducted several studies of geology students working in the field as part of her PhD research in Higher Education Earth Science. The studies used ethnographic methods, consisting of participatory observations and interviews of individual student, to study students' practices of fieldwork and associated identity work in the field. In one study, the second author stayed with a group of MSc students and their supervisors for 12-days in the field while the students' collected data for their MSc theses (Malm, 2020).

The ethnographic observations of the fieldwork included both the students' individual work, their interactions with the supervisors and with the group of students working in the field. During the first 2 days everyone worked together as a group covering a large geographical area, after which the students worked alone for 2 days in smaller areas. The observations of one of the students, Ehm, in the field aimed at

understanding how the student solved problems, used previous knowledge, collected data and engaged in the field, thus documenting the lived experiences of the student during a period of fieldwork (Feig, 2010). Extensive field notes were recorded before, during and after the fieldwork (Emerson et al., 2011; Walford, 2009) in order to document as many impressions as possible, for example the cooperation and dialogue between participants, the supervision of the student, the physical environment and how the participants engaged in it.

One year later, an interview was conducted with Ehm. By this time, Ehm had graduated from university. The interview aimed at exploring how the student had used the data from the field and how their thesis developed from fieldwork to finished product. The interview was performed as a timeline interview (Adriansen, 2012) to learn how the student made sense of the different events during the year.

In this portrait, we analyse the observations from the field and explore, in depth, how Ehm's practices of doing geology in the field intersect with a continuing process of developing a geoscience identity. An analysis of the timeline interview is used to illustrate how the identity negotiations performed in the field are negotiated and re-negotiated by the student when working with the data in the laboratory, writing up the thesis and after graduating.

7.3.4 Issues of Positionality

Empirically, we draw on our own involvement and research in geoscience programmes at two different research-intensive universities in Scandinavia – the University of Copenhagen and the University of Oslo. In this chapter, we use our positions, insights and access to knowledge within the field of geosciences as empirical material, hence, issues of positionality are important (Edwards, 2002; Neal & Gordon, 2001; Rose, 1997). We have worked together during the last 10-years both in a supervisor-student relation and as colleagues in a number of research and development projects (Madsen et al., 2021; Madsen & Malm 2011, 2017; Malm & Madsen 2014, 2015a, b; Malm et al., 2015, 2020). We interact with the people we analyse, and we have different professional and personal relations to them. This creates a wide range of ethical considerations including being both insiders and outsiders in our research. As pointed out by Adriansen and Madsen (2009), "When doing insider research it is necessary to address the insider relationships explicitly in order to reveal the complexity of research relations" (p. 146) both in relation to the research matter and in relation to one's interviewees. To address this, we have tried to make our insider and outsider roles as transparent as possible in the above section without hampering the ethical issues of reporting from our studies and our interaction and relations with the people involved. In addition, we are both in various degrees and positions insiders in relation to the research matter as we are trained within the disciplines of geography (first author) and geology (second author) and have both participated in numerous fieldwork settings. This means that

in the analysis we draw on our knowledge of the content, practices and perspectives shared in the community of researchers doing geoscience fieldwork.

7.4 Portraits of Negotiating a Geoscience Identity in Learning Situations

In this analytical part of the Chapter, we provide thick descriptions of how disciplinary knowledge is negotiated and contested in different learning situations. We explore this by showing how students interact with geoscience knowledge and the doing of geoscience in the field. Hence, we show how the three dimensions of science identity (competence, performance and recognition) intersect and are negotiated in specific geoscience fieldwork learning situations.

7.4.1 Portrait 1: How to Make Sense of Disciplinary Knowledge

The first time we met Ada, we talked about their way into the geology programme. After graduating from high school, Ada thought about becoming a geologist but decided to complete an MSc within a different field; becoming a geologist felt like "Too geeky a choice" at the time. However, after completing an MSc degree in another field and not finding a job, Ada applied for the geology programme because "I want to do something that makes me happy" (1st interview, August).

When Ada started attending courses, reflections on the reasoning processes in geology began. The two first courses were a course in Earth Systems (introduction to geological processes, systems and materials) and a course on geophysics (introduction to geophysical exploration and groundwater systems). In the Earth Systems course, Ada was introduced to the rock cycle, how sediments are deposited and how that can provide insights into prehistoric environments, Ada said:

> It seems like they [the teachers] know very little, and then they make a huge story out of it, without really having the evidence, that bothers me (…) It seems like this is how it's done, to make a hypothesis and then I would think, that one should disprove it, but it doesn't really happen here, they just prove the hypothesis (2nd interview, October).

In this quote, Ada is struggling with the interpretive nature of geology (Dodick et al., 2009; Frodeman, 1995) as an epistemology that conflicts with their understanding of science. The reasoning in geology uses a narrative form of logic in contrast to the hypothetical deductive method (Cleland, 2001; Watson, 1969). Within the natural sciences, it has been argued that we use six different types of reasoning; the type described above is referred to as historically based evolutionary reasoning (Kind & Osborne, 2017). Here, evidence relies "On constructing theories about what might have happened in the past" and "Such theories have succeeded

because they have been the best possible inferences for what exists" (Kind & Osborne, 2017, pp. 12–13). In the discipline of geology, this means formulating multiple hypotheses based on field observations as part of the research process (Chamberlin, 1890; Cleland, 2001). When deciding between the hypotheses, the geologist constantly re-evaluates observations in the search of that piece of evidence that can make one hypothesis more likely than others (Cleland, 2001). In the quote, Ada reflects on the reasoning process in geology in relation to the hypothetical deductive reasoning process, which is a familiar epistemology for them from other natural sciences. Ada is surprised at not meeting this method when learning to interpret sediments, structures and fossils in geology.

Looking at Ada's negotiations of science identity through the whole year, it seems in hindsight that already from this point, Ada started negotiating a part of the discipline of geology as not 'real' natural science.

The next two courses Ada attended were a palaeontology course (the study of prehistoric species and the development of life on Earth) and a course on mineralogy and metamorphic petrology (the study of the mineralogical and chemical composition of rocks in Earth systems). Later in the first year, Ada reflected on the previous semester:

> I was often really frustrated [during the palaeontology course], but [the teacher] understood it, did not get mad at me and was just trying to answer my questions … [The teacher] understood the frustration and said: "I understand, it's not very smart, but you know there are a lot of other animals, who are also stupid" (4th interview, March).

In the interview, Ada explains how learning palaeontology was challenging when needing to learn details (e.g., how ancient creatures have moved on the ocean floor or eat) and not learning the overall picture (e.g., why these details matter in the geological story). Ada questions the production of knowledge when presented with full interpretations of the ancient species' ways of living and the connection to geological history, knowing that it is based on few observations or small details. When constructing a geological story, the geologist applies a narrative form of logic, where the observed details start to make sense as they are placed in the overall structure of an area or in Earth's history (Frodeman, 1995; Watson, 1969). Ada is therefore on the right track in trying to make sense of the details and the 'full story', here the evolution of living organisms. However, the concerns and difficulties experienced can still be linked to understanding the interpretive type of reasoning, as it includes a judgement of which details are important. The complex nature of this type of reasoning and the challenges in learning become evident in Ada's learning process. However, the quote also shows how Ada is recognised by the teacher for adapting a critical learning approach. The teacher explains that some species are not that complex, they are just simple and 'stupid' and understanding their ways is just a small part of understanding the whole system. This recognition plays an important part in Ada's negotiations of belonging in the study programme, as Ada finds a way to make sense of palaeontology with the recognition and help of the teacher. Ada's need to put the details into a larger picture is acknowledged as an appropriate way

of thinking, though not all details are equally important. Learning the difference and making these judgements is important when developing a selection strategy as part of the geological interpretation.

In the second part of the academic year, the students attended a course in sedimentology (the study of sedimentary rocks formed by sand, silt, chalk and clay) and a course in magmatic petrology (the study of the mineralogical and chemical composition of rocks in deep Earth systems). In the sedimentology course, Ada again struggled with the interpretive type of reasoning and getting recognition from the teacher. In the second part of the academic year, the students began negotiating the subfields within the discipline differently; the interviewed students, including Ada, perceived sedimentology as less scientific, although in various degrees. The students considered sedimentology to be 'storytelling' and very different from igneous petrology and mineralogy, as these disciplines use mathematics and chemistry, hence other types of reasoning to support interpretations (Malm, 2014). The room for interpretation and creativity seemed larger in sedimentology and the students understood that interpretation can be discussed and several answers are possible. This clearly sets the type of reasoning apart from the experimental natural sciences (Cleland, 2001) and the students were negotiating this in various ways in relation to their science identity. For Ada, the negotiation was reinforced by not being recognised by the teacher:

> I found a proper definition in the book, and then I brought it the other day [to class] and the teacher was not entirely happy with me (Ada smiles). [The teacher] said: "Now I have to be careful with what I say, when I come over here" (4th interview, March).

Ada's approach to learning was contested by this teacher as the teacher hesitated to answer the (many) questions. Ada experienced that when the teacher did answer, the explanation was different from the definitions in the textbook. Ada therefore brings the textbook to class and asked directly how to understand the different explanations. In the situation, Ada experienced having gone too far in terms of questioning, it was not a legitimised practice in the learning situation to ask this type of question. In contrast to the previous course, Ada received no recognition for questioning and exploring, and was left with the impression of being 'too much'. After this, Ada focused more on the textbook than learning in class. At this time, Ada also chose to focus on the course in magmatic petrology.

As summer approached the students spent more time in the field. A seven-day trip to the island of Bornholm (with many sedimentological localities) was the final and the longest field trip of the year. On this field trip the students applied the interpretive type of reasoning many times in different situations, guided by the teachers. To illustrate the challenges of learning the interpretive type of reasoning we show the difference of presenting sedimentology as science in the making (as experienced in the field, see Fig. 7.1) and as a ready made science (as presented in the classroom, see Fig. 7.2).

Being in the field provides access to and experience with conducting observations and learning that the observations can motivate different interpretations.

Fig. 7.1 Stevns Klint at Højerup in Denmark. (*Note.* Fieldwork with students observing the face of the cliff and trying to make sense of what they observe, illustrating science in the making (Latour, 1987; Madsen et al., 2021). Photos taken by Rie Hjørnegaard Malm, published in Madsen et al. (2021))

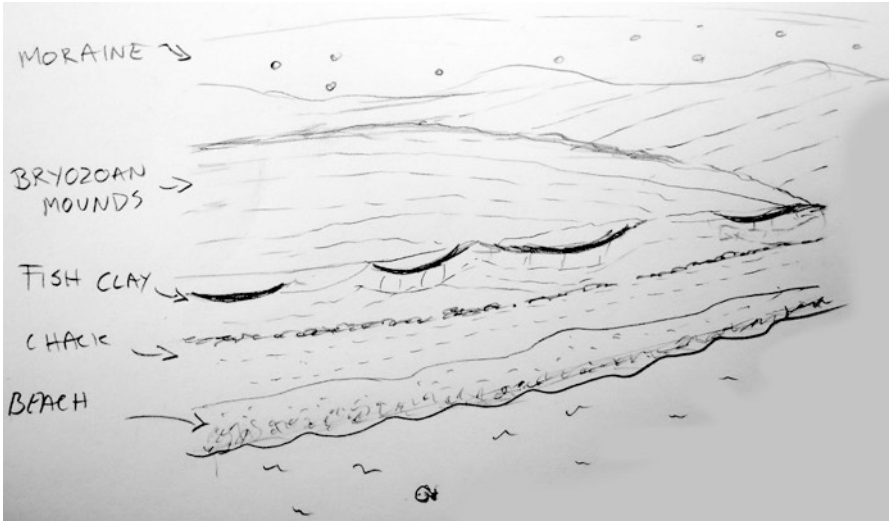

Fig. 7.2 Sketch of Stevns Klint at Højerup, matching the area in the photograph in Fig. 7.1. (*Note.* The sketch only displays the most prominent features of the cliff. Hence, there is an interpretation and a selection process behind what is included in the sketch. The reasoning process behind how the sketch is constructed (the transposition from the observed, illustrated with the photograph above) is often hidden for students in class and lecture-halls and shown as ready-made science (Latour, 1987). Sketch made by Rie Hjørnegaard Malm)

Hence, they have first-hand experience of the interpretive reasoning process. Ada says about the field trip:

> Sedimentology, I found out, is a discipline that works when you are out in the field, it does not work to sit and stare into some boring dry textbook, the discipline is simply not for that, (…) But when you're out and look at the outcrops, then it's pretty exciting actually, so I'm starting to like it a little better (5th interview, June).

In the above quote on fieldwork, Ada is on the way to developing the embodied type of thinking required for working in the field (Raab & Frodeman, 2002). The fieldwork provides access to learning about where to look, how to look, and what to infer from observing. For Ada, the experience in the field started re-negotiations of the discipline and sense of belonging. Ada realised why the teachers were not able to precisely answer the questions in class – because the same observations can prompt a series of possible interpretations, and to make solid inferences, one constantly needs to consider alternative interpretations.

At the end of the first year, Ada felt more comfortable in studying geology and reported being interested in focusing on mineralogy or petrology. Until this point, Ada's negotiations had indicated that deselecting sedimentology was in line with interpreting sedimentology as a 'less scientific' discipline. However, during the first year and especially during the fieldwork encounter, Ada learned to see how interpretations are done and thereby accessed some of the tacit knowledge that was not made visible in the beginning of the first year, and this expanded their understanding of geology as a discipline.

The analysis of Ada's story shows how identity work and negotiations of disciplinary practice are central in making sense of scientific content in relation to the different reasoning types in geology. Ada initially identified geology as a 'hard' science discipline (i.e., deductive and based on testing hypotheses). The interpretative reasoning styles in geology were new to Ada and learning this type of reasoning was difficult with no explicit access to the tacit knowledge it builds on. Ada's way of challenging and questioning the scientific practice was central to their individual learning process but also to their identity process. Understanding the scientific reasoning processes in geology is linked to how science is performed and Ada experienced and explored both the different types of science content and how they are performed differently in the various sub-disciplinary practises. Ada struggled with performing a knowledge production that could be recognised by the teachers in specific learning situations and thereby with gaining acknowledgement in the process. Expressions like feeling 'too much' indicate how a narrow space for acknowledged performance is established in the disciplinary culture. By following Ada throughout the first year, it became visible that establishing disciplinary knowledge in different learning settings and types of recognition constantly influence and, in various ways, interact with learning and identity processes.

7.4.2 Portrait 2: Tacit and Embodied Practices with Instruments

> Two students are standing very close to the wall of granitic gneiss with basaltic intrusions. The wall is part of a quarry that has been exploited for many years for road construction material. Trucks are driving by from the larger quarry below and other trucks are coming to the quarry where they are loaded with sorted rocks and then leave again. We have been directed to the wall where no quarry work is occurring today. We are all wearing helmets and luminescent vests.
>
> Along the wall the students begin describing and understanding the geological structures by measuring the spatial orientation of the different observable structures in front of them. I go towards two students engaged in the measurements. They are sharing one compass, one student holds the compass and moves their body to align with the wall, the other student asks questions about the practice of aligning one's body and holding one's hands in position.
>
> They are discussing the process of measuring to assure each other that they are placing themselves in the right spot and holding the compass at the right angle to do the measurement. Then they discuss what they are trying to measure [the spatial distribution of the different layers now completely eroded]. The two students are trying out the procedure of measuring with the compass in a number of places while they move along the wall to find out how the structures are spatially oriented. It seems like they have a common understanding of how they are measuring.
>
> A group of students gather around the teacher further down the wall of granitic gneiss in the quarry. By moving their body and being explicit about the position of their hands, the teacher uses the compass to show how to conduct the measurement, and the students, either in pairs or alone, are trying out the procedures. Students raise questions and the teacher answers by showing and doing the measurement over again with body and hands. The two students measuring along the wall reach the group of students and the teacher. They seek reassurance of their practices by asking the teacher a number of questions. The teacher reaches out for the compass and shows them how.
>
> After a while, we leave the granitic gneiss and walk towards the bus; the next stop is further north. Here, surrounded by forest we will find old weathered down volcanic cores and search for small pieces of mantle xenolith, the treasure of the day to bring home! (Fieldnotes, first author).

In the above, the students were learning to conduct a 'strike and dip' measurement of a geological structure in order to understand the spatial orientation of the observed structures. This consists of multiple tasks of both bodily doing things and using mental abstractions, as well as managing to combine the two. It includes both explicit and tacit knowledge of how to measure, what and how to interpret, as well as being able to formulate and articulate a geological structure. As Malm (2020) shows in a study of third-year BSc geology students, after weeks of practicing hitting rocks in a specific area, they are able to know which type of rock they are hitting with the hammer just by the bodily experience and sound created by the hitting. Learning this embodied way of using a hammer is a tacit type of geological knowledge. The measurement of strike and dip with a compass is another instance of embodied tacit geological knowledge.

Tacit knowledge implies two parts of knowledge; one part gives access to the other part – Polanyi (1966) formulates this as "We know the first term only by relying on our awareness of it for attending to the second" (p. 10). Hence, we are often

not able to explicate the first part as it becomes a practice we perform with a purpose of understanding something else. It is only when our understanding of the phenomenon is flawed that our attention is directed to the first part of the tacit knowledge. Measuring strike and dip, that is, the spatial orientation of a geological feature with a compass, is a good example of this. When measuring several features in the same area, the geologist is able to tell how the features relate to each other. This information can for example be used to evaluate the timing of events creating the features, that is, constructing a timeline of relative age. This is part of constructing the geological story of the area – taking a small piece of information and relating it to the whole. Hence, the actual measurement of the strike and dip is in the terms of Polanyi the first term that we only know for attending to the second, namely the spatial orientation of the layers. Conducting the measurement includes choosing a place to measure that represents the true orientation of the feature, and this can be difficult in places where there are no clear indicators. Hence, you might not measure the true orientation and thereby gain data that do not make sense in the geological story. As students are repeatedly exposed to making these choices and evaluating them, over time they will learn 'where to measure', 'what makes sense' and 'seeing' in a geological setting. They might be able to practically do the measurement on many types of surfaces and only start to evaluate how they did it when something is not right or does not add up in the data. The practice becomes embodied. In this sense, they will have an embodied tacit understanding of doing the measurement and only notice it when something does not 'make sense'.

Let us return to the observations of the students in the field. A geologist must be able to describe and communicate the geological structure that they observe in the field. This involves a process of sketching, measuring and classifying. In the above observation of students and their teacher in the field, the focus is on practicing the ability to measure strike and dip as part of the process of describing the geological structure of the wall of granitic gneiss with basaltic intrusions. The actual measurement is the means to understand the geological structure. For the experienced geologist, in this case the teacher, the knowledge of how to measure the strike and dip is an embodied tacit knowledge used to describe the geological structure. For the teacher to teach the students to make strike and dip measurements the teacher shows the practice again and talks to the students about what it means. This is what Polanyi describes as "An ostensive definition" (Polanyi, 1966, pp. 5–6). This means to point something out for the student, a combination of a "Naming and pointing" (Polanyi, 1966, p. 5). In the case with the strike and dip measurement, we can describe how to make the physical measurement (how to use the compass), but how to translate that into a geological structure and be able to describe the geological structure is tacit. In the learning situation, we must trust the students to be able to see what "we have not been able to communicate" (Polanyi, 1966, p. 6). Similarly, in the work by Goodwin (2000) where he analyses the colour practises (determining the colour of the dirt they are excavating) of archaeologists he talks about the setting's *opaqueness* to outsiders. Only by becoming a member of the cultural community does this opaqueness dissolve.

This portrait of BSc students in the field demonstrates how the process of learning 'what makes sense' and how developing embodied tacit knowledge in the

field – which is an important competence within geology – are strongly linked to access to the disciplinary culture held by teachers. In Portrait 3 we turn our attention to an MSc student collecting data in the field to show the ways in which the dimensions of performance and recognition play a central role in understanding the student's challenges of embodying a science identity.

7.4.3 Portrait 3: Being a Geologist

During their first days in the field, the student Ehm, and the two supervisors observe several outcrops together. The scientific content of the MSc thesis is discussed as new discoveries are made and new limitations found. The work environment is enthusiastic and the small group constantly work out new hypotheses to fit the observations. The supervisors and the student discuss how the different hypotheses can be approached and what the focus of the fieldwork can be.

At the different localities, all of them are making observations, taking notes and samples at the same time. They discuss what they see and how it can be interpreted. The group work long days in the field and use the evenings to look at maps, discuss the data and new ideas.

Then the student works alone for a few days. The group have agreed upon a preliminary plan for the fieldwork, and the type of observations and interpretations the student needs for their thesis. The student visits both new localities alone and returns to some previously visited localities. The student systematically collects data and makes notes of the questions that arise during the work. In these days Ehm often says "I have no idea what I am doing" and "It is so difficult to see what they [the supervisors] saw" but continues and seems somewhat comforted that the supervisors can help.

When Ehm and the supervisors meet in the field again, they continue to explore, discuss ideas and develop the hypothesis. The supervisors negotiate the responsibility with the student saying "So now, you show us what we need to see". The student is thus expected to take charge and to ask questions, however, although the supervisors express this shift in roles, they often get caught up in their own explorations, leaving the student with more and more questions unexplained. In the beginning, Ehm asks many questions, tries to explain the difficulties and participate in discussions. But as the days pass Ehm becomes quieter, and spends a lot of time checking their notebook. The research question is still open and the first half of the fieldwork has not provided a clearer idea of what to focus on.

This pattern continues, Ehm continuously tries to follow the supervisors' ideas and hypotheses, both in the field and in the late evening discussions over the map. The supervisors are enthusiastic, clearly enjoy these discussions and thrive in the field. The supervisors are keen on collaborating with Ehm and genuinely try to help and support. One of the supervisors tells me that this student does a great job, it is a difficult task but the student seems "Tough, and knows their way around the field". The supervisors clearly trust the student and see that the student performs well in the environment.

But insecurity seems to build up in the student. At this stage, Ehm has a few days alone, and these days in the field are completely different from the previous. The student is ruminating over the data collection, visits several sites to check the data, and at one point states: "Why did I set out to do this in the first place, when it is so unlikely that I will succeed? I remember when I was a child, I took a test, and it showed that I was not good at spatial thinking. Then why am I standing here and working with this? This is not who I am".

The student and I leave the field utterly exhausted (Fieldnotes, second author).

The geological fieldwork and collecting data from the field formed the backbone of Ehm's thesis work and part of the research group's further explorations of the area. Our analysis explores how the disciplinary culture is reflected in the working culture of the group and how both influence Ehm's individual experiences in the field. In the above, we first see how the group work with multiple hypotheses (Cleland, 2001) and the supervisors see connections at the localities based on their embodied experience (Raab & Frodeman, 2002). The group does an open exploration of the area, which aligns with a field-based research project in geology.

We see that Ehm is concerned about collecting 'the right data' and that being under a time constraint is stressful. The open research process and the lines of thinking are invisible and to some extent not available to the student. The supervisors rely on Ehm's previous training and experience and the fact that they recognise Ehm's performance in the field: Wearing the right clothes, keeping a notebook at hand, handling a compass correctly, asking sensible questions, being interested, taking lots of samples and working hard. This performance of fieldwork practices is recognised by the supervisors as valid within the disciplinary culture. The dimensions competence, performance and recognition (Carlone & Johnson, 2007), and particularly their intersections become visible here. The student performs as being competent, is recognised as being competent, but does not recognise themselves as being competent. In addition, the supervisors include the student in their work as an apparent equal, they often say that the student's observations are interesting and use them to advance their common ideas.

The student is being included in the community of practice and recognised as a legitimate participant (Lave & Wenger, 1991). However, when Ehm experiences difficulties with practicing geoscience, for example, keeping track of the hypothesis and seeing what the supervisors see in the field, Ehm engages in identity work by starting to question their own competence, which quickly leads to questioning both past, present and future ideas of becoming a geologist. This relates to feeling a sense of belonging (why did I set out to do this…), in relation to the disciplinary culture and embodied and tacit knowledge production (when the student starts questioning the observation and reasoning process).

> A year after being in the field, Ehm explains that many months were spent in the laboratory doing analysis, failing and trying, again and again. The results kept being 'wrong' and Ehm ruminates over the data collection in the field and feels convinced that mistakes were made during the fieldwork. The months pass by and in the end Ehm needs to show some of the analysis to the supervisors. When finally doing so, the supervisors react with great surprise; the analysis shows a new, unexpected pattern. Over the last month of the student's thesis process, the supervisors become more and more convinced that the data provides evidence for a new interpretation of the area. Ehm has not made a mistake, the fieldwork and following analysis in the laboratory has provided the research group with a new and exciting scientific story to tell. A story that later leads to a new publication about the area.
>
> At the time of the interview, Ehm acknowledges this as an exciting development and talks about the positive response during the exam, however, it is clear that Ehm still struggles with the experiences from the field (Fieldnotes, second author).

The insecurities about how to observe and 'seeing' what the supervisors see, combined with difficulties in understanding the complicated geological story, build up during the fieldwork. This feeling of being insecure about the fieldwork and data collection stays with the student in the laboratory, influencing the learning and research process, and continues to affect the student throughout the writing process and is still present after graduation. The student finds it difficult to acknowledge their own contribution to the results and continuously refers to 'making mistakes', not being prepared enough for the fieldwork and not being competent enough to 'see'. This ongoing negotiation of not belonging persists within the student and evidently the experiences in the field and reflections on the fieldwork has had a major impact on the way the student cannot identify as competent and as a legitimate participant.

By using science identity, we see how negotiations of competence in the field involve identity work and negotiations of becoming a geologist. This portrait shows how students have to 'be' and be able to 'see' in a specific way, to be recognised in the field by others. The specific performance of being competent in the field means that the students need to navigate the disciplinary culture in order to belong. As this portrait illustrates, this can amplify students' feeling of not 'fitting in' as they struggle to find ways of recognising *themselves* as competent aspiring geologists. Ehm performs in line with the disciplinary practice and culture, gets recognition from the supervisors and clearly has competence to produce valuable research data. However, Ehm still struggles with recognising their own achievements and feeling they belong. Why does this fieldwork become so problematic? Our analysis is that the student connects being competent in the field with being a 'good' geologist and having the experience of having failed in the field has consequences for the student's self-image as a future geologist. In this sense, the student experiences the disciplinary culture as excluding. The strong emphasis on the fieldwork practice and associated idea of how to be as a field geologist hinders the student in recognising their own accomplishments beyond the fieldwork and thereby hinders them in trusting the data collected in the field as they are analysed in the laboratory. Thus, the student has no strategies for separating competence in the field and being competent in the following laboratory, analysis and writing processes. The insecurities arising from the fieldwork made it difficult to negotiate a place within geology, in spite of having performed well, having received recognition and made an important contribution to research. The student does not work as a geologist today.

7.5 Discussion and Concluding Reflections

> It was not that any of us commented on the shoes, it seemed obvious that they were not aligning to the code of conduct and, apparently, so strongly that the student felt a need to express this as a first thing when entering the group. As more students arrived also more students with sneakers arrived. In the end, a mix of sneakers and hiking boots went on the field trip. However, not only the shoes were noticed, also types of trousers, jackets and hammers were noticed, I'm sure, although not verbally commented on (Fieldnotes, first author).

Returning to the wearing of sneakers, we wish to draw attention to the disciplinary aspect of recognition and competence in our understanding of how science identity is negotiated and performed in specific learning situations. In the three portraits given, we show how the three dimensions of science identity – competence, performance and recognition (Carlone & Johnson, 2007) – intersect and are negotiated in specific geological fieldwork learning situations. All three portraits illustrate how the students' learning experiences and identity work intersect with disciplinary knowledge and culture. In Portrait 1, the student is navigating teaching practices, disciplinary culture and knowledge production in relation to the interpretive nature of geology and includes ideas of science, in Portrait 2 the student is negotiating the tacit embodied practice of how to conduct strike and dip, and in Portrait 3 the student engages in identity work in relation to how to 'see' as a geologist in the field. Hence the tacit and embodied knowledge that are part of the disciplinary culture play into the students' identity work related to competence, performance and recognition within the discipline.

The portraits also illustrate how the embodied and implied knowledge are present across different teaching and learning practices throughout a study programme from first year of BSc to MSc level. In Portrait 1, the first-year student is simultaneously navigating how to understand the scientific approaches in geology, the different interactions with teachers and their patterns of recognition as well as finding a way to belong in the discipline. In Portrait 2, we see how the teacher holds embodied tacit knowledge, which per definition is difficult to teach BSc students orally and the teacher therefore constantly shares the practice of handling the instrument when conducting the measurement. The same mechanism is in play in Portrait 3, where the supervisors work side by side with the MSc student and by their doings show how they develop their understanding of the area and the hypothesis simultaneously. Based on these analyses, we demonstrate how including studies of tacit and embodied knowledge in concrete learning situations can unfold students' identity work when establishing their disciplinary knowledge in geology. Hence, we advocate including disciplinary culture in our understanding of competence, performance and recognition when we talk about science identity.

Science identity within a discipline takes many forms, both visible and tacit, and for the students it requires identity work in relation to performing in specific ways in order to be recognised as competent within the discipline. However, we have also shown how a disciplinary culture can become part of exclusion practices in specific learning situations by producing a narrow space for students to perform within, gain recognition from and feel competent in. In order to allow for wider participation in geology, we advocate a disciplinary culture that allows for an inclusion of different types of belonging and various ways of becoming a geologist.

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