Teaching and learning through scientific practices in the laboratory in biology education

Exploring modelling through representation construction as scientific practice

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Mari Sjøberg
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Summary

The overall aim of this thesis is to explore challenges and opportunities with teaching and learning through scientific practices in the laboratory in biology education. Teaching science as inquiry has been a recommended approach to laboratory work in both secondary and undergraduate education for a long time. However, the way laboratory work often is implemented at both levels of education is criticized for communicating a misleading image of science. The notion of scientific practices aims at working against the mistaken idea that there is a single scientific method, focusing solely on experimental exploration, by directing the attention towards other practices, such as modelling. By 'teaching through scientific practices,' I mean an approach to science teaching that engages students in scientific practices (for instance, modelling) in order to learn about nature of science and science concepts, models and theories. My focus is on *practice* in the laboratory and in the thesis, I have investigated *practice* in two different ways. First, I have investigated upper secondary biology teachers *practices* as reported in a survey and group interview (Article I). Secondly, I have analyzed undergraduate biology students' modelling *practices* through microscale analysis of their reasoning when constructing representations in the laboratory (Article II and III). The empirical context of these case studies is an instructor–researcher collaboration focusing on supporting students' representation construction in the laboratory.

Article I focus on biology teachers reported practice and challenges with laboratory work, particularly focusing on scientific practices. The findings show that the major reported aim with laboratory work is to illustrate content knowledge and that they primarily implement teacher-directed laboratory work where the laboratory report plays an important role. However, the findings also indicate that they integrate aspects of scientific practice, such as the use of hypothesis, in the teacher-directed activities without taking into considerations that the students are not actually testing the hypothesis. The results show that the teachers experience a mismatch between implementing open inquiry and the goal of teaching content knowledge and we conclude that the biology teachers struggle to design appropriate contexts for addressing aspects of scientific practice.

Article II focus on undergraduate biology students' reasoning when constructing representations in a laboratory context. In order to support students' representation construction, the Instructor explicitly discussed representations together with the students by arranging a plenary drawing session. To investigate students' reasoning and the

development of representations, we used a combination of two analytical approaches: tools from social semiotics to analyze students' drawings, and interaction analysis to understand their social interactions in relation to this. Our analysis showed that students' self-produced representations supported their reasoning in several ways: their initial naturalistic representations were an entry point for a process of selection and abstraction, that eventually led to a more scientific model focusing on the molecular mechanism. However, the findings also suggest that students' task framing was important for their reasoning process. While one group of students seemed to frame the task as a modelling activity, another group framed it according to the conventions of a laboratory report. Even though their initial representations seemed to trigger important questions, instead of pursuing those questions, they remained loyal to the laboratory report genre, placing their focus on the reporting of empirical results rather than reasoning through representations.

Article III seeks further insight into the role of different representations, including gestures, in students' model-based reasoning. In this case study, the Instructor increased the support given to the students in terms of explicit reflection on the representations construction during the inquiry. We conducted an interaction analysis to examine students' interactions and used a framework of different gesture types in order to investigate the role of gestures in students' model-based reasoning. The analysis showed that drawings and gestures together were important in focusing and extending the students' inquiry. Further, gestures representing molecules were important when sharing ideas about the molecular interactions they were supposed to model. Further, the analysis showed that drawings, gestures and material artefacts were important resources in connecting theoretical scientific ideas with observations made in a practical exercise.

Together, these findings shed light on the challenges and opportunities with teaching through scientific practices in the laboratory in biology education. Based on the presented findings, I argue that the focus on the scientific practice of planning and carrying out investigation in the laboratory, which is currently the most important focus in the curriculum, is problematic as long as biology teachers/instructors primarily aims at illustrating content knowledge, and not teaching about nature of science. Further, I argue for the fruitfulness of a focus on modelling through representation construction in the laboratory. The findings from Article II and III shows how different representations support students' model-based reasoning. Further, I argue that the focus on representation construction also support the development of conceptual understanding. Therefore, such a focus thereby solves some of the challenges reported in Article I, such as the experienced

tension between learning science and scientific inquiry. Finally, I argue that science education courses can play an important role in preparing future biology teachers for teaching through scientific practices in the laboratory by highlighting that scientific practice is more than experimental exploration and specifically address the potential of modelling as a scientific practice in the laboratory.

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Article I **Sjøberg, M**., Gregers, T. F., Ødegaard, M. & Tsigaridas, K. G. (2020). Biology teachers' border crossing between cultures: From a scientific culture to a school culture. *Nordic Studies in Science Education*, *16* (1).

Article II **Sjøberg, M.** & Knain, E. Undergraduate students' multimodal reasoning: representation construction in immunology in the laboratory. Manuscript to be submitted for review in *Research in Science Education*.

Article III **Sjøberg, M**., Furberg, A. & Knain, E. Students' model-based reasoning in immunology: the role of drawings, gestures and material artefacts. *Science Education*. Manuscript in review.

Part I

Extended Abstract

Preface

Even though scientific research is primarily supposed to fill gaps remaining in a given field's vast knowledgebase, it is also culturally embedded and personally motivated. Therefore, in this preface, I will briefly describe my own journey, along with some personal beliefs that have motivated the research presented in this thesis. I write this to make the personal embeddedness of the research transparent for the reader.

Science – biology, in particular – was always my favourite subject in school. Nature's complexity is fascinating, and no art can really compete with nature as a creator. Gaining insight into this complexity – from how genetic code is transcribed into traits in living organisms to the details of how new lives come into existence – has great value. However, while studying biology, I sometimes felt that the enormous collection of facts we were supposed to learn was prioritised at the expense of learning about the practices of science. Just as the knowledge, theories and models are fascinating, so are the practices and ways of thinking that have created them. Osborne (2014) states: 'one of the major contributions that science has made to our culture is building a commitment to evidence as the basis of belief; in so doing, the scientific tradition has promoted rationality, critical thinking and objectivity' (p. 580). However, sadly, the different scientific practices (Osborne, 2014) and styles of reasoning (Kind & Osborne, 2017) that have resulted in the established knowledge are often reduced to a single method: 'the scientific method' (Windschitl et al., 2008).

My own experience with 'the scientific method' in the laboratory came in upper secondary chemistry. I remember feeling that we were playing some kind of game in which we were supposed to discover things the teacher had already planned. The disappointment I experienced when I did not discover what I was supposed to find and had to begin again was discouraging. This motivated me to start reading philosophy instead. In philosophy, I felt that reasoning was more prominent and that I could work, to a larger degree, with the big questions on the edge of our current knowledge.

However, after working with ideas while pursuing a bachelor's in philosophy, I was again drawn to the 'study of life' – that is, biology (Hessen, 2005; Mayr, 1997). Therefore, I decided to pursue a master's degree in human toxicology at the National Centre for Occupational Health in Norway. For two years, I investigated the chemical carcinogenesis of human lung cells based on exposure to different carcinogens in the laboratory. It was fascinating to be part of a research group and doing authentic research. I even co-authored a scientific article, based on much of the work I had presented in my master's thesis (Bersaas et al., 2016). However, I also realised that I liked working with people more than I liked working with cells. I was admitted to the Teach First Norway programme, which aims to recruit students, who have earned master's or Ph.D. degrees in science, to the teaching profession. One of the programme's main ideas is that good science students will also become good teachers. I read science education literature as part of my teacher education, and I was inspired by the ideas in these works – particularly the ideas about nature of science as part of scientific literacy, presented by Svein Sjøberg's book (2009).

After working as a teacher for two years, I applied for a PhD position. However, when reading the vast amount of literature about teaching science as inquiry, the nature of science and scientific literacy, I was surprised that so many of these ideas and findings were unknown to me as a teacher. I consider my own journey, from being a biology student to being a 'researcher' in biology, a teacher and a teacher educator, as a cultural border-crossing experience, with which I still struggle at times. Alongside pursuing my Ph.D. these past few years, I have been working as a science educator (naturfagdidaktikk) as part of the practical–pedagogical education (PPU). During these years, most of my students have had similar backgrounds as myself: disciplinary master's degrees before they decided to become teachers. The courses I have taught are quite short, and I have really found it difficult to give these students insight into what science education is, how it should be taught and why it should be taught in such a short amount of time. Therefore, a personal motivation behind work presented in this thesis is to improve biology education and to understand how I can help ease the cultural border crossings for future biology teachers.

1 Introduction

The aim of this thesis is to explore challenges and opportunities with teaching and learning through scientific practices in the laboratory in biology education. My main focus is on exploring modelling through representation construction as a scientific practice. By 'teaching through scientific practices,' I mean an approach to science teaching that engages students in scientific practices (for instance, modelling) in order to learn about nature of science and science concepts, models and theories. Even though I believe an important aim of engaging students in scientific practices is for them to gain knowledge about nature of science, my focus in this thesis is on *practice* in the laboratory and not on explicit reflection on nature of science. In line with several scholars, I believe that knowledge about nature of science is best learned through experience in a situated practice, intertwined with content (Duschl & Grandy, 2013; Erduran & Dagher, 2014; Nersessian, 2008; Osborne, 2014).

I situate my research in the field of didactics (Wickman, Hamza, & Lundegård, 2018, 2020), or biology didactics – that is biology teachers' own academic discipline. In this thesis, I present a detailed, microscale analysis of students' reasoning in a laboratory context. I also present findings about how biology teachers describe their own practice in the laboratory. These findings will give insight into the challenges and opportunities of teaching and learning through scientific practices in the laboratory, which will hopefully be valuable for biology teachers (and university instructors) when they are planning, carrying out and analysing teaching. Further, this knowledge will also be valuable for biology teacher educators and curriculum developers – that is, all those involved in biology education and biology teacher education.

For decades, researchers have recommended that science be taught through inquiry (National Research Council, 1996, 2003; Rocard et al., 2007). Concerning undergraduate biology education, reports highlight the importance of shifting from traditional, cookbook laboratory exercises toward giving students authentic research experiences (National Research Council, 2003; American Association for the Advancement of Science, 2010). Arguably, inquiry-based teaching increases students' interest in science, nurtures their critical thinking and creativity and improves their acquisition of content knowledge and their understanding of nature of science (National Research Council, 1996, 2003, 2012; Rocard, et al., 2007; Tytler, Prain, Ferguson & Clark, 2020).

Recently, in the United States (US), the notion of 'inquiry' has been replaced by that of 'scientific practices' (National Research Council, 2012; Osborne, 2014; Crawford, 2014). In Norway's ongoing curriculum reform, the upper secondary 'Young Biologist' competence area has been replaced by 'Practices and Reasoning in Biology' (Utdanningsdirektoratet, 2019b). However, the abilities necessary for accomplishing scientific inquiry (National Research Council, 1996) are very similar to the eight scientific practices presented in the US Framework for K–12 Science Education (Osborne, 2014; Crawford, 2014), many of which are also represented explicitly in the Norwegian curriculum. In this thesis, I will use the notions of 'teaching through scientific practice' and 'teaching science as inquiry' interchangeably.

As the laboratory is a central context for scientists' knowledge construction (Latour, 1999; Knorr-Cetina, 1999), it has been considered an appropriate place for teaching through scientific practices (Hofstein & Lunetta, 1982, 2004; Hodson, 1998). However, laboratory work often involves students simply following a cookbook approach to arrive at predefined results (Hofstein & Kind, 2012; Séré et al., 1998; Turner, Paradise & Johnson, 1998), which is not considered effective for developing students' conceptual understanding (Abrahams & Millar, 2008) nor students' knowledge about nature of science (Schwartz, Lederman & Crawford, 2004). On the contrary, it contributes to the misleading notion that there is a single scientific method (Hodson, 1996, 1998; Kind, Kind, Hofstein & Wilson, 2011). Windschitl, Thompson and Braaten (2008) claim that 'the scientific method' has become a 'cultural lore' about what it means to teach through inquiry; this is also the case at the undergraduate level (Windschitl et al., 2008), which 'emphasizes the testing of predictions rather than ideas, focuses learners on material activity at the expense of deep subject matter understanding, and lacks epistemic framing relevant to the discipline' (p. 941).

The notion of scientific practices aims at working against this mistaken impression of 'the scientific method' and the overemphasis on experimental exploration at the expense of other practices, such as modelling and argumentation (National Research Council, 2012). Further, according to Osborne (2014), the notion of scientific practices is clearer in terms of what the students are supposed to learn by participating in scientific practice. In line with Osborne (2014), I believe that such student engagement primarily has value when it can help students 'develop a deeper and broader understanding of what we know, how we know, and the epistemic and procedural construct that guides its practice' (p. 587). There is a close connection between scientific practices and reasoning, as reasoning is central to all scientific practices (Erduran & Dagher, 2014; Osborne; 2014). Modelling can be considered one of several scientific practices (Osborne, 2014) or styles of reasoning (Kind & Osborne, 2017), but it can also be considered the defining characteristic of all scientific inquiry (Upmeier zu Belzen, van Driel & Krüger, 2019; Windschitl et al., 2008). Windschitl et al. (2008) suggest that model-based inquiry is a fruitful alternative to 'the scientific method' as it more authentically reflects the nature of scientific inquiry and supports the development of conceptual understanding.

An important theoretical assumption in this thesis is that language is crucial to both scientists' and students' knowledge construction. Talking, writing, reading and representing science characterise all scientific practice (Norris & Phillips, 2003; Wellington & Osborne, 2001; Osborne, 2014). The concepts of 'models' and 'representations' are often used interchangeably in the literature (Lehrer & Shauble, 2010; Windschitl et al., 2008). However, representations include a broader range of semiotic resources, such as spontaneous talk, metaphors, gestures and manipulation of artefacts (Hubber & Tytler, 2013), and they can be considered language resources or tools for modelling (Angell, Kind, Henriksen & Guttersrud, 2008; Lehrer & Schauble, 2019). Models are representations of a more deliberate kind (Hubber & Tytler, 2013) and can be defined as 'specialized representations that embody aspects of mechanism, causality, or function to illustrate, explain, and predict phenomena' (Schwarz et al., 2009, p. 634). In this thesis, I use the concept modelling through representation construction to refer to the process by which models are created. Therefore, even though I distinguish between representations and models, the processes of modelling and representations construction will be used interchangeably, and are considered central scientific practices. It is argued that, by foregrounding representation construction and negotiation, students can experience how knowledge is transformed through a sequence of re-representations, and this authentically reflects the relationship between theory and evidence, which characterises nature of science (Latour, 1999; Roth & Mcginn; 1998; Tytler & Prain, 2013). Supporting students' representation construction through guided inquiry (Knain et al., 2017; Tytler, Prain, Hubber & Waldrip, 2013b), which authentically reflects scientific practice, can contribute to their development of a conceptual understanding (Tytler & Prain, 2013). This approach is consistent with those focusing on model-based reasoning and modelling (Gilbert & Justi, 2016; Hubber & Tytler, 2013; Lehrer & Schauble, 2006), and it is argued that representation construction can promote scientific reasoning (Tytler, Prain, Hubber & Haslam, 2013a) and creativity (Tytler et al., 2020). The representation construction approach developed by Tytler et al. (2013) is important for the developmental work that is the empirical background for some of the work presented in this thesis.

Though teaching science as inquiry has been recommended for some time, research shows that there are several challenges involved, and many teachers struggle to teach science as inquiry (Capps & Crawford, 2013; Crawford, 2014; Gyllenpalm, Wickman & Holmgren, 2012). Some research focuses on the relationship between teachers' knowledge about nature of science and/or their experience with authentic scientific inquiry and their teaching practice, but research shows that this is a complex relationship (Bjønness & Knain, 2018; Lederman & Lederman, 2014; Windschitl & Thompson, 2006). Other scholars focus on teachers' understanding of what it means to teach science as inquiry, suggesting that there is some confusion about what this approach actually entails (Crawford, 2014; Gyllenpalm, Wickman & Holmgren, 2012; Hodson, 2014, Osborne, 2014). Some of the myths about inquiry-based teaching are that open inquiry is the golden standard toward which all science teaching should aim and that students must always pursue their own questions (Crawford, 2014). Osborne (2014) argues that confusion about the differences between *learning* science and *doing* science contributes to the confusion as teaching through inquiry often has several aims: learning content knowledge, learning about scientific inquiry and learning to do science (Hodson, 2014). Hodson (2014) points to the tension between learning to do science and learning science content knowledge; when students are involved in designing investigations, the content learning outcome is often uncertain. However, when they are not involved in planning and designing investigations, 'the activity ceases to be doing science in any meaningful sense' (Hodson, 2014, p. 2536). The challenge with teaching science as inquiry can be connected to an overemphasis on content knowledge in science education (Linder et al., 2011; Osborne & Dillon, 2008), and studies show that, with laboratory work, teachers most often aim to illustrate content knowledge (Högström, Ottander & Benckert, 2006; Ottander & Grelsson, 2006). Gyllenpalm (2010) argues that, as long as inquiry is primarily considered only a pedagogical strategy for learning content knowledge and not a goal in itself, inquiry-based teaching will be problematic.

In this thesis, I will argue that it can be fruitful to understand the challenges of teaching science as inquiry in light of the different cultures in biology (teacher) education. As in many other countries (Gyllenpalm, 2010), upper secondary science teacher education in Norway is located in different departments at the universities. These can be defined as different cultural institutions as they are characterised by various aims, values and practices (Corbo, Reinholz, Dancy, Deetz & Finkelstein, 2016; Gyllenpalm; 2010). Future biology teachers will also be influenced by the science/biology education they received at their specific schools – that is, they will be influenced by the culture of school science (Windschitl et al., 2008). In the

Swedish context, Gyllenpalm and Wickman (2011b) distinguish between four relevant cultural institutions for science teachers: scientific research, pure science courses (undergraduate courses), science education courses and school science. These are also relevant in the Norwegian context, focusing on biology education. However, the largest part of future upper secondary biology teachers' education takes place in science departments. Therefore, in line with Crawford (2014), I argue that an important area for further research is how undergraduate courses can contribute to prepare future teachers for teaching science as inquiry. Gyllenpalm and Wickman (2011a, 2011b) find that some terms related to inquiry, such as 'experiment' and 'hypothesis', are used differently in science education courses and in the pure science courses of science departments; they suggest that this contributes to conflating the methods of teaching with the methods of scientific inquiry. Thus, the important point is that different cultural institutions in science teacher education have different overall aims (Gyllenpalm, 2010; Osborne, 2014); scientific research aims to develop new knowledge and methods, while school science aims to teach established knowledge and methods. This makes science, and biology, education '*fundamentally different* from the activity of science' (Osborne, 2014, p. 580, emphasis in original).

Further, in line with the aim of developing new knowledge, universities will often seek to recruit new scientists. Traditionally, the aim of science education has also been to prepare students for further studies in science and, eventually, to recruit new scientists (Duschl, 2008; Osborne & Dillon, 2008). However, such a focus is not relevant for most students (Osborne & Dillon, 2008), and, today, the science education community considers scientific literacy its major goal (Linder et al., 2011; Sjøberg, 2009). The aims of upper secondary biology education are to prepare students for further studies in biology at the university level and to develop their scientific literacy (Utdanningsdirektoratet, 2013a). Upper secondary courses, such as biology, experience tension between two overall goals: recruiting scientists and developing students' scientific literacy. Larsson (2019) has investigated physics teachers' educations in Sweden, finding implicit assumptions that the goal of teaching physics is to create physics experts and that it is deemed unnecessary for students to learn how to teach physics. Molander and Hamza (2018) have found that the transformation of a person's professional identity from 'scientist' to 'science teacher' can be challenging. This points to difficulties facing upper secondary science teacher education programmes – which are divided across different cultural institutions – and suggests that science departments can play an important role in upper secondary science teacher education (Larsson, 2019).

Tensions between the different cultural institutions and their overall aims in science teacher education are also relevant for the specific aim of teaching through scientific practice, which is the primary focus of this thesis. In undergraduate biology education, the arguments for engaging in inquiry often focus on developing students' inquiry skills and preparing them for research careers (Basey, Mendelow & Ramos, 2000; National Research Council, 2003). In the school context, engaging in scientific practices primarily has value when it is used to develop students' knowledge about nature of science, a crucial aspect of scientific literacy (Erduran & Dagher, 2014).

At the time of writing this thesis, the school curriculum in Norway is in the midst of a renewal process. Subject renewal in biology is still in progress, but a committee hearing has suggested a core element: 'Practices and Reasoning in Biology' (Utdanningsdirektoratet, 2020). In this hearing, laboratory work, including the development of practical skills, was highlighted as a central part of Practices and Reasoning in Biology. This was also the case in the previous biology curriculum, under which students were supposed to learn how to plan and carry out investigations in the laboratory in all other curriculum areas (Utdanningsdirektoratet, 2013a). The new curriculum will similarly require students to be able to plan, carry out and present experimental data. However, modelling is also highlighted as an important part of Practices and Reasoning in Biology (Utdanningsdirektoratet, 2020).

Laboratory work and scientific practice are also important to undergraduate biology education, as exemplified in a bachelor's programme from the University of Oslo (2020a). In that programme, students are supposed to learn laboratory techniques, define problems and formulate hypotheses that can be tested in experiments. This goal is remarkably similar to the goal of upper secondary biology education mentioned above. This undergraduate education also emphasises the discussion and communication of results and, thereby, the role of language in scientific practice (University of Oslo, 2020c), which is another important focus in upper secondary biology education (Utdanningsdirektoratet, 2013a; Utdanningsdirektoratet, 2020). Therefore, even though there are tensions between these cultural institutions, their goals of engaging with scientific practices in the laboratory is remarkably similar.

1.1 Empirical context

The work presented in this thesis is based on collaboration between the Department of Biosciences and the Department of Education (Institute of Teacher Education and School Research) at the University of Oslo, aiming to better integrate these institutions when it comes to biology education. This collaboration began with the ‘Biology Teacher Survey’, which was administered to biology teachers in Norway. Initial analysis of the survey results revealed a need for more knowledge supporting teachers in teaching through scientific practices in the laboratory; it also pointed to the importance of undergraduate biology education for future biology teachers’ practices. Therefore, I began collaborating with an immunology professor, who taught a laboratory lesson in immunology as part of a bioscience BSc programme. This laboratory lesson and the collaboration with the professor is important empirical context for the work presented in this thesis. Even though this course was part of pure undergraduate biology education, many future biology teachers have also participated in the course, and it is, therefore, a good opportunity to model (a different kind of modelling) how laboratory work can be carried out for future biology teachers. I chose to collaborate with this professor because she expressed the intention to teach through scientific practice in the laboratory and was familiar with the upper secondary curriculum and the ideas behind the ‘Young Biologist’ curriculum area focusing on teaching biology as inquiry. According to Wong, Hodson and Yung (2009), professional scientists can help develop science educators’ views on scientific practice by providing authentic contexts. Thus, another reason I chose to focus on this laboratory lesson was that I saw it as an interesting opportunity to collaborate with a professional scientist to develop knowledge about teaching through scientific practice in the laboratory. Of course, professional scientists are not necessarily experts on knowledge about science, as Lakatos’s famous quote illustrates: ‘Most scientists tend to understand little more *about* science than fish about hydrodynamics’ (Lakatos, 1970, as cited in Osborne, 2014, p. 580). However, scientists are experts on laboratory practices and on disciplinary discourse (Airey & Linder, 2009). This professor is a leading scientist in the field of immunology, has authored over 130 scientific publications and has received several prizes for scientific innovation. Initially, her interest was in the antibody as a molecule (basic research), but this has gradually shifted toward antibody modelling and innovation to improve biological therapeutics.

The aim of the laboratory lesson was to illustrate the unique characteristics of antibodies, as well as their usefulness for developing biotherapeutics. Antibodies are also used in diagnostics, often together with *enzyme-linked immunosorbent assay* (ELISA). For instance, ELISA is used to diagnose diseases by detecting antibodies against against HIV and, more recently, SARS-CoV-2.

In the laboratory, the practical exercise involved investigating the sensitivity and specificity of different diagnostic tests (pregnancy and ovulation tests). The students were not supposed to deliver a standard laboratory report. Rather, each group made a ‘journal’ on the large, white, bench-protector paper placed on the laboratory benches. In these journals, they were supposed to define important immunological concepts and make a drawing of the principle behind the diagnostic tests. As there was no authorised representation of the molecular design of the pregnancy tests, the students had to make a model of the design themselves. This can be characterised as a modelling activity, but it also resembles the engineering practice of ‘designing solutions’ (National Research Council, 2010), and, thereby, it reflects the professor’s practice as a researcher focusing on antibody modelling and innovation to improve biological therapeutics. In a pilot case study, we observed that many students struggled to make their own representations, and the professor was probably not aware of how challenging this modelling activity was for the students. Therefore, the instructor–researcher collaboration focused on supporting students in constructing their own representations.

1.2 Aim of the thesis and rationale behind the studies

The overall aim of this thesis is to explore challenges and opportunities of teaching and learning through scientific practices in the laboratory in biology education, with a main emphasis on modelling through representation construction as a scientific practice.

The following research questions are this project’s focus:

1. What are upper secondary biology teachers’ reported practices and challenges when it comes to teaching through scientific practices in the laboratory, and what is the role of biology teacher education in preparing teachers for laboratory work?
2. How can a focus on modelling through representation construction as scientific practice support biology students’ reasoning in the laboratory?

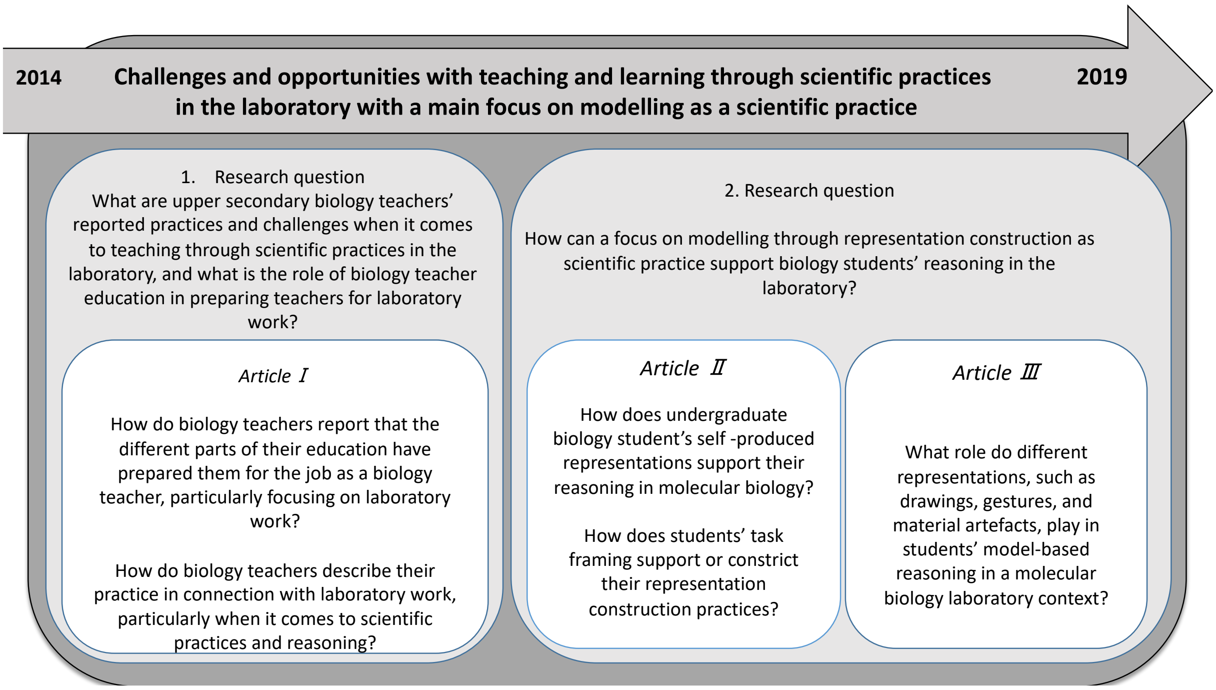

Figure 1. The overall aim and research questions, alongside the research questions for Articles I–III.

In the following paragraphs, I will describe the rationale behind each of the studies presented in this thesis. The two main research questions given above represent two phases of the work. In the first phase, an important goal was to investigate upper secondary biology teachers' reported practices and challenges when it comes to teaching through scientific practices in the laboratory, as well as the role biology teacher education plays in preparing teachers for laboratory work. In line with the didactics tradition (Wickman, Hamza & Lundegård, 2018, 2020), this goal was motivated by a belief in the value of teachers' experience and wisdom. I believe, following Hamza, Palm, Palmqvist, Piqueras and Wickman (2018), that researchers have as much to learn from teachers' practice as teachers have to learn from researchers' results. Therefore, teachers' existing practices and challenges must be taken into account when developing didactical knowledge (Wickman, Hamza & Lundegård, 2018).

Much previous research about teaching science as inquiry has focused on science teachers (Bjønness & Kolstø, 2015; Gyllenpalm et al., 2012; Knain & Kolstø, 2011). Further, based on knowledge (and experience) with the various cultural institutions of biology teacher education, we were interested in the role biology education plays in preparing biology teachers to teach through scientific practice in the laboratory. The aim of Article I was, therefore, to understand biology teachers' challenges with laboratory work in light of tensions between different cultures in biology teacher education. The following research questions were addressed.

- How do biology teachers report that the various parts of their educations have prepared them for their jobs, particularly focusing on laboratory work?
- How do biology teachers describe their practice in connection with laboratory work, particularly regarding scientific practice and reasoning?

Some findings from this article were especially important in giving direction to this thesis. First, biology teachers reported that they lacked knowledge about biology didactics, in general, and particularly about how to design teaching in the laboratory. This pointed to the importance of developing knowledge about how to teach through scientific practices in the laboratory. Further, many biology teachers reported that their experiences with laboratory work in undergraduate biology education were very important for their practice in the laboratory as biology teachers. This motivated us to focus on laboratory work in undergraduate biology education. Finally, the results indicated that many biology teachers struggled with designing teaching contexts appropriate for addressing aspects of scientific practices in the laboratory.

The second phase of the work focused on investigating practice in the laboratory in undergraduate biology education. Particularly, I focused on how a focus on modelling through representation construction as scientific practice can support biology students' reasoning in the laboratory? I present two case studies focusing on students' reasoning while constructing representations. The empirical context of the case studies was the instructor–researcher collaboration focusing on supporting students' representation construction, as mentioned in the empirical context (see also Chapter 4). Article II presents a case study from a laboratory lesson in 2016. The following research questions guided the work in this article.

- How do undergraduate biology students' self-produced representations support their reasoning in molecular biology?
- How does students' task framing support or constrict their representation construction practices?

Article II revealed the fruitfulness of focusing on modelling through representation construction in the laboratory, but there were also some challenges. Before a laboratory lesson in 2019, we continued the collaboration, investigating how to support students' representation construction (see Chapter 4). Therefore, Article III sought further insight into how students' representation construction can be supported in the laboratory – particularly considering the role of drawings, gestures and material artefacts. The following research question guided Article III.

- What roles do different representations, such as drawings, gestures and material artefacts, play in students' model-based reasoning in a molecular biology laboratory context?

1.3 Biology education in a Norwegian context

Upper secondary teacher education in Norway consists of education from different cultural institutions. As mentioned above, in the Swedish context, Gyllenpalm and Wickman (2011b) distinguish between four relevant cultural institutions for science teachers: scientific research, pure science courses (undergraduate courses), science education courses and school science. These are also relevant in the Norwegian context focusing on biology education. *Scientific research* refers to research at a university level through which the aim is to gain new knowledge and new methods. *Pure science courses* (undergraduate science courses) are held in university science departments and are often led by active researchers. Although these courses are taken by many future biology teachers, they do not focus on teacher education. *Science education courses* (science didactics) are often held in a different university department and taught by science education researchers and/or experienced teachers. They focus on science teachers' professional knowledge, asking 'What do science teachers need to know?' (Wickman, Hamza & Lundegård, 2018, 2020). Finally, *school science* is part of the school science culture and refers to science subjects in lower and upper secondary school. The term *school biology* can be used to refer to the part of the school science culture that is only concerned with biology. In lower secondary school and the first year of upper secondary school, biology is integrated with general science courses, and students can choose whether to continue with biology courses in the second and third years of upper secondary school.

There are two main paths to becoming a biology teacher in Norway: a five-year, integrated teacher education programme and a five-year master's programme in biology plus a year of teacher education (six years total) – that is, a practical–pedagogical education (praktisk–pedagogisk utdanning; PPU). Both paths combine courses relating to the different cultural institutions mentioned above. Most of the education will occur in science or biology departments, and those who pursue master's degrees in pure biology will receive a larger proportion of their education from science/biology departments. Such students will often become part of the culture of scientific research as they work on their master's theses. Figure 1 overviews the two paths to becoming a biology teacher, exemplified by the programmes at the University of Oslo (2020a, 2020d). Note that the master's programme in biology is a separate five-year programme and leads to a master's degree in biology. Those who would like to become teachers can add to this education by taking the PPU course.

<table>
<tr><th>Semester</th><th rowspan="3">Integrated teacher education program (5 years)</th><th>Master program in biology and Practical–pedagogical education (6 years)</th></tr>
<tr><td>12</td><td rowspan="2">Practical–pedagogical education (PPU) at The faculty of educational sciences (UV)</td></tr>
<tr><td>11</td></tr>
<tr><td>10</td><td rowspan="3">Master degree in science or science education</td><td rowspan="4">Master in biology (Department of biosciences)</td></tr>
<tr><td>9</td></tr>
<tr><td>8</td></tr>
<tr><td>7</td><td rowspan="2">Courses in science education at the faculty of mathematics and natural sciences (MatNat) and in pedagogy at The faculty of educational sciences (UV)</td></tr>
<tr><td>6</td><td rowspan="6">Courses in science, primarily in biology, at the faculty of mathematics and natural sciences (MatNat)</td></tr>
<tr><td>5</td><td rowspan="5">Courses in science at the faculty of mathematics and natural sciences (MatNat)</td></tr>
<tr><td>4</td></tr>
<tr><td>3</td></tr>
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Figure 2. Overview of the two paths to becoming a biology teacher in Norway

2 Theoretical background

2.1 Culture and language

An important theoretical assumption in this thesis is that it impossible to separate science learning from learning a specialised scientific language (Lemke, 1990; Norris & Phillips, 2003; Wellington & Osborne, 2001). In this thesis, I combine theoretical perspectives from sociocultural theory (Linell, 1998; Vygotsky, 1978) and systemic functional linguistic theory (and social semiotics) (Halliday, 2003, 2013; Kress, Jewitt & Tsatsarelis, 2001). Wells (1999) describes the complementary contributions of Vygotsky and Halliday to the centrality of language in learning, both of whom point to the importance of the cultural context for learning and see language as a meaning-making resource. Vygotsky's (1978) contribution importantly provides an understanding of the inseparable relationship between cognition and words; thoughts come into expression through words. Therefore, learning can be investigated by directing the analytical focus towards students' social interactions as situated in cultural contexts. We do not have direct access to students' minds (Linell, 1998), and it is, therefore, important to understand students' behaviours in connection with their social and cultural contexts.

Halliday's (2003, 2013) systemic functional linguistic theory of language sees language as a semiotic tool – as a resource for meaning-making. Therefore, when we are learning language, we are also learning *through* language. One of Halliday's important contributions is the understanding of how the semantic structure of a language constitutes a culture. We learn through language as we interpret text and context in light of each other. A text is interpreted through expectations gained through experiences in similar situations.

In this thesis, I focus on different cultural institutions relevant to biology education and biology teacher education. Cultural institutions can be defined as systems of shared beliefs, communicative patterns, values, practices and material artifacts that the members of the institution 'use to cope with their world and with one another, and that are transmitted from generation to generation through learning' (Corbo, Reinholz, Dancy, Deetz & Finkelstein, 2016, p.1). The term 'discourse' is closely related to culture, with a primary focus on language use. Gee (2008) defines 'Discourse' as follows.

A Discourse with a capital 'D' is composed of distinctive ways of speaking/listening and often, too, writing/reading coupled with distinctive ways of acting, interacting, valuing, feeling, dressing, thinking, believing, with other people and with various objects, tools, and technologies, so as to enact specific socially recognizable identities engaged in specific socially recognizable activities. (p. 155)

The different cultural institutions in biology education are, therefore, characterised by different Discourses. The relationship between situation, text and culture in Halliday's theory can be illustrated by an onion model. Figure 3 below is adapted from an onion model presented by Knain (2015, p. 11). However, I have placed two onion models side by side to illustrate the challenges of transforming genres, texts and practices between Discourses (and cultural institutions), as this is important in my thesis. The figure also illustrates that one aim of the school science Discourse is future participation in scientific Discourse. However, I am also interested in how participation in scientific Discourse prepares a student to become a teacher; therefore, in Figure 3, the arrows point both ways.

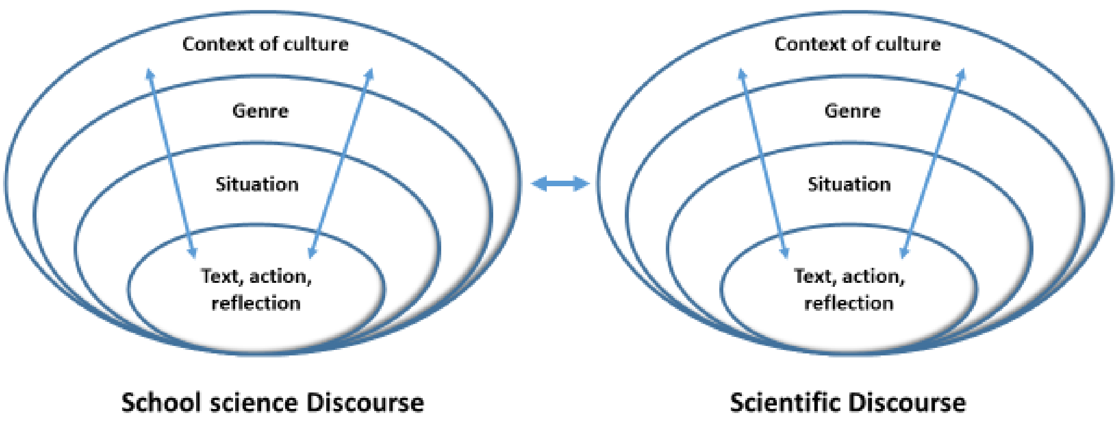

Figure 3. Onion model showing the school science and scientific Discourses

Knain (2015) exemplifies the relationship between text and context using an experimental report. Looking at one onion model, the two inner circles can illustrate a particular report (text) in a specific situation (context). The 'up' arrows illustrate the point at which there would be no genre or Discourse without the individual texts. The 'down' arrows illustrate that the cultural context of which texts are a part is an important component of how texts are interpreted and understood; they represent meaning potential at the cultural level. As Figure 2 shows, *genre* is an intermediate level between situation and culture. The notion of 'practices' is also closely related to genres (Knain, 2015), and, in my thesis, the ideas of genre and practices will be considered as closely connected concepts.

The onion models in Figure 3 clearly indicate that context is an important part of learning. Drawing on perspectives from Halliday (2013), Knain sees teaching as the 'task of designing contexts appropriate for students' learning' (Knain, 2015, p. 48). Regarding higher education, Airey and Linder (2009) frame science learning as participation in the disciplinary discourse and state that the aim of university science is, thus, for students to become 'fluent in a system of semiotic resources' that characterises the disciplinary discourse (p. 44).

Based on the relevant cultures and Discourses in biology teacher education, I have designed Figure 4 to illustrate the relationship between these Discourses. This figure is also inspired by the different cultures in science/biology education, as described by Gyllenpalm and Wickman (2011b).

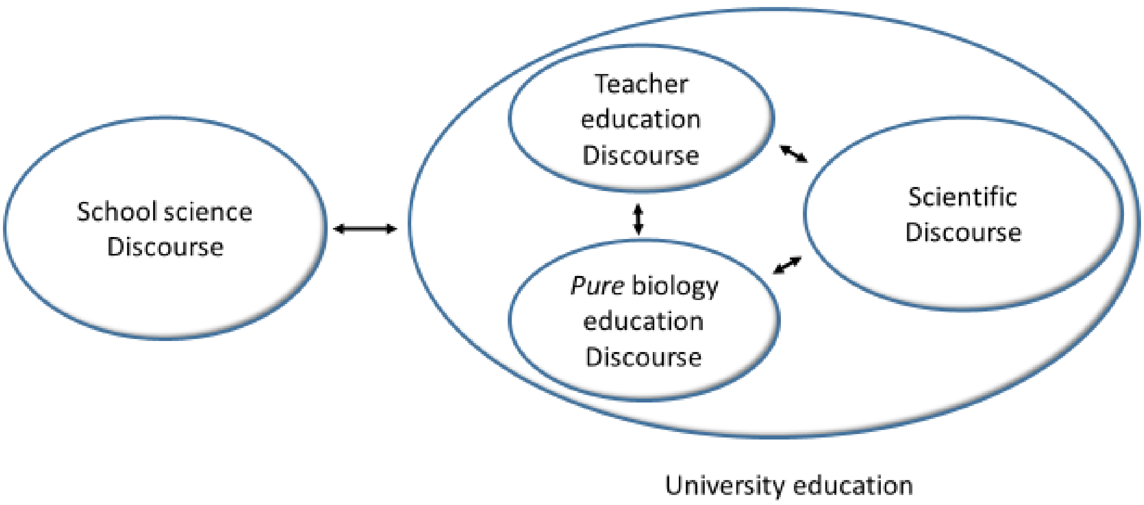

Figure 4. Relevant Discourses in biology teacher education

Future biologists and biology teachers will travel through these Discourses as part of their educations. They will begin in the school science Discourse (and school biology) before continuing with the pure biology education (undergraduate biology education) and scientific

Discourse. Further, biology teachers will pass through the (science) teacher education Discourse before they start working in the school environment again.

2.2 Social semiotics

Scientific language consists of several different representational modes, such as written and spoken language, drawings, images, gestures, mathematics and so on. According to Kress et al. (2001), linguistics can only offer a partial account of learning in science. To understand scientific meaning making, it is, therefore, necessary to include all signs, which is accomplished through the discipline of *semiotics*. In social semiotic theory, Lemke (1990) and Kress and colleagues (Kress, 2010; Kress & van Leeuwen, 1996) have developed Halliday's ideas further to include all signs. Social semiotic theory deals with meaning in all its appearances (Kress, 2010) and can, therefore, provide a language for describing communication through various representational modes. The 'sign' is the fundamental unit in social semiotic theory and, according to Kress (2010), signs are made and not passively reproduced (Kress et al., 2001). Rather, sign making is always motivated by and based on the sign maker's interest in the situation. *Interest* means that all the experiences the sign maker has had in life are made into a coherent entity that has a particular focus in a particular moment. The question is, what is critical for the sign maker at this moment? When students' texts vary, this variation is an expression of the students' differing interests, and their sign making is evidence of their learning what 'being scientific' (Kress et al., 2001, p. 132) means.

According to Airey and Linder (2009), the disciplinary Discourse consists of different representations, tools and activities made up of different modes, such as images, gestures, working practices, apparatuses and so forth. In this thesis, I define representations as 'signs that stand for something that will be meaningful to someone' (Hubber & Tytler, 2013, p. 111). Thus, representations are a broad group of semiotic resources, including spontaneous talk, metaphors, gestures and manipulation of artefacts (Hubber & Tytler, 2013). These can be defined as different modes of representations. Different modes of representations have different potentials and limitations for learning (Kress et al., 2001) or 'different possibilities for representing disciplinary ways of knowing' (Airey & Linder, 2009, p. 29). According to Airey and Linder (2009), students must experience a 'critical constellation of modes' to access disciplinary knowledge holistically. This is analogous to the necessity of viewing a physical object from different angles (facets) to really understand the object (Airey & Linder, 2009). The mathematical mode gives access to some facets, while experimental work gives access to others. Similarly, each concept has a critical constellation of semiotic resources the students must grasp – again to understand the concept holistically (Airey & Linder, 2017; Tang, Tan & Yeo, 2011). A concept can thereby be defined as the sum of its representation (Givry & Roth, 2006).

2.3 Science studies (philosophy of science)

The notion of scientific practice has its origin in the field of science studies (National Research Council, 2012). According to Hodson (1998), laboratory work should be 'grounded in a view of science that is philosophically sound' (p. 93). As this thesis is concerned with teaching through scientific practices in the laboratory, it is important to include a section focusing on research from the field of science studies (philosophy of science). According to Duschl and Grandy (2013), three movements in the philosophy of science characterised the twentieth century. The first is logical positivism, and 'the scientific method', which often defines how laboratory work is performed in the culture of school science, is clearly underpinned by this tradition (Kind et al., 2011). The second is the history-based view of theory development and conceptual change, which has been influenced by philosophers, such as Lakatos and Kuhn, who characterise scientific progress in terms of paradigm shifts, research programmes and heuristic principles (Duschl & Grandy, 2013). Important contributions from this second movement are the critique against a single scientific method accounting for theory development (Feyerabend, 1975) and the idea that observation is not an unproblematic concept. The third movement is the 'naturalized philosophy of science' (Duschl & Grandy, 2013). Here, a naturalistic perspective is taken to account for the growth of scientific knowledge by looking into actual social and cognitive practices and the material world of scientists. The focus on model-based scientific practices is grounded in this movement (Duschl & Grandy, 2013).

Laboratory studies are science studies focusing particularly on scientists' knowledge construction in laboratories. They have helped shift the focus from being solely on the experiment to being on the full spectrum of laboratory activities involved in producing knowledge (Knorr-Cetina, 1995). Knorr-Cetina (1999) defines laboratories as 'reconfigurations of natural and social orders' (chapter 2, section 2.1) and goes on to say:

> Laboratories are based upon the premise that objects are not fixed entities that have to be taken 'as they are' or left by themselves. In fact, one rarely works in laboratories

> with objects as they occur in nature. Rather, one works with object images or with their visual, auditory, or electrical traces, and with their components, their extractions, and their 'purified' versions. (chapter 2, section 2.1)

This illustrates how important representations are to knowledge construction in laboratories.

Other studies have similarly highlighted the importance of representations in scientists' knowledge-building practices (Latour, 1999; Latour & Woolgar, 1986; Nersessian, 2008). Scientists work with inscriptions (materialised representations) of various types, and these are translated through 'cascades of inscriptions' into more abstract representations, such as graphs (Latour, 1999; Roth & McGinn, 1998).

It has been argued that, in science education, conceptions about nature of science are based primarily on perspectives from physics (Duschl & Grandy, 2013; Osborne, 2014). Knorr-Cetina (1999) makes an important contribution by focusing on the differences between the epistemic culture in high-energy physics laboratories and molecular biology laboratories. As this thesis is concerned with biology education, I will draw on Knorr-Cetina's (1999) characterisation of the epistemic culture in the molecular biology laboratory to explore opportunities for teaching through scientific practice in the laboratory. While the epistemic culture of high-energy physics is characterised by a 'loss of the empirical', where experience provides an 'occasional touchstone that hurls the system back upon itself', laboratory work in molecular biology can be characterised as a benchwork style of doing science with object-oriented processing (Knorr-Cetina, 1999, section 4.1). The epistemic culture of molecular biology is based on maximising its contact with the objects and materials in question. Objects in molecular biology are subject to 'almost any imaginable intrusion' (Knorr-Cetina, 1999, section 4.3). They are smashed into fragments, reduced to extractions, purified, washed, frozen, heated, counted, pipetted, placed in a centrifuge and so on. These intrusions are organised sequentially into steps, summarised in protocols. In fact, Knorr Cetina (1999) argues that what are often called 'data' have the characteristics of signs, as they are 'technically generated indicators pointing to an underlying reality of molecular processes and events' (section 4.1). Similarly, data can be included in the definition of representation applied in this thesis.

3 Review of relevant research

In this chapter, I will review some research relevant to the overarching aim of this thesis. As my project takes place at the intersection of several areas, this review will also focus on research from those areas: (3.1) teaching science as inquiry, (3.2) modelling as a scientific practice, (3.3) nature of science, (3.4) laboratory work in educational contexts and (3.5) learning with representations.

3.1 Teaching science as inquiry

Inquiry-based teaching has been recommended as a central method for science teaching for a long time (National Research Council, 1996, 2003; Rocard et al., 2007) and has recently been replaced by the notion of 'scientific practices' in the US Framework for K–12 Science Education (National Research Council, 2012). This framework is influential worldwide, as well as for the ongoing curriculum reform in Norway. The eight scientific practices in this framework are: asking questions, developing and using models, constructing explanations, engaging in arguments from evidence, planning and carrying out investigations, analysing and interpreting data, using mathematical and computational thinking and obtaining, evaluating, and communicating evidence. A distinguishing feature of this framework (National Research Council, 2012) is a shift from having students formulate and test hypotheses towards an increased focus on scientific modelling and argumentation (Crawford, 2014). Further, compared to previous writings about teaching science as inquiry, there is an increased focus on integrating content knowledge with scientific practices (Crawford, 2014).

Teaching science as inquiry is closely related to the idea of teaching through scientific practices (Crawford, 2014) and the research on teaching science as inquiry is, therefore, relevant for this thesis. The effectiveness of inquiry-based teaching has been previously documented (Furtak, Seidel, Iverson & Briggs, 2012). However, it is also a theme for continued discussion (Sjøberg & Jenkins, 2020) and is complicated by the fact that this teaching approach is defined in different ways and has several potential learning outcomes (Crawford, 2014). Still, research has increasingly focused on *how* teaching science as inquiry can be supported rather than whether it is effective (Crawford, 2014).

Several scholars have made different classifications to characterise the levels of guidance teachers provide under the existing traditions. In a Swedish context, Gyllenpalm, Wickman and Holmgren (2012) have constructed a taxonomy of instructional approaches in which inquiry is divided into three tasks that can either be given or open: question/problem, method and answer/result. In expository and discovery instruction, all three aspects are given – the typical 'cookbook' instruction that often characterises laboratory work. However, in discovery instruction it is played out as if these things are not planned in advance and the students are led to believe that they discover the results. In both guided inquiry and open inquiry, the answer is typically not found in a textbook. Further, while both the question and method are given in guided inquiry, only the question is given in inquiry instruction, and, in open inquiry, the question, method and answer are all open and are not given to students. Research shows that many teachers tend to associate inquiry with hands-on activities, freedom and spontaneity (Gyllenpalm et al., 2012). However, studies also indicate that teachers must provide scaffolding for inquiry-based approaches to succeed (Bjønness & Kolstø, 2015).

Attempting to make pre-service science teachers implement model-based inquiry in science methods courses, Windschitl et al. (2008) have found several beliefs about scientific inquiry that stand in the way of a model-based mode of thinking about inquiry. For instance, Windschitl and Thompson (2006) have determined that pre-service teachers believe scientists' claims are always based on direct observations. Some teachers think 'making claims that attempt to link data with unobservable processes [is] recklessly speculative'(Windschitl et al., 2008, p. 949). Further, by investigating teachers' practices, the same authors have found that the 'hypothesis' concept is used like guessing in relation to outcomes that are not part of a larger explanatory framework or model. Teachers tend to base their inquiries on what appears testable, and they seem to believe that experimentation is the only valid method of investigation (Windschitl & Thompson, 2006; Windschitl et al., 2008). These authors also report that one of the major challenges to getting teachers to employ model-based inquiry is to make them think about testing ideas rather than testing only predictions or variables (Windschitl et al., 2008). Bjønnes and Knain (2018) explore how a science teachers' beliefs about nature of science connect with other beliefs in a situated practice. They found that what seemed to be positivist beliefs about nature of science were affected by concerns about the students as well as other pedagogical considerations, pointing to the complex relationship between teachers' understanding of nature of science, and their teaching practices.

3.2 Modelling as a scientific practice

Developing explanations in the form of models is often presented as the major aim of science (Nersessian, 2008). Several scholars, therefore, argue that models should play a central role in science education, including at higher levels (van Driel, Krüger & zu Belzen, 2019; Gilbert & Justi, 2016). In upper secondary physics, Angell et al. (2008) argue for an empirical–mathematical modelling approach to physics instruction and suggest that physics students should obtain a 'view of nature of physics as a modelling enterprise' (p. 258). However, in an attempt to make physics teachers apply an empirical–mathematical modelling approach, Angell et al. (2008) have found that teachers pick ideas they consider interesting and adapt them to their own educational practices. Thus, Angell et al. (2008) highlight that, to develop physics education focusing on modelling, teaching about models is as necessary.

In the literature on modelling, scholars often differentiate between using models as media ('models of') and using models as research tools ('models for') (Upmeier zu Belzen, van Driel & Krüger, 2019). 'Models as media' refers to using models to communicate science content knowledge to students, which is the focus of much research in the modelling literature (Grunkorn, zu Belzen & Kruger, 2014). On the other hand, when models are used as research tools, the link to scientific practice is clear, and this point has gained increased attention recently (Upmeier zu Belzen et al., 2019). To study teachers' and students' modelling competence, a framework has been developed, which sees modelling competence as the ability to reflect on models and modelling: 'the ability to gain insightful knowledge with models, to be able to judge models with regard to their purpose, and to reflect on the process of gaining knowledge through models and modelling' (Upmeier zu Belzen et al., 2019, p. 11). Research has shown that pre-service biology teachers can be successfully trained via explicit reflection on the framework for modelling competence, which ultimately leads to increased modelling competence (Günther, Fleige, zu Belzen & Krüger, 2019). However, according to Günther et al. (2019), the students did not benefit from the teachers' increased competence. This may suggest that, though explicit reflection in teacher education is important, experienced practice is also vital. Windschitl et al. (2008) suggest that model-based inquiry makes visible some key epistemic traits characterising scientific knowledge – that it is revisable, testable, generative, explanatory and conjectural (p. 943). Further, studies have also shown that a modelling approach (including explicit reflection) can contribute to developing students' epistemological understanding of scientific inquiry (Lehrer, Schauble & Lucas, 2008; Schwarz & White, 2005).

3.3 Nature of science

One important aim of engaging in scientific practice is that it may contribute to developing knowledge about the procedural and epistemic construct involved in scientific knowledge production – that is knowledge about science (Osborne, 2014). Several different concepts have been used to capture knowledge about science. ‘Ideas of science’ (Osborne et al., 2003), ‘features of science’ (Matthews, 2012) and the ‘nature of scientific inquiry’ (Lederman & Lederman, 2014) are examples, but the most widely used concept is, perhaps, nature of science (Erduran & Dagher, 2014; Lederman & Lederman, 2014). One of the leading approaches to teaching about nature of science is the consensus approach, which, according to Duschl and Grandy (2013), is mainly inspired by the second movement in the philosophy of science, defined in Section 2.3. The consensus approach is based on a list of principles or statements on which philosophers of science largely agree (Lederman, 2002; McComas & Olson, 1998). For instance, one of the important principles is that there is no one scientific method, as pointed out by Feyerabend (1975). Another crucial principle is that scientific knowledge is tentative, theory-laden and socially and culturally embedded (Lederman & Lederman, 2014). However, this approach has been criticised for simply asking students to accept a list of statements about science, illustrated through activities with little relation to science: ‘Domain-general characteristics are insufficiently tied to the rich context that might exemplify specific procedural and epistemic effects’ (Osborne, 2014). The consensus approach has also been criticised for making an artificial distinction between the nature of scientific knowledge and scientific inquiry (Dagher & Erduran, 2016; Duschl & Grandy, 2013; Irzik & Nola, 2014) and for focusing only on domain-general aspects of science that are primarily based on perspectives from physics (Duschl & Grandy, 2013, Osborne, 2014). Though the list of principles in the consensus view does describe domain-general characteristics, a recent book on biology education (Kampourakis & Reiss, 2018) also uses it to inform teachers about how they should teach the nature of biology (Lederman, 2018). However, scholars have highlighted the need for more research into the domain-specific aspects of nature of science (Erduran & Dagher, 2014) and scientific reasoning (Fischer, Chinn, Engelmann & Osborne, 2018).

Teachers’ challenges with teaching through inquiry have been related to their limited understanding of nature of science. Indeed, a significant amount of research has been conducted on teachers’ and students’ understanding of nature of science. This research shows that both teachers and students lack an advanced understanding of nature of science and that students must reflect explicitly on nature of science to develop a sophisticated understanding of it (Lederman & Lederman, 2014). This implies that students will not come to understand nature of science simply by doing science (Lederman & Lederman, 2014). However, much of this research is based on investigating students and teachers' views on nature of science through surveys or interviews (Lederman & Lederman, 2014). Van Eijck, Hsu and Roth (2009) are critical of the idea that students *have* a particular understanding of nature of science and that this understanding can be measured in a decontextualized manner. Further, they are critical towards assessments aiming at measuring this understanding verbally when science is multimodal in nature. They state that 'Verbally articulated knowledge only reflects a particular part of knowledge constructed in a particular setting and focusing on this part inherently brings about bias in students' "images of science"' (van Eijck et al., 2009, p. 615). They also refer to studies focusing on gestures, such as that of Givry and Roth (2006), which has demonstrated that it is necessary to focus on several representational forms to fully understand students' conceptions of science.

According to Duschl and Grandy (2013), explicitly teaching about nature of science means engaging students in authentic scientific practices – having them learn about nature of science *through* experience and not just by accepting a list of statements. For instance, Duschl and Grandy (2013) also point to the research programme of Lehrer and Schauble, who focus on engaging students with scientific practices, such as modelling (Lehrer & Schauble, 2008, 2012). This is in line with the my view on teaching nature of science in this thesis.

3.4 Laboratory work in educational contexts

In biology, laboratory work is a central approach at both the undergraduate and upper secondary levels (American Association for the Advancement of Science, 2010; Ottander & Grelsson, 2006; Turner et al., 1998). A large European project (Psillos & Niedderer, 2003) has determined that laboratory work in upper secondary and undergraduate science education is performed similarly across countries, with students following teachers' instructions (Séré et al., 1998). One of the recommendations based on this project is that teachers must differentiate between different goals in the laboratory (Séré, 2002). However, research on science teachers' aims with laboratory work shows that they largely intend to illustrate content knowledge, develop practical skills and stimulate interests (Högström et al., 2006; Ottander & Grelson, 2008; Welzel et al., 1998). A case study with four experienced upper secondary biology teachers in Sweden has shown that they did not see the aim of learning about scientific inquiry as important. This study also indicates that the laboratory report was an important part of laboratory work in biology, and that only laboratory work that resulted in laboratory reports was actually assessed (Ottander & Grelson, 2008).

In undergraduate biology education, a comparison between traditional lab courses and lab courses including authentic research experience shows that students participating in the latter type developed more positive attitudes towards authentic research and an increased interest in pursuing a research career (Brownell, Kloser, Fukami & Shavelson, 2012). Interestingly, this study also refers to the confusion about what ‘inquiry’ means and chooses the notion of ‘authentic research experiences’ instead of inquiry to avoid confusion. This points to slightly different interpretations of what it means to teach science as inquiry at the undergraduate level in biology and in a school settings.

According to Millar, Tiberghien and Le Maréchal (1998), the major aim of laboratory work is to connect ideas with observations. Attempting to investigate the effectiveness of laboratory work, Abrahams and Millar (2008) analyse a sample of 25 laboratory lessons in English secondary schools. Based on observational field notes and interviews, they indicate that laboratory work is effective in terms of having students do what they are supposed to do with physical objects. However, it is less effective in terms of having the students use scientific ideas, and there is little reflection on the collected data. Abrahams and Millar (2008) also show that learning about scientific inquiry or nature of science is not usually an aim of laboratory work.

Hofstein and Kind (2012) have reviewed the research published on laboratory work from 1960 to 2012, concluding that a major challenge is the focus on manipulating equipment at the expense of manipulating ideas. They argue that a focus on argumentation can provide a new rationale for laboratory work (Hofstein & Kind, 2012). In a study examining how the laboratory environment can affect and support students’ argumentation, Kind et al. (2011) investigate students’ argumentation in connection with different laboratory tasks. They hypothesise that laboratory work can support students’ argumentation because students generate their own data in the laboratory. This can provide a stimulus for debate as data interpretation prompts argumentation. However, Kind et al. (2011) find that, when their sampled students actually carried out the experiment, the task led to less argumentation. They, therefore, suggest that one reason it is challenging for students to engage in argumentation in connection with laboratory work is that students tend to take data as ‘true’.

3.5 Learning with representations

As scientific language is multimodal in nature (Lemke, 1990), learning with multiple representations is important for learning science. Several studies in a book concerning multiple representations in biology education (Treagust & Tsui, 2013) demonstrate the importance of such representations to learning biology (Roth & Pozzer-Ardenghi, 2013; Srivastava & Ramadas, 2013; Yarden & Yarden, 2013). For instance, in a study examining undergraduate students' understanding of the three-dimensional structure of DNA, Srivastava and Ramadas (2013) illustrate the importance of gesture and analogy for linking several different representations of DNA and, thereby, improving students' understanding of DNA structure. Using animations, Yarden and Yarden (2013) investigate how the biotechnological method *polymerase chain reaction* (PCR) is taught and learned, finding that animations are a more effective approach than still images. A major challenge to understanding biotechnology is understanding the methods involved (Falk, Brill & Yarden, 2008), which often require advanced equipment unavailable to students. However, research also indicates that actual experience of the material equipment is crucial to understanding the methods and the representations that result from their use. Representations in biology exist along a continuum of increasing abstraction, from photographs and naturalistic drawings to diagrams and graphs (Roth & Pozzer-Ardenghi, 2013). Scholars agree that major barriers to students learning science are grasping how to link different modes of representations and mastering the transformations between representations (Tang et al., 2011). Roth and Bowen (2001) investigate how professional scientists read graphs, finding that their interpretations of those graphs are tied to an embodied practice and are dependent on the scientists' familiarity with the phenomena behind the graph, a point also made by Knorr-Cetina (1999). Further, Bowen and Roth (1998) have determined that the foundation that helps scientists interpret graphs is missing from biology lectures at the undergraduate level. Gestures are important semiotic resources in biology lectures at different educational levels (Pozzer-Ardenghi & Roth, 2005). Also, Roth and Tobin (1997) suggest that students' difficulties in understanding physics lectures arise because they experience the translations between different representations as being ontologically distinct, while, in scientific practice, they argue, the translation between a phenomena and its re-representations are smooth (Roth & Tobin, 1997). Roth and Lawless (2002a) argue in favour of 'the tremendous opportunities that lie in asking students to describe and explain phenomena in the presence of materials and equipment' and that gestures can provide a bridge between physical experiences and abstract theoretical language (Roth & Lawless, 2002a, 2002b). According to Airey and Linder (2009), more research must be conducted concerning how students come to understand the critical constellation of semiotic resources (representations) necessary to holistically comprehend disciplinary ways of knowing in higher education. Some research along these lines has already been conducted in the physics field (Fredlund, 2015), but more is necessary in biology.

4 Methodology

In this chapter, I will focus on the methodologies applied in this thesis. First, I will give an overview of the different methods applied and how they go together, and, in Section 4.1, I will briefly describe the survey and group interview. In Section 4.2, I will provide more information about the instructor–researcher collaboration, which is the empirical background of the two case studies, and, in Section 4.3, I will describe my analytical procedures. Finally, in Section 4.4, I will discuss the trustworthiness of the research.

The aim of this thesis was to explore the challenges and opportunities of teaching and learning through scientific practices in the laboratory in biology education, and my main focus was on *practice* in the laboratory, which is the unit of analysis in Articles II and III. However, Article I focuses on how upper secondary biology teachers describe their own *practice* in the laboratory. Even though undergraduate biology education and upper secondary biology education belong to different cultural institutions, I will argue that laboratory work at these levels likely share many of the same challenges and opportunities. Therefore, the applied methodologies represent a form of triangulation in relation to the overall aim of exploring the challenges and opportunities of teaching and learning through scientific practices in the laboratory (Creswell & Miller, 2000). For instance, laboratory work, in both upper secondary school and introductory courses at the bachelor's level, aims to teach existing knowledge and methods and, is, therefore fundamentally different from laboratory work in scientific research. The fundamentally different goals of biology *education* and biology *research* pose challenges for laboratory work in educational settings (Osborne, 2014), and these challenges are shared by upper secondary and undergraduate biology education. Further, the goals of engaging with scientific practices and laboratory work are remarkably similar in upper secondary and undergraduate education, focusing on laboratory skills, planning and carrying out investigations and communicating results (University of Oslo, 2020a; Utdanningsdirektoratet, 2013a; 2020). Clearly, however, there are also important differences between laboratory work in undergraduate and upper secondary biology education. For example, undergraduate courses are often taught by practicing scientists, who are generally responsible for the laboratory courses in their fields of expertise, as exemplified by the professor and the immunology laboratory course in this thesis.

On the other hand, as the different studies in this thesis focus on laboratory work across different cultural institutions in biology (teacher) education, the findings can hopefully contribute to improving biology (teacher) education as a whole, in addition to supporting transitions between different parts of biology education. Figure 5 overviews the methodologies and analytical approaches applied in this thesis.

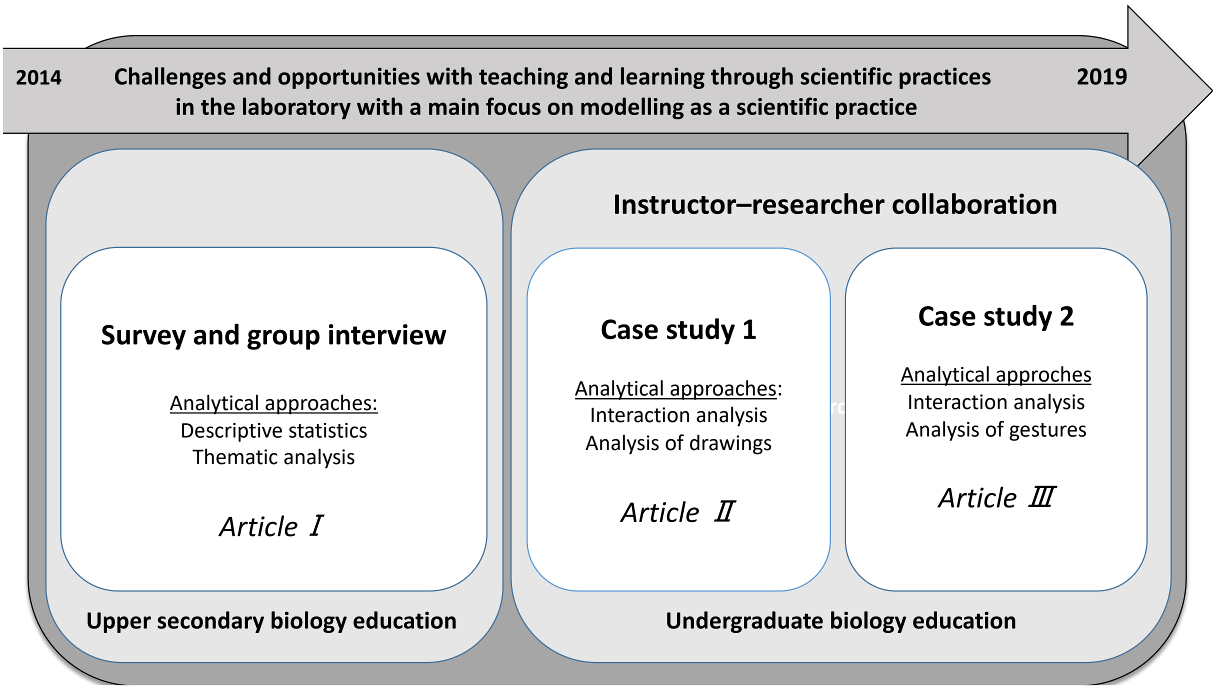

Figure 5. Overview of the methodologies and analytical approaches applied in this thesis

As described in Section 1.2, the two overall research questions guided two phases of the work, but they also guided the chosen methodologies. In the first phase, an important initial step was investigating upper secondary biology teachers' practices and challenges when teaching through scientific practices in the laboratory, as well as the role of biology teacher education in preparing teachers for laboratory work. As few previous studies focus on biology teachers in Norway, I found it appropriate to examine the great amount of data provided by the Biology Teacher Survey as a starting point for further work.

In the second phase, I was interested in *how* a focus on modelling through representation construction can support undergraduate biology students' reasoning in the laboratory. The two studies examining two different laboratory lessons in 2016 and 2019 can be considered case studies. Case study research is used to investigate a case within its real-life context in-depth (Yin, 2009), and it is useful for answering how, why, and what questions. The analytical approaches applied in these case studies will be described in Section 4.3.2.

4.1 Survey and group interview with biology teachers

The Biology Teacher Survey was initiated by Tone Fredsvik Gregers at the Resource Centre for Biology Education in the Department of Biosciences at the University of Oslo, in collaboration with science educators from the Department of Education. Article I focused primarily on a qualitative analysis of open-ended questions about teachers' practices in the laboratory and how their educational backgrounds prepared them for their practice as biology teachers. Asking teachers about their practice does not necessarily provide an exact picture of that practice, but it does say something about their *ideas* and concerns when it comes to practice in the laboratory. The Biology Teacher Survey's question about laboratory work was open-ended, which was particularly appropriate for investigating teachers'concerns and conceptualisation. In the group interview, we presented an initial analysis of the answers to this question. In this way, by beginning with the teachers' own initial conceptualisations from the survey, we gained even more insight into existing practices and challenges. For more information about the methodology in the survey and group interview, I will refer to Article I.

4.2 Instructor–researcher collaboration

This section describes some relevant aspects of the instructor–researcher collaboration, which is the empirical background of the two case studies presented in this thesis. This collaboration started in 2015 and lasted until 2019. During these years, I have met several times with the professor of the immunology course (hereafter, the Instructor). Initially, these meetings were intended for me to understand the aim of the laboratory lesson, as well as the Instructor's previous experiences with the lesson and how the design had developed over the years. To understand the Instructor's background as a researcher, I also observed a lecture for biology teachers, 'Biotorsdag', arranged by Tone F. Gregers at the Resource Centre for Biology Education, University of Oslo, at which the Instructor discussed how her own research has contributed to the development of biological therapeutics. We also met before the two case studies reported in the articles to consider how small changes in the design could contribute to supporting students' reasoning (for more details, see the following sections). Additionally, during data analysis, I discussed the students' laboratory journals and interaction excerpts with the Instructor.

I video recorded the laboratory lesson three times (in 2015, 2016 and 2019). I was also present as an observer and took pictures of material artefacts, of the blackboard during the lesson and of students' representations while they were working. The 2016 laboratory lesson was a pilot case study, and the observations made during it, along with information from my informal conversations with the Instructor, led me to choose to focus on modelling through representation construction. In the 2016 pilot case study, the video recording primarily focused on the Instructor and the plenary activities. In the following, I will first provide more background for why we chose to focus on modelling through representation construction.

4.2.1 Pilot case study

The laboratory lesson was a one-day event, beginning with a 45-minute lecture and continuing in the laboratory for five hours. In addition to the leading Instructor, another instructor was also participating in the laboratory lesson. I was only present as an observer. In the laboratory, the practical exercise involved investigating the sensitivity and specificity of different diagnostic tests: pregnancy and ovulation tests. As mentioned in the introduction, the students were not supposed to deliver a standard laboratory report. Rather, each group made a 'journal' on the large, white, bench-protector paper placed on the laboratory benches, and this was intended to be the starting point of a conversation with one of the instructors at the end of the day. In the journal, they were supposed to define important immunological concepts and make a drawing of the principle behind the diagnostic tests and discuss the usefulness of antibodies in diagnostic tests. As there was no authorised representation of the tests' designs at molecular level, this task could be considered a modelling task. Further, according to the Instructor, the drawing task, alongside the conceptual definitions, was a good starting point for 'talking immunology' with the students as it made the students' understanding visible.

The design of this laboratory lesson, and of the drawing task in particular, had several features in line with a representation construction approach (Tytler et al., 2013). In such an approach, students are supposed to actively explore phenomena through representation construction and negotiation in a process of guided inquiry. The laboratory lesson was, thus, a form of guided inquiry. The Instructor provided the question, and the students were only partly involved in designing the methodology. However, the results were not known in advance and the Instructor did not know all the details about how the tests were designed. In fact, the tests had been developed over the years in which the laboratory lesson has been offered, according to the Instructor. Further, in a representation construction approach, students are supposed to coordinate representations across modes. The students had to coordinate their observations about the different pregnancy tests, as well as the figure of the general ELISA-assay presented in the introductory lecture.

However, even though the design of the laboratory lesson had several features in line with a representation construction approach, the Instructor was probably not aware of how challenging this was for the students, and representations were not discussed explicitly in the pilot-study. We observed, in the laboratory lesson from 2014, that many students simply copied a figure of the ELISA-assay from the lecture notes given by the leading Instructor. This corresponds to research showing that academic language (disciplinary discourse) is often taken for granted by university instructors (Airey & Linder, 2009) and science teachers (Osborne, 2014), and they do not understand that the meanings they take for granted are difficult to understand from the outside (Northedge, 2002).

4.2.2 Case study 1

Prior to the laboratory lesson reported in Article I, I met with the leading Instructor to discuss how to support students in constructing their own representations. In the representation construction approach, it is important that representations be explicitly discussed and that the teacher play different roles in scaffolding and critiquing students' representations. I presented some of the principles developed by Tytler et al. (2013, p. 34) related to the importance of explicitly discussing the principles. I highlighted how crucial it is that students construct their own representations, as well as the potential learning gains from such activities. The Instructor suggested arranging a plenary drawing session, during which some students could present their suggestions of the principle behind the diagnostic test, which should then be explicitly discussed. As the aim with the drawing activity was that students should draw the diagnostic tests they investigated during the practical exercise, in which there was no authorised representation, the Instructor chose a group of students, who had already made such a model, to present their work on the blackboard. For more details about the actual implementation of this case study, see Article II.

4.2.3 Case study 2

Before the case study in 2019, I met with the Instructor again to discuss the design. We did not discuss the principles explicitly this time, but my recommendations were inspired by this approach, along with the observations and analysis from the previous case study. Results from the first case study pointed to the fruitfulness of having students explicitly reflect on representations. However, the results also showed that some students struggled with constructing their own representations and that they focused on reporting results rather than constructing representations. Therefore, we discussed the importance of presenting the drawing task explicitly from the beginning before having the students practically investigate the tests. That way, the exploration of the design could be important in students' framing of the task. Further, to make it clear that this was a form of authentic inquiry, I suggested that the Instructor state very explicitly that they had just received a package of diagnostic tests from a pharmaceutical company but did not know all the details of how they were designed. During representation construction, it is important that the activities are meaningful for the students (Tytler et al., 2013) so that the process becomes a form of inquiry. By presenting the task of investigating the test designs from the beginning, the students' practical investigations, including reading from the instruction manuals, could help them explore the designs and develop ideas. For instance, some of the instruction manuals gave information about the antibodies used. We also discussed the importance of making representational resources explicit for the students. The Instructor pointed to the representational resources, such as the figure of the ELISA-assay, and encouraged the students to read the tests' instruction manuals to search for information about the designs. The principles also highlights the importance of constant reasoning between representations and an object's observable features (Tytler et al., 2013). When the drawing task was explicitly presented from the beginning, the students' modelling would potentially develop alongside the practical inquiry of the tests. Finally, in order to increase the focus on explicitly discussing representations, the Instructor decided to implement more plenary drawing sessions.

4.2.4 Data collection for the case studies

As the case studies focused on students' representation construction, I placed head cameras on some students (see Figure 6). I also installed video cameras elsewhere in the room (five cameras in total), led the recordings and made decisions about when to move the cameras to capture the plenary activities. Figure 6 overviews the laboratory and the placement of cameras during the final intervention (2019). The laboratory was similarly organised and the cameras similarly placed in the 2016 case study.

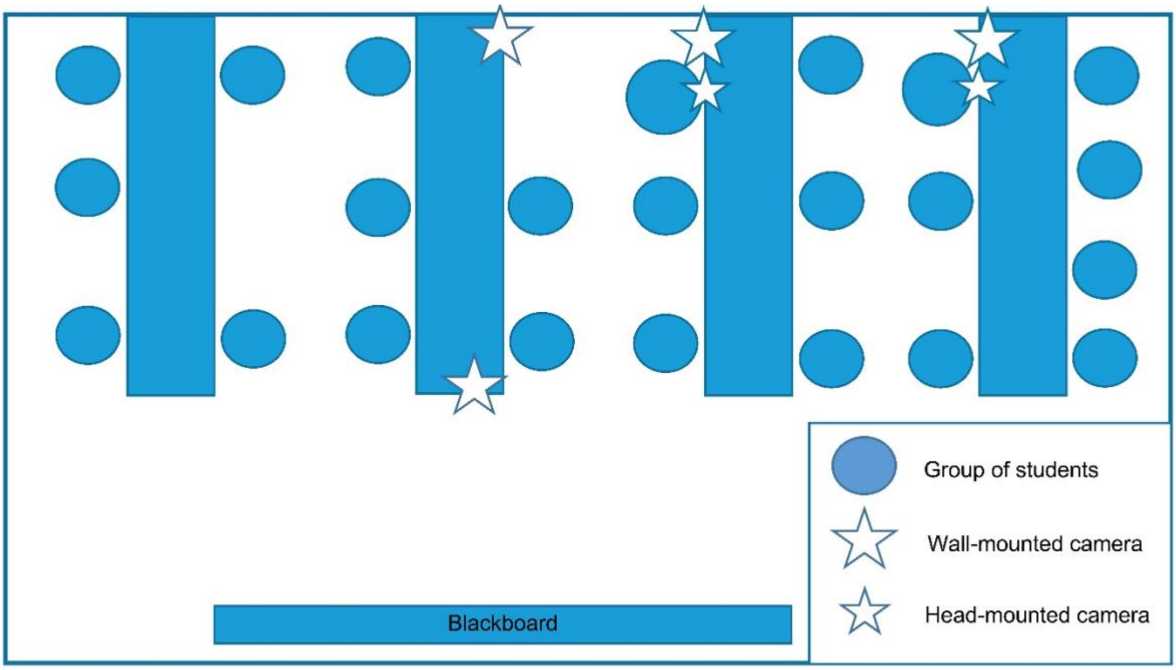

Figure 6. An overview of the laboratory and the placement of different cameras

As Figure 6 shows, I chose to focus on two groups, and one student from each of those groups wore a head-mounted camera. Using head-mounted cameras is particularly appropriate for investigating students' representation construction, as the cameras show the students' perspective (Frøyland, Remmen, Mork, Ødegaard & Christiansen, 2015). However, because the camera is placed on the head of only one student, there is a risk that it will not capture other important things happening around the students. Therefore, I also chose to place wall-mounted cameras beside the two focal groups. Finally, I placed a camera focusing on plenary activities in front of the blackboard, but this camera was moved according to the plenary activities.

4.3 Analytical procedures

In this section, I will present the analytical procedures applied in the analyses depicted in the three focal articles. To begin, I will highlight thematic analysis (4.2.1), which was the most important analytical procedure applied in Article I. I will then discuss the combination of interaction analysis and social semiotic analysis (4.2.2), the approaches applied in Articles II and III.

4.3.1 Thematic analysis

Thematic analysis (Braun & Clarke, 2006) was chosen to analyse the open-ended questions from the Biology Teacher Survey. This approach is used to analyse qualitative data by searching for patterns (Braun & Clarke, 2006). It is flexible and can be implemented in different theoretical frameworks. Braun and Clarke (2006) describe a stepwise approach to performing thematic analysis, and these steps were followed in analysing the open-ended questions, as well as the transcripts from the group interview, presented in Article I. The data programme NVivo was employed for the analysis. When conducting a thematic analysis, researchers must make various decisions. For instance, they must decide whether the analysis should focus on giving a rich description of the whole dataset or of only particular aspects of the dataset. In Article I, we initially focused on the whole dataset but subsequently narrowed the focus to investigate particular details.

4.3.2 Interaction analysis combined with social semiotic analysis

The analytical approach in Articles II and III consisted of interaction analysis combined with social semiotic analysis of different representations. The combination of these two analytical approaches is particularly fruitful when studying how students reason when they are constructing representations (Knain, Fredlund & Furberg, in press). Interaction analysis is a 'method for empirical investigation of the interactions of human beings with each other and with objects of their environment' (Jordan & Henderson, 1995, p. 39). Interaction analysis is dependent on video technology, which provides an opportunity to replay sequences over and over, and it is also often used alongside ethnographic fieldwork as it can help identify important interactions that can be studied in greater detail through video analysis. The ethnographic fieldwork in this thesis comprised my presence in the laboratory during the lessons, collected journals and photographs taken and the notes I took as the lessons unfolded. After data collection, the next step is to create an overview of the data corpus, often called a *content listing* (Jordan & Henderson, 1995). This process was initiated soon after the data was gathered to take advantage of my presence in the laboratory. I made several content listings: one overview of the whole lesson focusing on the plenary activities and an overview of each of the groups and how their work related to the plenary activities. The first part of the analysis centred on identifying parts of the lesson during which the teacher and students focused on representations, since this was the theme in which we were interested. This part of the video data was roughly transcribed. After we became more familiar with the data, we started to look for small segments of coherent interactions, called *episodes*. Together, these episodes had a narrative structure. In selecting the final episodes to be analysed in more detail, we chose those that showed this narrative structure and, thereby, the development of students' reasoning. In both Articles II and III, the idea of *interaction trajectory* is used to refer to this narrative structure (Furberg & Arnseth, 2009; Furberg, Kluge & Ludvigsen, 2013). The final episodes were chosen because the students' interactions, and the role of representations in these interactions, were particularly transparent. After the final episodes were selected, I transcribed these interactions in detail by playing each video several times, including finer and finer details as the transcription process continued. In analysing the excerpts, the focus was not primarily on the meaning of each utterance but on how meaning developed in the students' interactions over time.

Interaction analysis examines students' interactions with each other and with other resources in the environment. As this thesis is interested in students' self-produced representations in modelling activities, we were particularly intrigued by how the students' interactions developed in relation to their representations. Therefore, in Articles II and III, we combined interaction analysis with social semiotic analysis to better capture the multimodal meaning making. In Article II, we analysed the students' drawings using analytical concepts from social semiotics (Bezemer & Kress, 2015; Kress & Van Leeuwen, 1996). By investigating students' drawings in relation to their moment-to-moment interactions, we acquired unique insights into students' multimodal reasoning. In Article III, we combined interaction analysis with a theoretical framework of different gesture functions in biology proposed by Pozzer-Ardenghi and Roth (2005). This description of gesture functions provided us with an understanding of the combined role of drawings and gestures in students' model-based reasoning.

4.4 Methodological considerations

An important assumption behind the work in this thesis is that there is no one scientific method, neither in the natural sciences nor the social sciences. Rather, there are different styles of reasoning (Crombie, 1994; Kind & Osborne, 2017) or epistemic genres (Hacking, 1992; Morgan, 2014), each of which has its own procedural and epistemic constructs for validating knowledge without answering to any higher 'standard of truth and reason than [its] own' (Hacking, 2012, p. 605). After an epistemic genre has been accepted as a valid form of reasoning, it becomes the standard of what it is means to reason in that particular field (Morgan, 2014). However, qualitative research is often judged by the criteria of other styles of reasoning or other epistemic genres (Morgan, 2014) – particularly experimental exploration and probabilistic reasoning. For instance, when case studies are compared to statistical studies, one criticism is that case studies only present one observation, while statistical studies present many observations. Nevertheless, it has been argued that case studies should be added to the framework of epistemic genres or reasoning styles (Morgan, 2014).

This thesis is primarily based on qualitative data and analysis. The studies presented in Articles II and III are case studies. In the following section, I will discuss some considerations or 'epistemic constructs' related to the general methodology and qualitative analysis applied in this thesis. I will focus on reliability (4.4.1), validity (4.4.2) and the generalisability (4.4.3) of the findings. I will also discuss some ethical considerations (4.4.4) related to the work.

4.4.1 Reliability

Reliability concerns itself with the trustworthiness and consistency of research findings and whether those findings are reproducible (Kvale & Brinkmann, 2009). In Article I, though I coded the data, all the researchers were involved in the process of determining the codes. When the coding process was complete, one of the other researchers coded 20% of the data material to ensure the reliability of the coding. As the coding was largely consistent, we did not change the codes.

In Articles II and III, we relied heavily on video data. Because of the importance of transparency to reliability, video data is a good starting point for providing reliable findings as they offer the opportunity to replay the data many times. In contrast, field notes depend on a person's ability to write down all important information in the moment. While working with video data, I have experienced how my first impression of what was going on in the students' interactions changed dramatically as I became more familiar with the data by replaying parts of the recordings. However, though video data involves less reliance on the ability of the researcher to capture details in the moment, the researcher must still make many choices, such as where to place the cameras, how to select episodes from the data, etc. To increase the reliability of the findings, I have tried to be as transparent as possible about these choices.

Reliability is also connected to the transcription process, and I have employed a modified version of the transcription guidelines developed by Jefferson (2004). I have also considered how these transcription notations have been used in video analysis in similar science education studies (Furberg et al., 2013; Ingulfsen, Furberg & Strømme, 2018). However, the transcript notations have been adjusted to the appropriate level of detail according to the aims and research questions of these studies. Therefore, they are not identical in Articles II and III.

As mentioned above, interaction analysis depends on video technology, which provides the opportunity to replay sequences of interactions over and over. The video data in this study have been replayed many times to create highly detailed transcripts. This is also a way to avoid confirmation bias (Jordan & Henderson, 1995, p. 45). I reviewed the video data alongside the transcripts one last time after completing the analysis to ensure reliability.

4.4.2 Validity

Validity refers to whether a study's inferences are supported by the data (Peräkylä, 1997) and whether the chosen method investigates what it intends to investigate (Kvale & Brinkmann, 2009). Creswell and Miller (2000) have described several different procedures researchers can employ to improve the validity of their research. One of the most important of these is triangulation. Case studies rely on multiple observations, and the observations are most often validated by several researchers (Morgan, 2014). There are several different types of triangulation: data source triangulation, researcher triangulation, theory triangulation and method triangulation (Creswell & Miller, 2000). In Article I, the first research question was answered by relying on both quantitative and qualitative data as a form of triangulating across data/methods. When analysing the excerpts in Articles II and III, the researchers discussed the transcripts and presented the excerpts and analysis to external researchers (e.g., at conferences and in research groups) to increase validity. As mentioned above, the leading Instructor in the laboratory lesson also read and commented on the transcript analysis and on the students' journals (including drawings). The Instructor's expertise and disciplinary knowledge were particularly important as the course content was advanced. Again in Articles II and III, combining analytical procedures served as another way of triangulating across observations. For instance, by analysing the progression of students' drawings and their discussions and interactions, the validity of the findings related to the students' conceptual meaning making increased. Regarding interaction analysis, validity was ascertained through an inherent methodological transparency: *validation through next turn* (Peräkylä, 1997, p. 416). As previously mentioned, in interaction analysis, the focus is not primarily on the meaning of each utterance but on how the meaning develops between utterances. Though the interpretation of single utterances can vary, the analytical focus remains on how utterances are interpreted by the other participants in the interactions.

Member checking is a validation procedure through which data and interpretations are returned to the respondents (Creswell & Miller, 2000). In Article I, we applied this procedure when we arranged a group interview for four of the survey respondents, so they could comment on the analysis. Another procedure for increasing validity is *researchers' reflexivity* (Creswell & Miller, 2000), which involves being explicit about personal beliefs and biases.

My experience as a biology student, a teacher and a teacher educator has certainly influenced the work in this thesis. Therefore, I have tried to be transparent about my own beliefs and background in the preface to this thesis.

4.4.3 Generalisability

Kvale and Brinkmann (2009) has defined three types of generalisability: naturalistic, statistical and analytical. As mentioned above, one critique against qualitative research studies, in general, and against case studies, in particular, is that they rely only on one case and that the findings, therefore, cannot be generalised beyond that single case. However, in qualitative research, the focus is on reaching analytical generalisation (Kvale & Brinkmann, 2009; Yin, 2018), which is concerned with the degree to which findings can be used to predict what is going to happen in similar situations. This depends on the relevant similarities and differences between these situations, and judgements about these relevant similarities rely on rich descriptions of the case studies (Kvale & Brinkmann, 2009). Because generalisability claims rely on rich descriptions, providing such descriptions is a crucial way to support such claims. I have attempted to provide rich descriptions of the articles' contexts, and I have also provided more contextual background about the instructor–researcher collaboration that is the empirical background of the case studies in this extended abstract. However, the claims about generalisability are based, not only on the empirical analysis presented, but also on a review of similar research and the theoretical perspectives presented.

4.4.4 Ethical considerations

To a large degree, this thesis is based on video data, which requires special attention to ethical points, as it is more difficult to maintain the anonymity of the participants when using video data (Derry et al., 2010). The studies in this thesis have been approved by the Norwegian Social Science Data Services (NSD) and have been carried out in accordance with NSD guidance. All students were informed, in advance, about the video recordings, the purpose of the study, who would view the data, that participation was voluntary and that they could withdraw from the study at any time. The students who elected to participate provided informed consent. Those who did not want to participate were placed outside the cameras' field of vision, and the cameras in the laboratory were positioned in such a way that this was possible. The data are stored on a secure server owned by the University of Oslo, and all data will be deleted now that the project is finished. In transcribing the video data, I replaced all names with pseudonyms to maintain participant anonymity.

5 Summary of the findings

In this section, I will summarise the articles in this thesis, providing a basis for discussing the project's overall contribution and implications.

5.1 Article I: Biology teachers' border crossing between cultures – from a scientific culture to a school culture

Mari Sjøberg, Tone Fredsvik Gregers, Marianne Ødegaard, Kristin Glørstad Tsigaridas (2020)
Nordic Studies in Science Education, *16*(1)

5.1.1 Aim, background and methods

This article sought to understand the challenges biology teachers face with laboratory work in light of tensions between the different cultures or discourses in biology teacher education. Biology teacher education in Norway, as in other countries (Gyllenpalm & Wickman, 2011b), combines courses from different cultural institutions, but there is little research concerning how these institutions contribute to preparing biology teachers for their jobs – particularly the role undergraduate biology education plays in this preparation. Norway's biology curriculum (Utdanningsdirektoratet, 2013a) explicitly states that students shall learn how to plan and carry out investigations in the laboratory, and this suggests that biology teachers should use more inquiry-based approaches in connection with laboratory work. However, Article I suggests that this is challenging for many teachers. The data in this study consists of answers from the Biology Teacher Survey, completed by 314 biology teachers, as well as information from a group interview with four of those teachers. We used thematic analysis to analyse the open-ended questions from the survey and the data from the group interview.

5.1.2 Results and discussion

The first research question was: 'How do biology teachers report that the various parts of their educations have prepared them for their jobs, particularly focusing on laboratory work?'
Our results show that teachers particularly highlighted content knowledge and experience with laboratory work in their pure biology education as being valuable for their jobs. Several teachers also reported that didactical knowledge was lacking from their education. For instance, they stated that they would like to have more knowledge about teaching methods and concrete examples of laboratory exercises. One teacher, referring to his/her education,

wrote: 'Laboratory work in school with students should have been a separate course'. We interpreted this as referring to challenges teachers faced with transferring their laboratory work experiences from their pure biology education into their practice in the laboratory as biology teachers.

The second research question was: 'How do biology teachers describe their practice in connection with laboratory work, particularly regarding scientific practice and reasoning?' Our findings confirm earlier research regarding teachers' laboratory practice; students follow recipes, intending to illustrate content knowledge (Högström et al., 2006; Séré et al., 1998). Our results also show that teachers experienced a mismatch between implementing open inquiry and the goal of teaching content knowledge. When it comes to concepts, such as 'hypothesis', teachers integrated them into a traditional 'cookbook' way of working in the laboratory without considering that the students were not actually testing the hypotheses. In line with our theoretical perspective and the importance of context for students' learning, we argue that what students learn from such activities is a new *genre*, which is about guessing or knowing the right hypothesis in advance. Therefore, the way scientific practices are integrated into traditional laboratory work results in a 'school version' of scientific practices. Laboratory reports also seemed to be important parts of teachers' practice. We conclude, that a major challenge for teachers is designing appropriate contexts through which to teach scientific practice and reasoning.

5.2 Article II: Undergraduate students' multimodal reasoning: representation construction in immunology in the laboratory

Mari Sjøberg, Erik Knain (manuscript to be submitted for review)
Research in Science Education

5.2.1 Aim, background and methods

This article investigated students' reasoning when constructing representations in a laboratory context. The scientific method is often associated with the idea of a controlled experiment (Lederman, 2004), but experimental exploration is only one of several different styles of reasoning, according to Kind and Osborne (2017). We hypothesised that focusing on representation construction in the laboratory would support students' model-based reasoning.

To investigate students' reasoning while constructing representations, we used a combination of two analytical approaches: tools from social semiotics to analyse students' drawings and interaction analysis to understand students' social interactions in relation to this. In the article, we presented a detailed moment-to-moment analysis of the learning trajectories of two pairs of students as they engaged in representation construction practices.

5.2.2 Results and discussion

The first research question we sought to answer was: 'How do undergraduate biology students' self-produced representations support their reasoning in molecular biology?' The analysis showed that students' initial naturalistic representations, focusing on what they did in the practical task, provided an entry point for reasoning about molecular mechanisms involving a process of selection and abstraction, which eventually led to a more scientific representation, or model. Further, analysis of the students' interactions showed that the mode of drawing was particularly fruitful in their shared reasoning about molecular mechanisms. The epistemological commitments of drawing forced the students into a deeper inquiry of the molecular interactions which led the students to describe the phenomena through several representational modes, which thereby also supported the development of conceptual understanding.

The second research question was: 'How does students' task framing support or constrict their representation construction practices?' Our analysis suggests that the first group of students framed the activity as a modelling activity, using the drawing to develop a model at the molecular level to explain observations at the macro level. Thus, the first naturalistic draft including the pregnancy test moved from being depicted in the first drawing to becoming a visual frame in the second. The second group, on the other hand, framed the activity as a laboratory report. Their initial work also seemed to trigger questions, but, when they struggled to resolve these questions through drawing, they used phrases such as 'the pregnancy tests in this experiment are based on the ELISA-principle' and, thereby, avoided explaining *how* the ELISA-principle was used in these tests. The results also indicate that, when the students struggled to resolve these questions, the laboratory report genre became a way to move forward. Therefore, instead of pursuing these questions, they stayed true to the laboratory report genre, focusing on reporting empirical results.

5.3 Article III: Students' model-based reasoning in immunology: the role of drawings, gestures and material artefacts

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5.3.1 Aim, background and methods

This article sought further insight into the role of different representations in students' model-based reasoning. It is argued that a focus on modelling through representation construction can support development of conceptual understanding, while at the same time authentically reflecting scientific practices (Schwarz & White, 2005; Tytler & Prain, 2013). It is also postulated that drawing in science can contribute to students' reasoning and representational competence (Ainsworth, Prain & Tytler, 2011). Previous studies have shown that gestures are important semiotic resources in biology lectures (Pozzer-Ardenghi & Roth, 2005) and laboratory settings (Roth, 2009) and that material artefacts provide affordances for gestures that represent abstract concepts. Gestures offer a bridge between physical experiences and abstract theoretical language (Roth & Lawless, 2002a, 2002b). In this study, we used interaction analysis, combined with a semiotic analysis of gestures, to study how gestures, alongside self-produced drawings and material artefacts, become resources for students' model-based reasoning.

5.3.2 Results and discussion

The analysis demonstrates that these different representations are important for students' model-based reasoning in several ways. First, these representations enabled students to focus and extend their inquiries into molecular mechanisms. Our results suggest that their initial drawings generated ideas that were explored further to understand the molecular mechanisms. In this exploration, pointing gestures were used to focus attention on specific details in the drawing, while their talk centred on more thoroughly exploring aspects *not* shown in the drawing. Pointing gestures took away the burden of naming things, so the students could verbally explore, for instance, how the molecules moved. Gestures were then used to add dynamic processes to the static drawing while exploring molecular movements. When the students extended their models to better explain their observations, they described the molecular interactions with words, such as 'antibodies binding antibodies'. However, they struggled to draw this – likely because such drawings would have required them to know exactly where the molecules would bind, as drawings display spatial relationships. The gestures representing the molecules were, therefore, crucial for expressing ideas about molecular interaction, which were later transformed into the drawings in the final model. We argue that focusing on modelling in the laboratory can help students connect ideas with observations, which has been considered the major aim of laboratory work. We showed how the students referred to their observations during the experiment while developing their models. In fact, the molecular interactions in their models and their observations of the pregnancy tests were made into a continuous narrative, supported by the use of gestures. Finally, we argue that students' situated inquiry reflects some of the epistemic traits of scientific knowledge construction, which could be the basis for explicitly reflecting on modelling or nature of science.

6 Discussion and implications

This chapter discusses the results of the three articles, particularly focusing on their contributions to the overall aim of the thesis, which was to *explore challenges and opportunities with teaching and learning through scientific practice in the laboratory in biology education, with a main focus on modelling as scientific practice.* The chapter is divided as follows. In Section 6.1, I will discuss the challenges and opportunities of teaching through scientific practices in the laboratory, focusing on different scientific practices and how they relate to teachers' existing practices. In Section 6.2, I will consider how a focus on modelling through representation construction as a scientific practice in the laboratory can support students' reasoning in the laboratory, and, in Section 6.3, I will present some implications of the project's results and considerations for different parts of biology education and biology teacher education.

6.1 Challenges and opportunities of teaching through scientific practices in the laboratory in biology education

The first overall research question in this thesis was: 'What are upper secondary biology teachers' reported practices and challenges when it comes to teaching through scientific practices in the laboratory, and what is the role of biology teacher education in preparing teachers for laboratory work?' The findings from Article I confirmed previous research showing that biology teachers' primary aim is to illustrate content knowledge in the laboratory (Högström et al., 2006; Ottander & Grelsson, 2006).

According to Gyllenpalm (2010), conflating teaching methods with methods of scientific inquiry is a major challenge for inquiry-based teaching as learning about scientific inquiry is often not considered a goal in itself – becoming only a method for teaching content knowledge. Also, Hodson (2014) points to the tension between the goals of teaching through inquiry and the goals of learning scientific content knowledge. Similarly, our findings from Article I showed that teachers experience tension between implementing open inquiry and the goal of teaching content knowledge. Further, the findings from Article I indicated that biology teachers integrated aspects of scientific practices, such as the use of hypotheses, into the traditional 'cookbook' way of working in the laboratory, without considering that the students were not actually testing the hypotheses. The result is a kind of discovery instruction, referring to activities where question, method and result are provided in advance but where the dramaturgy is played out so that the students are led to believe that they discover the results themselves (Gyllenpalm et al., 2012). However, such activities are highly problematic, as students learn to play this game of guessing the right hypothesis, methodology and results. Further, this can lead to the development of 'hypothesis fear' under which students are afraid of guessing the wrong hypothesis (Gyllenpalm et al., 2012).

Many scholars argue that teachers must differentiate between different goals in the laboratory, as different goals require different methods and contexts (Hodson, 2014; Séré, 2002). Therefore, concerning the scientific practices *asking questions* and *planning and carrying out investigations* in the laboratory, I will argue that it is particularly important for teachers to differentiate between goals, where learning about procedural and epistemic constructs, such as the importance of control of variables, is considered a goal in itself. In the current Norwegian curriculum, students are supposed to plan and carry out investigations in the laboratory (Utdanningsdirektoratet, 2013b). A similar aim is suggested in the new curriculum (Utdanningsdirektoratet, 2020). Undergraduate biology education also focuses on teaching students how to develop hypotheses and plan investigations in the laboratory (University of Oslo, 2020a). However, given that biology teachers' aims with laboratory work most often seem to be to illustrate content knowledge and not to teach about scientific inquiry (Ottander & Grelsson, 2006), there are obvious challenges with these goals. Gyllenpalm (2010) argues that, as long as teachers use inquiry as a method for teaching content knowledge, and not a goal in its own right, teaching science as inquiry will be problematic. However, Gyllenpalm (2010) is primarily concerned with the aspects of scientific inquiry related to experiments and the use of hypotheses. One of the ideas behind the notion of scientific practices (National Research Council, 2012) is to work against the overemphasis on experimental exploration in scientific inquiry by also directing attention towards other practices, such as modelling and argumentation. Similarly, the tension Hodson (2014) describes is primarily between *doing science* and *learning science content knowledge*. According to Crawford (2014), it is a myth that students must always pursue their own questions and that the golden standard for science teaching is open inquiry. Perhaps, the aim of open inquiry or authentic research in the laboratory is too ambitious given the restrictions of this environment – such as many students, limited access to laboratories or resources, and the pressure to cover content knowledge that biology teachers often feel.

The findings from Article I suggested that the laboratory report is an important part of biology teachers' practice in laboratory work, as also indicated by previous research (Ottander & Grelsson, 2006), and biology teachers consider students' learning to write in this genre as an important preparation for further studies in biology. According to Keys (1999), the laboratory report (experiment genre) is an appropriate genre when students are involved in designing the investigation or when the data shows some interesting variation. However, Article I also indicated, in line with previous research (Hofstein & Kind, 2012; Séré et al., 1998), that it is common practice in the laboratory for students to follow instructions given by the teacher. When the laboratory report genre is used in connection with such teacher-directed activities, it tends to becomes a routine, involving little reasoning, in which the students learn to copy the knowledge claim that is supposed to be validated in the exercises (Keys, 1999).

In Article II, we focused on students' reasoning in a laboratory exercise at the undergraduate level. We showed how the students framed the task by the laboratory report genre, even when they were not asked to write a standard laboratory report. The laboratory report genre became a way to move forward when they struggled with the actual task, but unfortunately didn't support students' reasoning. Writing in the experiment genre (laboratory report) has the potential to support students' scientific reasoning (Keys, 1999). However, when used in connection with experiments intended to validate specific content knowledge, it leads to reporting rather than reasoning, which becomes a way of 'doing laboratory work'; our findings suggested that this is also the case at undergraduate levels. However, more research is necessary to validate such claims.

Hofstein and Kind (2012) assert that focusing on argumentation can provide a new rationale for laboratory work and an alternative to the 'positivistic' image of science portrayed through standard 'cookbook' laboratory activities. Laboratory work can support students' argumentation because the students will have ownership over their own data (Kind et al., 2011) and can thereby learn from establishing connections between the methodologies and the results. However, this would require that the students be involved in designing the methodologies that require changes in teachers' practices. I will argue that a focus on analysis and interpreting data in the laboratory can promote scientific reasoning and argumentation, while remaining more in line with teachers' existing practices. However, this would require activities involving datasets that show some interesting variation (Osborne, 2014). This is an area of further research and development that should be pursued concerning teaching through scientific practice in the laboratory.

In this section, I have discussed challenges and opportunities associated with teaching through scientific practices in the biology laboratory, focusing on different scientific practices in relation to teachers' existing practices. I believe that the notion of scientific practice can open new ways of conceptualising inquiry in the laboratory that is more in line with biology teachers' existing intentions and practices, while authentically reflecting scientists' knowledge construction practices. In the next section, I will focus on the fruitfulness of modelling as a scientific practice in the laboratory.

6.2 Modelling as a scientific practice in the laboratory

Several scholars have argued that concentrating on modelling or representation construction in a process of guided inquiry can promote students' scientific reasoning (Tytler et al., 2013a; Tytler et al., 2020) and conceptual understanding, while authentically reflecting scientific practices (Tytler & Prain, 2013; Windschitl et al., 2008). Knorr-Cetina (1999) argues that laboratories should be characterised as more than the place where experiments happen. Similarly, I will argue that laboratory work in an educational setting should be used to make visible more than the experimental style of reasoning (Kind & Osborne, 2017). In fact, I believe that the association of laboratory work solely with the experiment and testing of variables (Windschitl & Thompson, 2006) stands in the way of some good opportunities for teaching and learning in the biology laboratory.

The second overall research question in this thesis was: 'How can a focus on representation construction and modelling as scientific practice support biology students' reasoning in the laboratory?' The findings presented in Articles II and III illustrated several ways in which a focus on representations supported students' reasoning. Inquiry-based teaching and laboratory work are sometimes criticised for being hands-on but minds-off approaches, focusing on *doing* rather than *thinking* (Abrahams & Millar, 2008; Hofstein & Kind, 2012). In a university setting, it is also claimed that the support given to students primarily focuses on using equipment (Airey & Linder, 2009). Therefore, one of the major challenges for pre-service teachers, when it comes to teaching science as inquiry, is making them think about testing ideas rather than predictions and variables (Windschitl et al., 2008). Articles II and III suggested that concentrating on representation construction can contribute to an increased focus on testing ideas. For instance, Article III showed that the students' inquiry was primarily about testing *ideas* and the importance of different representations – such as drawings, gestures and spoken language – in sharing and communicating these ideas.

We also illustrated how the mode of drawing was important for generating ideas during the students' inquiry into molecular mechanisms. The centrality of ideas and creativity in scientific reasoning has previously been highlighted by several science educators (Kind & Osborne, 2017; Lehrer & Schauble, 2010; Tytler et al., 2020), while others have pointed out that giving too little attention to the importance of ideas in scientific knowledge progression undermines the importance of creativity in science (Kind & Osborne, 2017). Through a focus on modelling, ideas are foregrounded (Lehrer & Schauble, 2010; Windschitl et al., 2008) and this contrasts with the positivistic image of science often reflected in the laboratories in educational settings (Hodson, 1996, 1998; Kind et al., 2011).

According to Millar et al. (1998), the major aim of laboratory work is to connect ideas with observations. However, due to the reported lack of effectiveness in reaching this aim (Abrahams & Millar, 2008), it is easy to question why students should spend so much time in the laboratory. As argued above, when students are involved in planning experimental methodologies, they benefit from establishing connections between the methodologies and the results. However, if the aim is not primarily to plan and carry out investigations in order to learn about scientific inquiry, why should the students spend so much effort on laboratory work? In Article II, we showed how the students' representations developed from a focus on what they did in the practical exercise, where the pregnancy tests were depicted in a naturalistic drawing, to a model, where the pregnancy tests became a visual frame for the explanation of the observations at a molecular level. We argued that this is a kind of model-based reasoning, which illustrates how representations and models develop towards increased abstraction (Roth, 2005; Roth & McGinn; 1998; Roth & Pozzer-Ardenghi, 2013). This provides a different rationale behind laboratory work and engaging students in 'doing science'. The focus is primarily on supporting students' experience of how phenomena are represented and re-represented in a series of 'representational passes' (Latour, 1999) or 'cascade[s] of inscriptions' (Roth & McGinn; 1998). Previous studies highlight the importance of experience with phenomena for understanding more abstract representations (Bowen & Roth, 1998; Roth & Bowen, 2001). Such research depicts that experienced practice of how scientific knowledge is re-represented is crucial for both students and scientists to understand more abstract scientific representations. This provides a rationale for *doing* science, in itself, as different modes of representation can represent transitions from the experienced world to abstract concepts.

A major difficulty for students in learning science is linking different modes of representations together and mastering the transformations between them (Roth & Tobin, 1997; Tang et al., 2011). Article III showed that the molecular interactions in the students' models and their observations of the pregnancy tests were connected through one continuous gesture with different functions. This finding suggested that gestures can provide a bridge between physical experiences in the laboratory and abstract, theoretical language, as shown in previous research (Roth & Lawless, 2002a, 2002b). Roth and Lawless (2002a) argue that there is great learning potential in asking students to describe and explain phenomena in the laboratory because of the materials and equipment in that setting. I will argue that taking a representation construction approach (Tytler et al., 2013) to laboratory work is fruitful for designing and developing such laboratory activities.

As a concept is the sum of its representations (Givry & Roth, 2006), and as a holistic understanding of concepts requires that they be described through several representational modes (Airey & Linder, 2017; Tang et al., 2011), it can be argued that the multimodal inquiry we demonstrated in Articles II and III also supports the development of conceptual understanding. In Article II, we illustrated that the drawing mode was particularly fruitful for exploring molecular mechanisms, through its affordance for, and epistemological commitment to, displaying spatial relationships. Further, Article III revealed that gestures were important in students' modelling and were used to display three-dimensional molecular structures when sharing ideas about molecular interactions. Previous research in biology has also shown that gestures can improve students' understanding of the three-dimensional structure of DNA (Srivastava & Ramadas, 2013). If these representations are important for students' understanding of the invisible entities in molecular biology, we should strive to design teaching environments that promotes their use. I will argue that a representation construction approach to laboratory work can contribute in accomplishing this goal. Further, I will argue that framing laboratory work as a representation construction approach can fulfil what is, in fact, many teachers' aim with laboratory work: illustrating content knowledge. Taking such a perspective, what is often considered data in the laboratory can, instead, be deemed representations, and teachers, alongside their students, can concentrate on explicit reflections about how phenomena are represented and re-represented during knowledge construction.

Several studies have pointed to the fruitfulness of learning with multiple representations in biology (Roth & Pozzer-Ardenghi, 2013; Srivastava & Ramadas, 2013; Treagust & Tsui, 2013; Yarden & Yarden, 2013). For instance, Yarden and Yarden (2013) have found that using multiple representations in animations when teaching about the biotechnological method *polymerase chain reaction* (PCR) was more effective than using only still images.

However, I believe, in line with other scholars (Airey & Linder, 2009; Tang, Tan & Yeo, 2011), that multimodal inquiry is not only a more effective approach; it is necessary in order to give students access to disciplinary ways of knowing (Airey & Linder, 2009). This is supported by studies showing that both students' and scientists' understandings of abstract representations in biology depend on their familiarity with the phenomena (Bowen & Roth, 1998; Roth & Bowen, 2001). According to Knorr-Cetina (1999, section 4.5.3), representations in molecular biology 'carry memories of lived and learned experience'. Knowledge of the actual experience, therefore, is often necessary to understand the representations. Knorr-Cetina (1999) characterises the molecular biology laboratory as an object-oriented, benchwork style of doing science. One can ask: Is it possible to obtain a holistic understanding of the nature of biology without doing laboratory work? In physics lectures, transformations between representations are often experienced as discontinuous (Roth & Tobin, 1997), but, in scientific practice, these transitions are experienced as continuous, which is a good reason for engaging students in scientific practice. I will argue that the *data* produced in laboratory settings, is one of the representational modes students' need to *see biology through* in order to really understand the nature of biology. I will argue that experimental work, in the sense of manipulating objects and materials, is a crucial part of the 'critical constellation of modes' (Airey & Linder, 2009) in the disciplinary discourse of biology. Again, I think this is what many biology teachers feel about laboratory work. For instance, one of the biology teachers in the group interview said, 'the students must engage with some hands-on work'. However, she did not say why. (This point is not reported in Article I). The challenge, I believe, is that most teachers, and particularly university instructors, are so deeply rooted in the academic language (Osborne, 2014) or disciplinary discourse (Airey & Linder, 2009) of their fields that it is difficult for them to understand that the meanings they take for granted – including transformations between different representations – are difficult for students, who are not fluent in the discourse, to understand (Airey & Linder, 2009; Osborne, 2014).

In line with other scholars (Lehrer & Schauble, 2010; Tytler & Prain, 2013; Windschitl et al., 2008) and supported by the findings in this thesis, I will argue that, by focusing on modelling through representation construction, the product and process of science can go hand-in-hand, mutually supporting the learning of each other. Thus, focusing on representation construction solves some of the challenges defined in Article I, such as the perceived mismatch between inquiry and the learning of content knowledge. The important point is that developing models and representations *is* a form of inquiry. In fact, modelling and representation construction are central to all scientific practice (Erduran & Dagher, 2014; Lehrer & Schauble, 2010; Tytler & Prain, 2013; Windschitl et al., 2008). When foregrounding representation construction and negotiation, students will experience how knowledge is transformed through a sequence of re-representations, and this authentically reflects the relationship between theory and evidence that characterises nature of science, it is argued (Latour, 1999; Roth & Mcguinn, 1998; Tytler & Prain, 2013). Duschl and Grandy (2013) assert that students should learn about nature of science through experience, and this points to the importance of designing appropriate contexts. One critique against the consensus approach to nature of science is that it leads to activities with little relation to science (Osborne, 2014). Similarly, scholars have found that, when teachers design inquiry-based activities, they base those inquiries on what seems testable and interesting, but with little relevance to science (Windschitl & Thompson, 2006; Windschitl et al., 2008). In a representation construction approach, inquiry is deeply intertwined with content.

Others argue that a focus on modelling can improve students' learning of nature of science (Schwarz & White, 2005) and that several epistemic features of scientific knowledge are made visible through model-based inquiry (Windschitl et al., 2008). In Article III, we suggested that students' activities reflected five epistemic features of scientific knowledge construction. However, more research is necessary to investigate whether such an approach can contribute to students' understanding of nature of science or modelling competence (Upmeier zu Belzen, van Driel, & Krüger, 2019). However, my focus in this thesis has primarily been on practice in the laboratory. After all, there would be no genres or cultures without specific texts and practices, and, though changing practice is not enough to change culture (Corbo et al., 2016), I believe that the findings and considerations presented in this thesis can provide some fruitful directions for changing laboratory work as an alternative to 'the scientific method' (Windschitl et al., 2008).

6.3 Border-crossing between cultures in biology education

One of the starting points for this thesis was the fragmented biology teacher education programmes, which are separated into different cultural institutions. A major challenge with teaching through scientific practice is confusion about what it means (Gyllenpalm, 2010; Hodson, 2014). According to Osborne (2014), this confusion exists particularly between two fundamentally different goals: the goal of learning science and the goal of learning *to do* science. In a school context, an important aim with engaging students in scientific practices is that it contributes to knowledge about nature of science (Osborne, 2014). In undergraduate biology education, on the other hand, the arguments for engaging students in scientific practices often focus on developing students' inquiry skills and preparing them for research careers (Basey, Mendelow & Ramos, 2000; National Research Council, 2003). The confusion over what it means to teach through inquiry can, therefore, be seen in connection to the border-crossing between cultures in biology teacher education. As future biology teachers pass through biology teacher education, they experience different versions of laboratory work (with different aims). The title of Article I in this thesis was 'Biology Teachers' Border-Crossing between Cultures' – referring to the challenges of transforming knowledge from teachers' reported experiences with scientific research or with laboratory work during their undergraduate educations to teaching. Most respondents to the Biology Teacher Survey reported in Article I hold master's degrees in biology, and they highlighted content knowledge and experience with laboratory work from the undergraduate education as being the most valuable outcomes of their educations for their job as biology teachers. This indicates that these teachers are highly influenced by the culture of pure biology undergraduate education and scientific research and points to the importance of these cultures for improving biology education, in line with previous findings from physics education (Larsson, 2019).

Considering the Norwegian biology curriculum (Utdanningsdirektoratet, 2013a; 2020), which foregrounds planning and carrying out investigations, testing hypotheses and developing practical skills, I will argue that such curriculum is mostly inspired by the goal of learning to do science and, thereby, preparing students for research careers. I also believe that such a focus is problematic, as it overlooks the importance of scientific literacy and knowledge *about* science, which is crucial in many different jobs, both in and outside of the biology field. I further claim that it is problematic if undergraduate curriculum primarily focuses on preparing students for research careers, as undergraduate biology education actually prepares students for many different jobs (e.g., biology teachers). I will argue that teaching through scientific practices will be problematic as long as it is not considered a goal in itself, but only a method for teaching content knowledge or a means to prepare students to *do* science and pursue research careers. However, in the previous section, I asserted that focusing on representation construction and modelling as scientific practice in the biology education laboratory is fruitful. With such foregrounding, there is less tension between scientific practice and developing conceptual knowledge as the process and product go hand-in-hand (Tytler & Prain, 2013). Thus, there is also less tension between the various overall aims of the biology education cultural institutions. Further, modelling through representation construction can provide a common focus for undergraduate and upper secondary biology education in the laboratory, and this can ease future biology teachers' transitions between cultural institutions, thereby improving biology teacher education as a whole.

Finally, I will point to the important role of science education courses in preparing biology teachers for implementing scientific practices. With the new curriculum in Norway focusing on 'Practices and Reasoning in Biology', science educators can play an important role by highlighting that scientific practice is more than experimental exploration. Further, in line with physics scholars (Angell et al., 2008), I will argue the importance of talking about models and modelling as scientific practice alongside communicating actual teaching approaches focusing on modelling through representation construction.

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Appendices

Appendix A. The survey

Appendix B. Consent form

Biologilærerutdanningen

Dette er en undersøkelse utarbeidet av Skolelaboratoriet for biologi ved Universitetet i Oslo (UiO) for å utrede utdanningen til biologilærere. Undersøkelsen skal kartlegge biologilærernes bakgrunn og hvilke ressurser de har med seg fra sin utdanning. Prosjektet er støttet med såkornmidler fra Senter for fremragende Utdanning og UiOs satsningsområde "Kunnskap i Skolen" (ProTed, NFR).
Noen av spørsmålene er obligatoriske og er merket med en stjerne.

side 1

Undersøkelsen er godkjent av Norsk Samfunnsvitenskapelig Datatjeneste. En fullstendig beskrivelse av undersøkelsen og hva det innebærer å være med kan du lese om ved å laste ned vårt informasjonsskriv

Tusen takk for at du deltar i undersøkelsen. Svarene dine er viktig for prosjektet.

1. Om læreren

Kjønn *

- ○ Mann
- ○ Kvinne

Alder *

- ◉ < 25 år
- ○ 25-30 år
- ○ 31-40 år
- ○ 41-50 år
- ○ 51-60 år
- ○ > 60 år

Stilling *

- ○ Adjunkt
- ○ Adjunkt med opprykk
- ○ Lektor
- ○ Lektor med opprykk
- ○ Annet

Visningen av dette elementet er avhengig av svar på «Stilling»

Hvis annet, hva?

[ ]

Fylket du arbeider i *

[ ]

Kommunen du arbeider i *

[ ]

side 2

Sideskift

2. Naturvitenskapelig utdanning

I hvilket år ble høyeste grad oppnådd? *

[Velg... ▾]

Ved hvilket utdanningssted ble høyeste grad oppnådd? *

- ○ Universitetet i Oslo (UiO)
- ○ Universitetet i Stavanger (UiS)

- Universitetet i Tromsø (UiT)
- Universitetet i Bergen (UiB)
- Norges teknisk-naturvitenskapelig universitet (NTNU)
- Universitetet i Agder (UiA)
- Universitetet i Nordland (UiN)
- Norges miljø- og biovitenskapelige universitet (NMBU, Ås)
- Høgskole
- Utlandet

Visningen av dette elementet er avhengig av svar på «Ved hvilket utdanningssted ble høyeste grad oppnådd?»

Hvis høgskole, hvilken?

Visningen av dette elementet er avhengig av svar på «Ved hvilket utdanningssted ble høyeste grad oppnådd?»

Hvis utlandet, hvor?

Antall studiepoeng/vekttall i biologi *

- 0-30 studiepoeng/0-10 vekttall
- 30-60 studiepoeng/10-20 vekttall
- > 60 studiepoend/> 20 vekttall

Hva er din høyeste oppnådde grad? *

- Cand. mag eller Bachelor
- Hovedfag eller Master
- Siv. Ing
- Dr. grad
- Annet

Fagretning/tema i din grad (som for eksempel cellebiologi, økologi, kjemi, naturfagsdidaktikk, energi etc)

Har du et annet utdanningsløp og/eller fagkombinasjon enn det som er beskrevet over?

- Ja
- Nei

Visningen av dette elementet er avhengig av svar på «Har du et annet utdanningsløp og/eller fagkombinasjon enn det som er beskrevet over?»

Hvis ja, hva/hvilken?

side 3

Sideskift

3. Pedagogisk utdanning

Ditt utdanningsløp *

- 5-årig integrert lektorutdanning (med master)
- 1-årig praktisk pedagogisk utdanning som påbygging
- 1/2-årig PedSem som påbygging
- Andre ordninger som for eksempel teach first

- ○ Ingen

I hvilket år avsluttet du pedagogisk utdanning? *

Velg...

Ved hvilken institusjon avsluttet du pedagogisk utdanning? *

- ○ Ikke relevant
- ○ Universitetet i Oslo (UiO)
- ○ Universitetet i Stavanger (UiS)
- ○ Universitetet i Tromsø (UiT)
- ○ Universitetet i Bergen (UiB)
- ○ Norges teknisk-naturvitenskapelig universitet (NTNU)
- ○ Universitetet i Agder (UiA)
- ○ Universitetet i Nordland (UiN)
- ○ Norges miljø- og biovitenskapelige universitet (NMBU, Ås)
- ○ Høgskole
- ○ Utlandet

Visningen av dette elementet er avhengig av svar på «Ved hvilken institusjon avsluttet du pedagogisk utdanning?»

Hvis høgskole, hvilken?

Visningen av dette elementet er avhengig av svar på «Ved hvilken institusjon avsluttet du pedagogisk utdanning?»

Hvis utlandet, hvor?

side 4

Sideskift

4. Undervisning

Antall år med undervisningserfaring (inkludert inneværende år) *

- ○ 0-1 år
- ○ 2-5 år
- ○ 5-10 år
- ○ 10-20 år
- ○ > 20 år

I tillegg til biologi, hvilke av disse fagene har du undervist i løpet av de siste 5 år? *

- ☐ Naturfag Vg1
- ☐ Fysikk
- ☐ Kjemi
- ☐ Matematikk
- ☐ Geofag
- ☐ Teknologi og forskningslære
- ☐ Informasjonsteknologi
- ☐ Andre

Hvis andre, hvilke?

Hvor ofte underviser du vanligvis i...

	hvert år	hvert 2. år	hvert 3. år	hvert 4. år eller sjeldnere
Naturfag Vg1	○	○	○	○
Biologi 1	○	○	○	○
Biologi 2	○	○	○	○

side 5

Sideskift

5. Utdanningen som forberedelse til skolehverdagen

På en skala fra 1 - 6, der 1 = svært liten grad og 6 = svært stor grad:
I hvilken grad mener du utdanningen din har forberedt deg på skolehverdagen i biologi og/eller biologidelen i naturfag Vg1 når det gjelder...

	1	2	3	4	5	6
faglig trygghet *	○	○	○	○	○	○
å variere undervisningen *	○	○	○	○	○	○
å designe undervisningsopplegg *	○	○	○	○	○	○
å gjennomføre biologiske laboratorieforsøk *	○	○	○	○	○	○
å gjennomføre feltarbeid *	○	○	○	○	○	○
å bruke elevenes refleksjoner i undervisningen *	○	○	○	○	○	○
å veilede i rapportskriving *	○	○	○	○	○	○
å veilede lesing og skriving av vitenskapelige tekster *	○	○	○	○	○	○
å bruke grunnleggende ferdigheter i biologi *	○	○	○	○	○	○
å koble samfunnsaktuelle problemstillinger til undervisningen *	○	○	○	○	○	○
å forberede elevene på eksamen *	○	○	○	○	○	○
å vurdere elevenes kompetanse *	○	○	○	○	○	○
å bruke læreplaner i planlegging av undervisningen *	○	○	○	○	○	○
å benytte nettressurser inn i undervisningen *	○	○	○	○	○	○
den generelle praktiske gjennomføringen av undervisningen *	○	○	○	○	○	○

På en skala fra 1 - 6, der 1 = svært liten grad og 6 = svært stor grad:
Hvor godt rustet er du i dag til å gi elevene forståelse for begreper og prosesser innen...

	1	2	3	4	5	6
bærekraftig utvikling	○	○	○	○	○	○
ernæring og helse	○	○	○	○	○	○
bioteknologi	○	○	○	○	○	○
biologisk mangfold	○	○	○	○	○	○
cellebiologi	○	○	○	○	○	○
funksjon og tilpasning	○	○	○	○	○	○

	1	2	3	4	5	6
fysiologien til mennesket	○	○	○	○	○	○
energiomsetning	○	○	○	○	○	○
evolusjon	○	○	○	○	○	○
genetikk	○	○	○	○	○	○
økologi	○	○	○	○	○	○
naturvitenkapelige arbeidsmetoder (forskerspiren/den unge biologen)	○	○	○	○	○	○

På en skala fra 1 - 6, der 1 = svært dårlig rustet og 6 = svært godt rustet:
Hvor godt rustet er du i dag til å...

	1	2	3	4	5	6
lage prøver *	○	○	○	○	○	○
rette og vurdere prøver *	○	○	○	○	○	○
gi underveisvurdering *	○	○	○	○	○	○
sette standpunktkarakter *	○	○	○	○	○	○

Hvor mange dager i løpet av et år gjennomfører elevene feltarbeid i...

	aldri	1/2-1 dag	1-3 dager	> 3 dager
Naturfag Vg1	○	○	○	○
Biologi 1	○	○	○	○
Biologi 2	○	○	○	○

Hvor ofte gjennomfører elevene praktisk laboratoriearbeid i...

	aldri	en gang i måneden	annen hver uke	hver uke	hver time
Naturfag Vg1	○	○	○	○	○
Biologi 1	○	○	○	○	○
Biologi 2	○	○	○	○	○

Forklar kort hvordan du gjennomfører felt, eventuelt hvorfor du ikke gjør det

Forklar kort hvordan du gjennomfører praktisk laboratoriearbeid, eventuelt hvorfor du ikke gjør det.

side 6

Sideskift

6. Etterutdanning

Ønsker du etterutdanning? *

- Ja
- Nei

Visningen av dette elementet er avhengig av svar på «Ønsker du etterutdanning?»

Hvis ja, hva ønsker du etterutdanning i?

Legger skolen til rette for at du kan delta på etterutdanning? *

- Ja
- Nei

Hvor mange ganger i løpet av et år deltar du vanligvis på etterutdanning? *

- ingen
- < 1 gang
- 1-2 ganger
- 2-3 ganger
- > 3 ganger

Visningen av dette elementet er avhengig av svar på «Hvor mange ganger i løpet av et år deltar du vanligvis på etterutdanning?»

Hvis du sjelden eller aldri deltar på etterutdanning, hva er årsaken?

- ☐ for liten tid
- ☐ for dårlig økonomi ved skolen
- ☐ jeg syns ikke jeg trenger det
- ☐ det er arbeidskrevende å ha vikar i klassen

Visningen av dette elementet er avhengig av svar på «Hvor mange ganger i løpet av et år deltar du vanligvis på etterutdanning?»

Andre grunner?

Ønsker du kompetansegivende videreutdanning (med avsluttende eksamen og studiepoeng)? *

- Ja
- Nei

Visningen av dette elementet er avhengig av svar på «Ønsker du kompetansegivende videreutdanning (med avsluttende eksamen og studiepoeng)?»

Hvis ja, hva ønsker du videreutdanning i?

side 7

Sideskift

7. Erfaringer

Sett i lys av den erfaringen du har som lærer, hva mener du manglet i din utdanning, både faglig og pedagogisk? *

Sett i lys av den erfaringen du har som lærer, hva har du hatt mest nytte av fra din utdanning, både faglig og pedagogisk? *

Sett i lys av den erfaringen du har som lærer, hva har du hatt minst nytte av fra din utdanning, både faglig og pedagogisk? *

side 8

Sideskift

8. Ytterligere kommentarer

Er du ferdig med spørreundersøkelsen? *

- Ja

Nettskjema v12.3

Appendix B. Consent form

Mari Sjøberg

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Participation in the research project 'The Budding Scientist'

Background and aim

This is a developmental research project that aims at developing laboratory work that reflect scientific practices and teaching in an authentic manner, and at the same time develop teaching methods in the laboratory that leads to deep learning in biology. The project is a collaboration between the biology professor and the educational researcher where we gather data, analyze results and make small changes to the teaching situation through several cycles with the same laboratory course.

What does it involve to participate in the study?

It will be gathered video- and audio recordings from the laboratory course. Artifacts from the course will also be gathered, such as the laboratory journals and instruction manuals. If you agree to participate in the study, this means that you will appear in the video material, and the analysis of the video material can result in scientific publications. Interested participant can have more information by request. Some students may also be asked to participate in an interview.

What happens with the information about you?

Researchers working on the project will have professional secrecy and all personal data will be treated with confidentiality. Only researchers connected to the project will have admission to the video recordings. It will not be possible to recognize any of the participants in the research publication. The data material will be stored on a secure server at UiO/USIT. All recordings will be erased when the project is finished, or latest by 31.12.2022. The project is registered at 'Norsk Senter for Forskningsdata'

Voluntary participation

It is voluntary to participate in the study. Also, you can resign from the study at any time without giving any reason for this. If you have any questions about the study, please contact Mari Sjøberg (tlf: 93603210).

Thank you for participating!

Mari Sjøberg

Mari Sjøberg

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Consent of participation in the project 'The budding scientist'

I have received information about the project and agree to participate ☐

Signature

Part II

The articles

I

Mari Sjøberg is a ph.d student in science education and her research interest is mainly related to scientific reasoning, nature of science and modelling in science and biology education

Tone Fredsvik Gregers is Senior lecturer in biology and head of the Resource Centre for Biology Education at the Department of Biosciences, University of Oslo

Marianne Ødegaard is professor in science education and her research interest is mainly in scientific literacy and the use of inquiry in learning science.

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Biologilæreres kryssing av kulturgrenser – fra en naturvitenskapelig kultur til en skolekultur

Abstract

The aim of this article is to understand biology teachers' challenges with laboratory work in the light of tensions between the different cultures, or discourses, in biology teacher education. The data material in this study consists of a survey with 314 responses from biology teachers as well as a group interview. Our findings suggest that teachers struggle to transform the knowledge and experience from their pure biology education into their practice in the laboratory. Concepts from a scientific discourse, such as 'hypothesis' and 'report', are therefore integrated into traditional teacher-directed laboratory tasks where the results are given in advance. We argue that this contributes to a misleading image of science. One of the major challenges for teachers, we argue, is to design appropriate contexts for addressing aspects of nature of science in the laboratory. However, many biology teachers report that they lack knowledge about teaching methods in the laboratory.

Introduksjon

Selv om det lenge har vært enighet om at formålet til naturfagene i skolen ikke bare er å gi elevene en forståelse av den etablerte, faglige kunnskapen, men også et innblikk i hvordan man har kommet frem til denne kunnskapen (Linder et al., 2011; Osborne & Dillon, 2008), er formålet med labarbeid i skolen som oftest å illustrere fagkunnskapen (Högström, Ottander, & Benckert, 2006). Labarbeid gjennomføres derfor ofte som lærerstyrte forsøk som er designet slik at elevene skal komme frem til et resultat som er bestemt av læreren på forhånd (Osborne, 2014). Denne måten å gjennomføre labarbeid på blir ofte kritisert for å gi et feilaktig bilde av naturvitenskapens egenart (Hodson, 1996, 1998, 2014). Det blir ofte hevdet at en åpen, utforskende undervisningsmodell er mer autentisk hvis man vil få frem aspekter ved naturvitenskapens egenart (Schwartz, Lederman, & Crawford, 2004), men lærere har ofte utfordringer med å gjennomføre slik undervisning (Bjønness & Knain, 2018; Capps & Crawford, 2013). Læreres manglende erfaring med autentisk forskning har blitt foreslått som en årsak til dette (Anderson, 2007). Ifølge Windschitl, Thompson, og Braaten (2008) tar lærere med seg det bildet av naturvitenskapens egenart som de har fått gjennom egen skolegang og overfører dette videre i egen praksis som lærere, til tross for at de har erfaring med forskning. Siden den naturvitenskapelige utdanningen unngår å snakke eksplisitt om naturvitenskapens egenart, bidrar den også indirekte til å opprettholde *status quo*, ifølge Gyllenpalm (2010).

I tillegg til at lærere vil være påvirket av erfaringer fra egen skolegang, vil biologilærere som jobber i den videregående skole (med elever på 15–18 år) ha sin utdanning fra flere forskjellige institusjoner: de *rene* naturvitenskapelige institusjonene og en lærerutdanningsinstitusjon. Tilsvarende ordninger gjelder mange andre land, og det gjelder også andre fag, som fysikk og kjemi (Gyllenpalm & Wickman, 2011b). Det finnes mye forskning på læreres praksis med labarbeid i skolen, men det er forsket lite på hvordan lærere selv opplever at de forskjellige delene av utdanningen deres har forberedt dem på dette. Det at biologilærerutdanningen er sammensatt av forskjellige kulturelle institusjoner, kan innebære noen utfordringer for biologilærere. Kryssing av kulturgrenser kan beskrives som prosessen hvor man beveger seg mellom to kulturer som har forskjellig språk, verdier, praksiser og forskjellig historie (Kang, Bianchini & Kelly, 2013). Hensikten med denne artikkelen er å forstå de velkjente utfordringene knyttet til læreres praksis med labarbeid i lys av spenninger mellom de forskjellige relevante kulturelle institusjonene i lærernes utdanning, og vi har formulert følgende forskningsspørsmål:

1. Hvordan rapporterer lærerne at de forskjellige delene av utdanningen deres har forberedt dem på jobben som biologlærer, særlig med tanke på labarbeid?
2. Hvordan beskriver lærerne sin praksis i forbindelse med labarbeid og hvordan de integrerer naturvitenskapelige praksiser og tenkemåter i denne praksisen?

Læreres praksis i laboratoriet

To av de viktigste målene med labarbeid i skolen er å støtte elevenes læring av fagkunnskapen og å få innblikk i naturvitenskapens egenart (Wellington, 1998). Forskning tyder riktignok på at læreres formål med labarbeid hovedsakelig er å hjelpe elevene til å forstå fagkunnskapen (Welzel et al., 1998). I Sverige fant for eksempel Högström, Ottander og Benckert (2012) gjennom intervjuer med lærere i den videregående skolen at deres formål med labarbeid først og fremst var å hjelpe elevene til å forstå fagkunnskapen, og at naturvitenskapens egenart sjelden ble nevnt av lærerne. I et stort europeisk prosjekt om labarbeid fant forskere at måten labarbeid blir gjennomført på, er ganske lik på tvers av land; studentene følger presise instruksjoner eller oppskrifter laget av læreren på forhånd (Séré et al., 1998). Studiet viser at dette også gjaldt på universitetsnivå. Forskning tyder også på at når det gjelder universitetsutdanningen i realfag, legger man lite vekt på naturvitenskapens egenart (Trumbull & Kerr, 1993). Gyllenpalm og Wickman (2011b) fant gjennom intervjuer med lærere at begreper som *hypotese* sjelden blir brukt i de rene naturvitenskapelige kursene.

Utforskende arbeidsmetoder

Under utforskende arbeidsmetoder følger man gjerne den samme forskningsprosessen som forskere: stiller spørsmål, lager hypoteser og samler og diskuterer data (Capps & Crawford, 2013). Jo flere av disse aspektene læreren har bestemt på forhånd, desto mindre er frihetsgraden for elevene (Knain, Bjønness, & Kolstø, 2011). I den norske læreplanen i biologi er det hovedsakelig hovedområdet *Den unge biologen* som ivaretar aspekter av naturvitenskapens egenart i biologifaget (Utdanningsdirektoratet, 2013a). Det står blant annet eksplisitt at elevene skal kunne planlegge og gjennomføre undersøkelser i laboratoriet. Dette innebærer at lærerne bør ta i bruk utforskende arbeidsmetoder med mange frihetsgrader. Tilsvarende hovedområder finnes også i fysikk, kjemi og naturfag (Utdanningsdirektoratet, 2013b). Mange lærere har riktignok utfordringer med å gjennomføre slike aktiviteter, og ofte tror lærerne at de arbeider utforskende selv når de ikke gjør det (Capps & Crawford, 2013; Gyllenpalm, Wickman og Holmgren, 2012). I Norge er en ny læreplan nå under innføring (Utdanningsdirektoratet, 2019c). Her er *Naturvitenskapelige praksiser og tenkemåter* et eget kjerneelement som skal prege arbeidet med de andre kjerneelementene. Et kjerneelement med tilsvarende innhold vil også komme i biologi (Utdanningsdirektoratet, 2019b). Forskning tyder riktignok på at nye læreplaner ofte tolkes og brukes innenfor de eksisterende tradisjonene og dermed gjøres om til noe kjent (Gyllenpalm, Wickman og Holmgren, 2012). I et forsøk på å gjøre de eksisterende tradisjonene knyttet til utforskende arbeidsmetoder eksplisitte, fant Gyllenpalm, Wickman og Holmgren (2012) at utforskende arbeidsmetoder ofte assosieres med praktisk arbeid, frihet og spontanitet.

Naturvitenskapelige praksiser og tenkemåter

En idé ved utforskende arbeidsmetoder er at de metodene som forskere har brukt for å komme frem til kunnskapen, også bør være de metodene elevene bruker for å lære seg kunnskapen (Hodson, 2014). Denne sammenblandingen mellom utforskende arbeidsmetoder og naturvitenskapelige metoder fører riktignok til frustrasjon og forvirring blant lærere og elever, ifølge Hodson (2014). Utfordringen er at hvis utforskning er for styrt, er det for ulikt måten forskere jobber på. Er de derimot for åpne, er faren stor for at elevene ikke kommer frem til det læreren har planlagt. Gyllenpalm og Wickman (2011a, 2011b) fant at en del begreper som opprinnelig stammer fra naturvitenskapen, slik som *eksperiment* og *hypotese*, ofte får en ny *pedagogisk* funksjon i skolen. Begrepet hypotese blir eksempelvis brukt som en gjetning på hva som kommer til å skje i et forsøk, i stedet for slik det brukes i naturvitenskapen, som en tentativ forklaring (Chalmers, 1999). Gyllenpalm, Wickman, & Holmgren (2010) knytter dette til sammenblandingen mellom utforskende arbeidsmetoder og naturvitenskapelige metoder, og argumenterer for at dette kan hindre lærere i å ta opp aspekter ved naturvitenskapens egenart eksplisitt i undervisningen

Biologilærerutdanning i Norge

I Norge er det hovedsakelig to måter å bli biologilærer på. Den tradisjonelle måten er ved å først ta en mastergrad i biologi og deretter en ettårig lærerutdanning, altså praktisk pedagogisk utdanning (PPU). Den andre måten er ved å følge et integrert femårig lektorprogram hvor man vil få to undervisningsfag i tillegg til en lærerutdanning. Felles for disse utdanningene er at man vil følge biologiundervisning sammen med andre biologistudenter i den *rene* biologiutdanningen og en lærerutdanning sammen med andre lærerstudenter. De som har en mastergrad i biologi, vil gjerne tilhøre en forskergruppe innen biologi og få et mindre prosjekt som en del av forskergruppens forskning. Som biologilærer er det altså flere relevante kulturelle institusjoner man vil bli påvirket av i jobben som biologlærer: en naturvitenskapelig forskningskultur, den *rene* biologiutdanningen, lærerutdanningen og egen skolegang.

Kultur og diskurs

Forskjellige kulturer karakteriseres gjerne ved forskjellige diskurser (Knain, 2015). Mange forskere understreker at det å lære naturvitenskap ikke kan skilles fra å lære det naturvitenskapelige språket (Lemke, 1990; Norris & Phillips, 2003). Halliday (2003) poengterer også at vi lærer *gjennom* språket sammen med den sosiale og kulturelle konteksten. Med utgangspunkt i teoretiske perspektiver fra Halliday (2003, 2013), definerer Knain (2015) diskurs som *tekst i kontekst*. Dette perspektivet understreker den gjensidige avhengigheten mellom tekst og handling i spesifikke situasjoner og den kulturelle konteksten de er en del av. En sjanger kan defineres som «standardiserte måter å gjøre ting med språk på i spesifikke situasjoner» (Knain, 2015, s. 9, vår oversettelse) og sjanger utgjør et mellomliggende steg mellom den kulturelle konteksten og den spesifikke situasjonen (Knain, 2015). Det å lære å mestre sjangre er en viktig del av læring i skolen. Dette innebærer at det ikke er uproblematisk å flytte praksiser fra en diskurs til en annen uten å ta hensyn til at den kulturelle konteksten har endret seg. Knain (2015) påpeker at formålet med naturfagene i skolen er fremtidig deltakelse i andre sekundære diskurser – for eksempel den naturvitenskapelige diskursen. Videre handler undervisningsplanlegging i stor grad om å designe passende *kontekster* for læring. Elevenes tekster kan ses på som indikasjon på om læringskonteksten er passende. Dersom elevenes tekster for eksempel likner tekster i den naturvitenskapelige diskursen, er det altså et tegn på at læringskonteksten er god. Labarbeid er en sentral praksis både i den naturvitenskapelige kulturen og i en skolekultur (Hofstein & Kind, 2012; Knorr-Cetina, 1999). Hensikten med labarbeid i naturvitenskapen er å bidra med ny kunnskap, mens hensikten med labarbeid i skolen ofte er å lære elevene eksisterende kunnskap (Osborne, 2014) De forskjellige kulturelle kontekstene kan derfor peke på noen utfordringer med å overføre andre praksiser knyttet til labarbeid fra den ene kulturen til den andre. Labrapportsjangeren i skolen har sin opprinnelse i den eksperimentelle rapporten fra den naturvitenskapelige diskursen. Denne kjennetegnes ved en IMRaD-struktur (Introduction, Method, Results and Discussion) hvor de forskjellige stegene gjenspeiler stegene i forskningsprosessen (Martin, 1992). Når elevene skal skrive rapport etter et skoleforsøk i skolen, må de rekonstruere det vitenskapelige formålet i en skolekontekst (Knain, 2015), og dette kan være utfordrende for elever (Knain, 2005). Gyllenpalm et al. (2012) fant at en del elever opplever en *hypotesefrykt* når de skal lage hypoteser i forbindelse med styrte forsøk, fordi de opplever at det egentlig handler om å gjette hva som er riktig hypotese. Disse eksemplene peker derfor på noen av utfordringene knyttet til design av undervisning i laboratoriet og overgangen fra en naturvitenskapelig kultur til en skolekultur.

METODE

Datamaterialet i denne studien kommer fra en spørreundersøkelse som har blitt besvart av norske biologilærere, og et gruppeintervju med fire av respondentene i etterkant. Tabell 1 gir en oversikt over hvilke data og analysemetoder som har blitt brukt til å besvare de forskjellige forskningsspørsmålene.

Tabell 1: Oversikt over data og analysemetoder som ble brukt til å besvare de forskjellige forskningsspørsmålene.

Forskningsspørsmål	Data	Analysemetode
Hvordan rapporterer lærerne at de forskjellige delene av utdanningen deres har forberedt dem på jobben som biologlærer, særlig med tanke på labarbeid?	Et lukket spørsmål om i hvilken grad utdanningen deres har forberedt dem på diverse aspekter av lærerjobben. (Besvart ved 6-punkts likertskala)	Deskriptiv statistikk
	To åpne spørsmål om hvordan utdanningen har forberedt dem på lærerjobben: «Sett i lys av den erfaringen du har som lærer, hva har du hatt mest nytte av fra din utdanning, både faglig og pedagogisk?» «Sett i lys av den erfaringen du har som lærer, hva mener du manglet i din utdanning, både faglig og pedagogisk?»	Tematisk analyse

Hvordan beskriver lærerne sin praksis i forbindelse med labarbeid og hvordan de integrerer naturvitenskapelige praksiser og tenkemåter i denne praksisen?	Et åpent spørsmål om deres praksis i forbindelse med labarbeid: «Forklar kort hvordan du gjennomfører praktisk laboratoriearbeid, eventuelt hvorfor du ikke gjør det». Gruppeintervju	Tematisk analyse Tematisk analyse

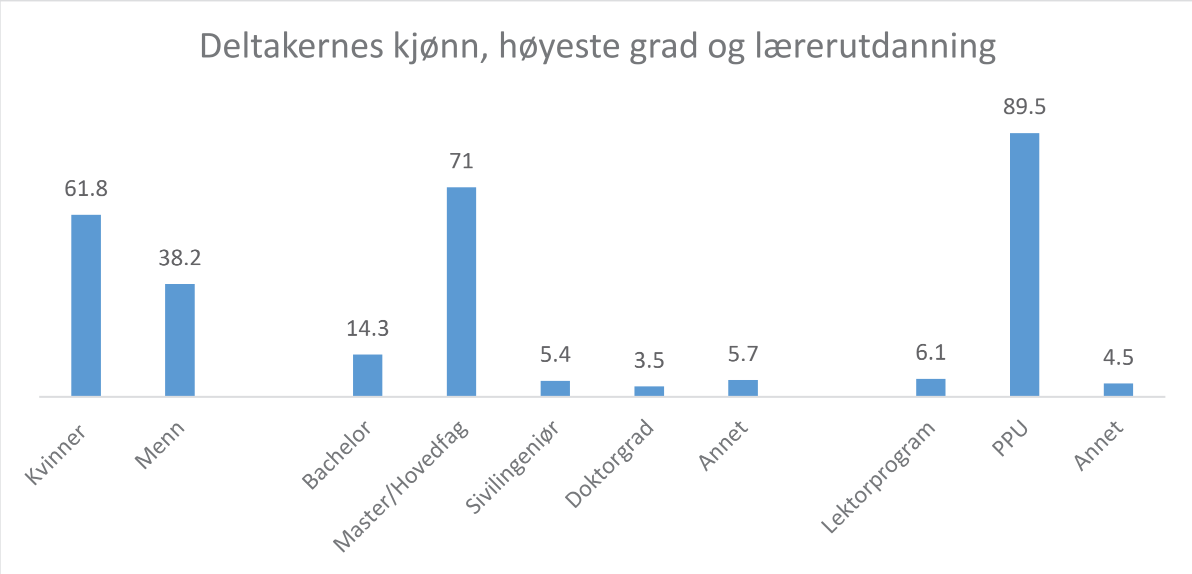
Om spørreundersøkelsen

Spørreundersøkelsen ble pilotert i to runder, først med to lærere og deretter med åtte lærere med variert undervisningserfaring og bakgrunn. Spørreundersøkelsen ble revidert etter dette og sendt ut til skoleledere på alle videregående skoler i Norge med forespørsel om å distribuere den videre. Undersøkelsen ble også distribuert gjennom en e-postliste til skolelaboratoriet i biologi og gjennom sosiale medier. Spørreundersøkelsen var anonym og inneholdt totalt 16 spørsmål. 9 spørsmål var lukkede og handlet om alder, kjønn, fylke og utdanning. Ett spørsmål ble besvart med en 6-punkts likertskala hvor 1 stod for «i veldig liten grad» og 6 «i veldig stor grad», mens de resterende spørsmålene var helt åpne, slik at lærerne selv kunne formulere et svar. Spørreundersøkelsen var delt inn i åtte kategorier: 1) om læreren, 2) naturvitenskapelig utdanning, 3) pedagogisk utdanning, 4) undervisning, 5) hvordan utdanningen har forberedt dem på lærerjobben, 6) etter- og videreutdanning, 7) erfaringer og 8) generelle kommentarer. Informasjon om læreren og hans eller hennes naturvitenskapelige og pedagogiske utdanning (punkt 1, 2, og 3) vil bli beskrevet i avsnittet nedenfor. I resultatene er det ellers kategori 4 og 5 vi har lagt vekt på. I tillegg til de spørsmålene vi rapporterer fra i denne artikkelen, var det også et spørsmål om feltarbeid, om lærernes ønske om etter- og videreutdanning og om annen yrkeserfaring. Vi har brukt analysen av noen av de andre spørsmålene til å validere vår tolkning. For eksempel var det et spørsmål om hva lærerne oppfattet som minst nyttig i utdanningen. Dette spørsmålet brukte vi til å validere analysen av de to andre spørsmålene om hvordan utdanningen har forberedt dem på jobben som lærer.

Deltakere på spørreundersøkelsen

314 norske lærere svarte på undersøkelsen. Det er ingen tilgjengelige data om antallet biologilærere i Norge, men det er omtrent 420 videregående skoler i Norge (Utdanningsdirektoratet, 2019a). Dersom vi antar at det er to biologilærere per skole, vil vi altså få en svarprosent på nesten 40 prosent. Alle fylker, utenom Svalbard, er representert. I og med at undersøkelsen ble distribuert til skoleledere og ikke direkte til lærerne, vet vi ikke hvor mange lærere som faktisk har mottatt undersøkelsen. Det kan også være at de som har svart på spørreundersøkelsen, er de som føler seg særlig godt kvalifisert, og at våre resultater derfor gir et noe skjevt inntrykk av alle biologilærerne i Norge. For likevel å kunne si noe om representativiteten av dette utvalget har vi undersøkt hvordan den geografiske fordelingen av respondentene samsvarer med antall skoler i forskjellige fylker i Norge. Fordelingen samsvarer relativt godt.

Figur 1 viser en oversikt over deltakernes kjønn og utdanningsbakgrunn. Figuren viser blant annet at majoriteten av respondentene har mastergrad, hovedfag eller doktorgrad og praktisk pedagogisk utdanning (PPU). Bare 6,1 prosent har fulgt et integrert lektorprogram. Ved hjelp av et åpent spørsmål i undersøkelsen har vi også funnet ut at flesteparten har mastergrad i biologi, men at det er også en del som har mastergrad eller doktorgrad innenfor andre realfag.



Figur 1: Svar oppgitt i prosent. Informasjon om deltakernes kjønn, høyeste utdanning (grad og lærerutdanning

Tematisk analyse

Tematisk analyse ble valgt som metode for analysen av de åpne spørsmålene i undersøkelsen (Braun & Clarke, 2006), og dataprogrammet NVivo ble brukt i analysen. Det var bare ca. 80 prosent som svarte på de åpne spørsmålene. Som beskrevet i den trinnvise metoden i tematisk analyse var det første steget å bli kjent med dataene. Vi holdt flere møter med alle forfatterne hvor vi diskuterte analysen underveis. Førsteforfatteren kodet først alle dataene, og en av de andre forfatterne kodet deretter 20 prosent av dataene for å undersøke om det var enighet om analysen, og dermed øke reliabiliteten. Fordi det var stor enighet om kodingen (80%), gjorde vi ingen endringer etter dette. Kodene er induktive og i størst mulig grad basert på lærernes egne formuleringer og hvordan de har svart på spørsmålet. Samtidig vil selvfølgelig analysen også være preget av forskernes førforståelse.

Når det gjelder det andre forskningsspørsmålet og det åpne spørsmålet om lærernes praksis med labarbeid, var hensikten med analysen først og fremst å forstå de velkjente utfordringene knyttet til labarbeid og hvordan naturvitenskapelige praksiser og tenkemåter integreres i denne praksisen. Hensikten er altså å gjøre noen analytiske generaliseringer (Yin, 2018). Dette spørsmålet ble bare kodet av en av forfatterne. For å validere denne analysen og få litt mer utdypende svar om lærernes praksis med labarbeid arrangerte vi et gruppeintervju med labarbeid som hovedtema.

Gruppeintervjuet

I gruppeintervjuet presenterte vi vår foreløpige tematiske analyse og 5–8 eksempler på svar fra spørreundersøkelsen under hvert tema. Vi mener at det at intervjuet tok utgangspunkt i svar fra spørreundersøkelsen, gjorde det lettere for lærerne å være ærlige og ikke bare svare det de tror forventes av dem. Vi valgte ut forskjellige svar som representerte bredden i svarene på undersøkelsen. Intervjuet varte i omtrent to timer. Etter at lærerne hadde blitt presentert for et tema og utvalg av svar fra spørreundersøkelsen, diskuterte de egne erfaringer knyttet til dette. Vi hadde altså ikke planlagt noen spørsmål på forhånd, fordi det var meningen at gruppeintervjuet skulle være minst mulig styrt fra vår side. Alle forfatterne var til stede under gruppeintervjuet, men det var førsteforfatteren som ledet det. Selv om vi ikke hadde planlagt noen spørsmål i utgangspunktet, kunne alle forfatterne stille spørsmål som måtte dukke opp underveis i samtalen. Lærerne ble bedt om å dele egne erfaringer og praksiser, men kunne også reflektere rundt hva de tenkte om andre læreres praksis. Temaene vi presenterte på gruppeintervjuet, var

– hensikt/begrunnelse
– lukkede eller åpne forsøk
– organisering
– kilder
– for- og etterarbeid

Gruppeintervjuet ble transkribert og i utgangspunktet kodet med samme koder som svarene på det åpne spørsmålet fra spørreundersøkelsen, men vi gjorde noen endringer når det gjelder de endelige temaene vi rapporterer om i resultatene. De endelige temaene er valgt fordi de er mest relevante for vårt forskningsspørsmål. I presentasjonen av resultatene har vi valgt ut noen utdrag fra gruppeintervjuet som representerer noen interessante problemstillinger og ideer knyttet til temaet og forskningsspørsmålet. Vi har skrevet om utdragene på en slik måte at de skal være forståelige å lese samtidig som meningsinnholdet bevares. Navnene vi bruker, er pseudonymer, og alle er presentert som damer, selv om en av dem var mann, slik at det ikke skal være mulig å identifisere deltakerne.

Deltakerne på gruppeintervjuet bestod av tre kvinner og én mann. De var alle fra Oslo eller Akershus og ble valgt av pragmatiske årsaker fordi de var en del av nettverket til Skolelaboratoriet for biologi. Tre av deltakerne, Linea, Sonja og Siri, hadde hovedfag i biologi og deretter PPU. Linea hadde i tillegg en mastergrad i realfagsdidaktikk. De var erfarne lærere med 15–20 års erfaring. Den siste deltakeren, Kari, var relativt nyutdannet og hadde fulgt et integrert femårig lærerutdanningsprogram.

RESULTATER

Vi presenterer først resultatene som er relevante for det første forskningsspørsmålet: Hvordan rapporterer biologilærere at de forskjellige delene av utdanningen deres har forberedt dem på jobben som biologilærer, særlig med tanke på labarbeid? Deretter presenterer vi resultatene som er relevante for det andre forskningsspørsmålet: Hvilke ideer og praksiser beskriver lærerne i forbindelse med labarbeid?

Hvordan utdanningen har forberedt dem på jobben som biologilærer

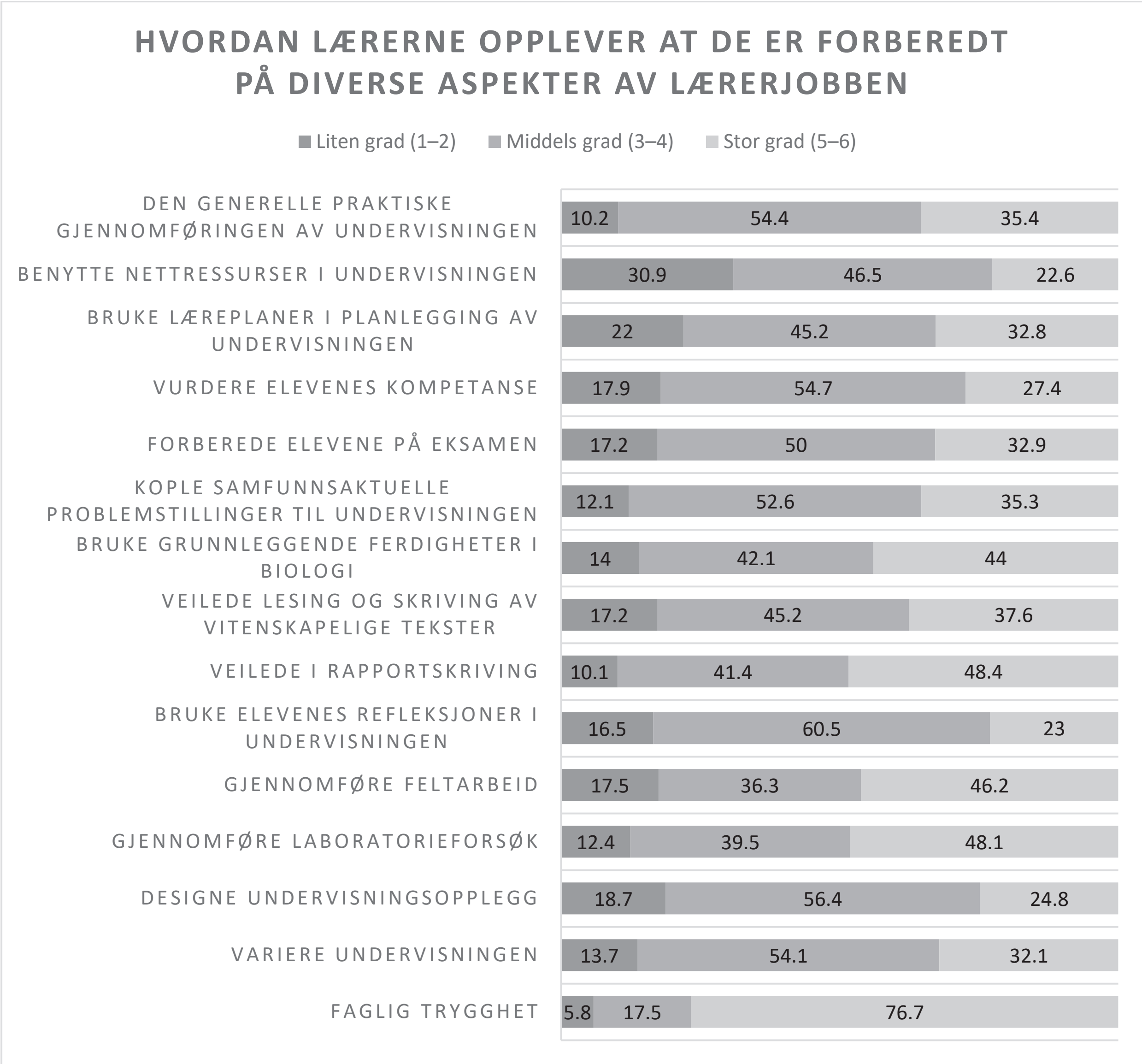
Resultatene viser at majoriteten av lærerne rapporterer at de er godt forberedt på de fleste aspektene ved lærerjobben. 76,7 prosent rapporterer at utdanningen har gitt dem faglig trygghet, og dette aspektet skiller seg tydelig ut som det flest lærere rapporterer at utdanningen i stor grad har gitt dem (se figur 2). I underkant av 50 prosent rapporterer at utdanningen i stor grad har forberedt dem på å gjennomføre lab- og feltarbeid samt å veilede skriving av rapporter. Bare rundt 20–30 prosent skriver at utdanningen deres har forberedt dem i stor grad på å variere undervisningen, designe undervisningsopplegg og å bruke elevenes refleksjoner i undervisningen.

I det følgende vil vi presentere resultatene av den tematiske analysen og de tre temaene – fagkunnskap, didaktisk kunnskap og lab- og feltarbeid.

Bredden og tyngden i fagkunnskapen oppleves som mest nyttig

Det er hovedsakelig den faglige tryggheten og bredden og dybden i fagkunnskapen lærerne rapporterer at de har mest nytte av i jobben som lærer. Det er altså det de har lært gjennom biologistudiet eller andre deler av den realfaglige utdanningen, som de opplever som mest nyttig. Noen trekker frem spesifikke fag som de mener har vært særlig nyttige, for eksempel fysiologi og genetikk. Lærerne skriver at solid fagkunnskap gir trygghet, evne til å se helhet og evne til å forstå og sette seg inn i ny kunnskap: *gode faglige kunnskaper til å kunne se helheten i faget og bredden i fagene mine*. Fagkunnskapen gir også engasjement og formidlingsevne, skriver noen. Arbeid med mastergrad eller annen forskererfaring har også gitt lærerne en dyp forståelse av faget: *innsikt og erfaring fra å ta et hovedfag som gav meg god faglig og metodisk trygghet som jeg tok med meg i undervisningen*. Det er altså ikke bare fagkunnskapen, men også en metodisk trygghet de har fått gjennom biologiutdanningen: *bruker mye av hovedfagets arbeidsmetoder og tankegods inn i realfagsundervisningen*.

Mange av lærerne er også opptatt av hvilke fag de mangler i jobben som lærer. Her blir for eksempel fysiologi, økologi, men også matematikk, ofte nevnt.



Figur 2: Svar oppgitt i prosent. Resultater av spørsmålet «I hvilken grad opplever du at utdanningen din har forberedt deg på følgende aspekter av lærerjobben?». Lærerne besvarte spørsmålet ved å krysse av fra på en 6-punkts likertskala.

Manglet noe didaktisk kunnskap

Det lærerne hovedsakelig skriver at de manglet kunnskap om etter endt utdanning, er vurdering, undervisningsmetoder, hvordan variere undervisningen, differensiering og grunnleggende ferdigheter. Det er gjerne praktiske aspekter ved vurderingsarbeid som blir nevnt: hvordan lage og rette prøver, arbeid med vurderingskriterier og forberedelse på eksamen, men også vurdering for læring og hvordan man vurderer labarbeid. Når det gjelder undervisningsmetoder, er det for eksempel en del som trekker frem at de gjerne skulle hatt mer konkrete eksempler: *eksempler på gode undervisningsopplegg og tips til konkrete måter å variere undervisningen på*. I tillegg til disse konkrete didaktiske aspektene er det også flere lærere som skriver at de gjerne skulle hatt mer undervisning i didaktikk. Særlig fagspesifikk didaktikk, som biologididaktikk, er det en del som skriver at de skulle hatt. Det er også slik at mange trekker frem didaktikkundervisningen som særlig nyttig i jobben som lærer.

Lab- og feltarbeid: «Lab i skolen med elever burde vært et eget fag»

I våre resultater ser vi at lærerne bruker begrepene lab- og feltarbeid i forbindelse med egen forskererfaring, kurs på universitetsnivå i biologi, kurs i lærerutdanningen og sin egen praksis i skolen, altså i forbindelse med flere forskjellige kulturer. Dette viser at lab- og feltarbeid er et gjennomgående tema i biologilærerutdanningen og noe som biologilærere er opptatt av. Det er riktignok erfaringen med lab- og feltarbeid gjennom biologistudiet lærerne hovedsakelig rapporterer å ha nytte av i jobben som lærer: *faglig kunnskap fra biologistudiet, samt egen erfaring fra labarbeid og ekskursjoner*. Mange lærere rapporterer å ha bred erfaring med forskjellige laboratorieøvelser og feltkurs gjennom biologistudiet som de mener er nyttig for jobben som biologilærer: «god fagundervisning med mye lab, felt og ekskursjoner». Erfaringen med lab- og feltarbeid gjennom arbeidet med mastergrad eller doktorgrad er også en nyttig erfaring som de rapporterer at de tar med seg i skolen: *egen felterfaring, egen forskererfaring*. Flere lærere skriver også at de manglet kunnskap om lab- og feltarbeid, men da gjelder det hovedsakelig kunnskap om gjennomføringen i skolen. Aspekter ved labarbeid i skolen som blir trukket frem som utfordrende er: eksterne faktorer (som mange elever), økonomiske begrensninger og små rom, men også aspekter som går på veiledning av elevene og design av undervisning: *planlegge praktisk biologi på egen hånd, ikke bare følge en oppskrift*.

Vi undersøkte hvordan de lærerne som skrev at de manglet kunnskap om lab- og feltarbeid, opprinnelig hadde svart på det lukkede spørsmålet om hvordan de var forberedt på å gjennomføre dette (se figur 2). Mange av disse hadde i utgangspunktet svart at utdanningen deres hadde forberedt dem godt på å gjennomføre labarbeid. Dette tyder på at overgangen fra labarbeid på universitet til skolen kan være utfordrende. En lærer skriver: *lab i skolen med elever burde være et eget fag* på spørsmålet om hva de manglet i utdanningen sin med tanke på jobben som lærer. Vi tolker dette som en refleksjon rundt dette med at overgangen fra universitet til skole kan være utfordrende når det gjelder labarbeid. En annen lærer skriver også eksplisitt at man burde lagt mer vekt på labarbeid i lærerutdanningen.

Praksis i laboratoriet

Vi skal nå presentere analysen som handler mer spesifikt om hvordan lærerne beskriver sin praksis med labarbeid, og hvordan de integrerer naturvitenskapelige praksiser og tenkemåter i denne praksisen. Vi beskriver fire temaer fra analysen: *Formålet med labarbeid: innlæring av fagkunnskap*, *Frihetsgrader:* lærerstyrte forsøk der elevene følger en oppskrift*, Bruken av hypoteser i styrte forsøk* og *Labrapport*.

Formålet med labarbeid: innlæring av fagstoff

Lærernes beskrivelser av formålet med labarbeidet handler hovedsakelig om at det skal synliggjøre teorien eller gjøre det lettere for elevene å forstå fagstoffet: *skal få de til å forstå bedre*. Labarbeid skal dessuten få elevene til å bli nysgjerrige, motiverte og engasjerte. Andre begrunnelser er at det gjennomføres fordi det står i læreplanen at elevene skal bli kjent med utstyr, og at det gir variasjon og diskusjon. Bare én lærer skriver at det gjennomføres fordi naturvitenskapelig metode er en viktig del av faget. Nedenfor følger et utdrag fra gruppeintervjuet hvor lærerne diskuterer formål med labarbeidet.

Utdrag 1:

1. Sonja: *Det er jo innlæring av fagstoff. De trenger litt hands-on også. Så det går jo ikke bare på fagstoffet, men også på metode innen biologi.*
2. Linea: *For eksempel det å lære seg å bruke et mikroskop.*
3. Sonja: *Og å gjøre forsøk, og så gjenta forsøket for å se at du kanskje må gjøre det litt flere ganger før du kan trekke de aller sterkeste konklusjonene.*
4. Linea: *Mm.*
5. Sonja: *Sånn at det er jo mange tilleggsmomenter.*
6. Linea: *Ja, og å* være kritisk til ting man leser om *i undersøkelser og sånn:* «*Superenkel forskning viser*»*. Det er mye forskning som presenteres i media, som egentlig er «superenkel forskning».*

I dette utdraget fra gruppeintervjuet bekrefter lærerne at hovedhensikten deres med labarbeidet er å synliggjøre teorien eller lære fagstoffet (1). Samtidig kommer det frem at det også handler om å lære metode innen biologi (1). Dette blir blant annet beskrevet som at de skal lære å bruke vitenskapelig utstyr (2), og at det er viktig å gjenta forsøk flere ganger før man kan trekke sterke konklusjoner (3). Dette tolker vi som at Sonja refererer til viktigheten av å kunne reprodusere funn i naturvitenskapen. Linea presenterer en idé om at elevene dermed kan utvikle seg til å bli kritiske til såkalt «superenkel forskning» som de blir presentert for i media (6). Det at disse metodologiske aspektene blir beskrevet som *tilleggsmomenter* (5), tyder riktignok på at lærerne tenker at elevene kan lære disse metodologiske aspektene av å gjennomføre forsøk der hovedhensikten er å synliggjøre fagkunnskapen.

Frihetsgrader: lærerstyrte forsøk hvor elvene følger en oppskrift

Materialet inneholder hovedsakelig beskrivelser av *lærerstyrte* forsøk hvor elevene følger en oppskrift eller fremgangsmåte bestemt av læreren på forhånd: *Jeg bruker bare forsøk med en gitt problemstilling og fremgangsmåte*. Noen skriver riktignok at de har åpnere eller utforskende forsøk også: *Jeg lar elevene planlegge sine egne utforskninger*. I gruppeintervjuet blir dette med frihetsgrader diskutert en del, og det kommer særlig frem noen utfordringer knyttet til åpne eller utforskende forsøk. De utfordringene som kommer frem, er særlig tid, en stor læreplan, eksamen, usikkert faglig utbytte og svake elever.

Utdrag 2:

1. Sonja: *Når du gjør praktiske forsøk, kommer det an på hvor du er i løpet. Du begynner gjerne med styrte forsøk, ikke sant? Og du skulle ønske du hadde nok tid til å fortsette med mange åpne, men da går det fort mange økter. Også har du den læreplanen som sier at de skal lære alle de tingene. Sånn at det blir jo en kombinasjon av styrte og litt åpne. Men jeg kan ikke ta det for åpent, for det tar for lang tid.*
2. Linea: *Ja hvis du lager et stort åpent forsøk, da. Og så bruker man kanskje en uke eller noe på det. Og så går det aldeles ikke som planlagt. Ja, da kommer det jo mye erfaringer for elevene da, men det kommer kanskje ikke så mye faglig som du hadde tenkt. Så det er litt skummelt å åpne veldig opp, for du skal jo egentlig gjennom pensum i biologi før påske. De skal jo ha skriftlig eksamen, og da* må *du jo ha gått gjennom alle temaene.*

I dette utdraget bekrefter lærerne at de opplever utfordringer med åpne forsøk (1, 2). Det kommer blant annet frem at lærerne oppfatter at åpne forsøk tar mye tid (1). Linea sier at hun opplever at det faglige utbyttet av åpne forsøk er usikkert eller lite, særlig dersom forsøket ikke går som planlagt (2). Dette utdraget tyder på at lærerne opplever et motsetningsforhold mellom åpne forsøk og faglig utbytte. På grunn av vektlegging av fagkunnskapen blir det derfor få åpne forsøk.

Svake elever er også en utfordring med å skulle gjennomføre åpne forsøk. Kari sier at hvis hun bare hadde hatt litt sterkere elever, hadde det vært lettere å gjennomføre. Så beskriver hun hva hun hadde gjort *dersom* hun hadde hatt sterkere elever:

Utdrag 3:

> *Da kunne man gå gjennom teorien og snakket om hypoteser og sånt noe. Og de kan gjerne gjøre det, og de kan gjerne feile, men når man snakker om det etterpå og viser de riktige resultatene og hvorfor man fikk feil, så skjønner de det. Men mine elever får ikke det til – derfor blir det kort gjennomgang og oppskrift.*

I dette utdraget beskriver Kari et forsøk hvor det ser ut til å handle om å reprodusere de *riktige* resultatene. Samtidig ønsker hun å snakke med elevene om hypoteser. Etterpå skal elevene kunne diskutere hvorfor man fikk feil. Dette blir riktignok oppfattet som for utfordrende for svake elever, noe som gjør at Kari heller gjennomfører forsøk med en kort gjennomgang og oppskrift.

Bruken av hypoteser i styrte forsøk

Bruken av hypoteser ser ikke ut til å ha noen sammenheng med om forsøk er styrt eller ikke. I spørreundersøkelsen skriver noen at læreren både lager hypoteser og beskriver fremgangsmåten, mens andre skriver: *elevene lager hypoteser, og jeg formidler fremgangsmåte*. Dette tyder på at hypotese ofte blir brukt i forbindelse med lærerstyrte forsøk. Følgende utdrag er fra gruppeintervjuet og handler nettopp om hvorvidt man bør bruke hypoteser i forbindelse med styrte forsøk:

Utdrag 4:

1. Linea: Når jeg har lukkede forsøk, sier jeg at vi ikke har noen hypotese. Dere må skrive en hensikt, *altså hvorfor vi skal gjøre dette forsøket. Men å lage en liksomhypotese for å teste noe man vet resultatene av, det blir det ikke noe særlig læring av i det hele tatt. Så det m*å jo være i de åpne forsøkene*, det da.*
2. Sonja: *Jeg gjør jo klassiske forsøk, for eksempel om fotosyntese. Det er et forsøk der du skal se på ytre faktorer som påvirker fotosyntesen. En hypotese da er at ved økt lysintensitet øker fotosynteseaktiviteten – det er hypotesen. Og da er det jo læring i det. Det å sette ord på hvorfor det er denne sammenhengen. Og så gjør vi forsøket, og så får vi håpe at det bekrefter hypotesen, da. Hvis ikke er det noe galt med forsøksoppsettet.*

Disse lærerne er altså noe uenige om bruken av hypoteser i forbindelse med styrte forsøk. Linea (1) ser ut til å mene at hypoteser primært bør brukes i forbindelse med åpne forsøk, mens Sonja (2) mener elevene kan lære av å bruke hypoteser også når det finnes et fasitsvar. Det de skal lære av å lage hypoteser, er riktignok knyttet til fagkunnskapen: å sette ord på sammenhengen mellom lysintensitet og fotosynteseaktivitet (2).

Kari sier hun bruker ordet hypotese mye. Hun bruker det som en gjetning på hva som skal skje i forsøk, og deretter observer man om det stemmer. Dette utdraget er fra Kari:

Utdrag 5:

> *Undervisningen min skal være eksamensrelevant, og det er en av de måtene jeg får inn forskerspiren på, ved å bruke ordet hypotese mye. Det kan virke banalt enkelt, men det er jo metodikk på et eller annet nivå.*

I dette utdraget kommer det frem at Kari tenker at hun ved å bruke ordet hypotese mye også får inn forskerspiren og metodikk. Riktignok virker det som om hun hovedsakelig bruker begrepet som en gjetning på hva som skal skje i et forsøk der det allerede finnes et riktig svar.

Labrapport

Labrapport er også et sentralt tema når det gjelder labarbeid. Noen skriver at elevene alltid skriver rapport etter labarbeid, mens andre skriver at de bare gjør det av og til. Begreper som ofte blir brukt, er *utfyllingsrapport* og *full rapport*. En del knytter rapportskrivingen til den vitenskapelige sjangeren og skriver at de legger vekt på at rapporten skal være vitenskapelig oppbygd og følge en IMRaD-struktur: *rapport etter IMRaD-metode*. Andre beskriver utfyllingsrapporter hvor elevene bare fyller resultatene inn i et skjema som læreren har laget på forhånd. Begrepet rapport blir dessuten ofte brukt i forbindelse med vurdering: *Rapporten er en del av karaktergrunnlaget*. Lærerne i gruppeintervjuet beskriver det som utfordrende for elevene å skrive i IMRaD-sjangeren og at de bruker mye tid på å lære elevene dette. Siri sier at elevene kan velge hva slags rapporter de ønsker å skrive. Dersom de ønsker å gjøre det veldig bra i faget, kan de skrive i IMRaD-sjangeren, men ellers kan de skrive en enklere rapport. Lærerne er enige om at det å kunne denne sjangeren er særlig viktig for dem skal fortsette å studere biologi på universitetet. I forlengelsen av diskusjonen rundt bruken av hypoteser sier Sonja at elevene blir litt forvirret når de skal skrive konklusjon, for da må de skrive det samme som de sa i hypotesen.

DISKUSJON

Hensikten med denne artikkelen var å forstå de velkjente utfordringene knyttet til læreres praksis med labarbeid i lys av spenninger mellom de forskjellige relevante kulturelle institusjonene i biologilærernes utdanning. Det første forskningsspørsmålet vårt gikk ut på hvordan biologilærere rapporterer at utdanningen deres har forberedt dem på jobben som biologilærer. For å svare på dette spørsmålet har vi brukt tre spørsmål fra undersøkelsen, og validiteten til disse resultatene er derfor styrket gjennom triangulering av metoder (Creswell & Miller, 2000). Analysen av det første spørsmålet viser at majoriteten av lærerne rapporterer at utdanningen hovedsakelig har gitt dem faglig trygghet, og de trekker frem fagkunnskapen som det mest nyttige for jobben som biologilærer. Deretter er det å gjennomføre lab- og feltarbeid, samt skriving av labrapporter, det som flest lærere rapporterer at utdanningen har forberedt dem på i stor grad. Det lærerne i minst grad opplever at utdanningen deres har gitt dem, er didaktiske aspekter ved lærerjobben, som det å bruke elevenes refleksjoner i undervisningen, designe undervisningsopplegg og vurdere. Den kvalitative analysen viser at det særlig er bredden og dybden i fagkunnskapen som beskrives som nyttig for jobben som lærer. Det kommer også frem at flere lærere skulle ønske de hadde hatt mer didaktikk og mer kunnskap om undervisningsmetoder. Når det gjelder hvordan utdanningen har forberedt lærerne på å gjennomføre lab- og feltarbeid, er det også hovedsakelig erfaringen gjennom biologistudiet lærerne trekker frem som nyttig. Samtidig er det flere som skriver at de manglet kunnskap om lab- og feltarbeid i skolen. I våre resultater ser vi at lærerne bruker begrepene lab- og feltarbeid i forbindelse med egen forskererfaring, kurs på universitetsnivå i biologi, kurs i lærerutdanningen og sin egen praksis i skolen, altså i forbindelse med flere forskjellige kulturer. Et problem med at begrepet *labarbeid* blir brukt på tvers av de relevante kulturene for lærere, er at labarbeid har forskjellig funksjon i disse kulturene (Osborne, 2014). En lærer skriver at *labarbeid i skolen med elever burde være et eget fag*, og vi har tolket dette som en refleksjon rundt dette med at labarbeid i skolen på mange måter er noe annet enn på universitetet. Vi vil derfor argumentere for at dette gjør kryssingen av kulturgrensen fra en naturvitenskapelig kultur til en skolekultur ekstra utfordrende, særlig når det gjelder labarbeid.

I det andre forskningsspørsmålet ønsket vi å undersøke lærernes beskrivelser av egen praksis i forbindelse med labarbeid, med særlig vekt på hvordan de integrerer naturvitenskapelige praksiser og tenkemåter i labarbeidet. Det at labarbeid blir brukt på tvers av de forskjellige relevante kulturene for lærere, altså i forbindelse med forskjellige diskurser, kan innebære noen utfordringer for lærernes praksis med labarbeid. Dette gjelder kanskje særlig når elementer som opprinnelig stammer fra en naturvitenskapelig diskurs, skal overføres til en skolekontekst hvor labarbeidet har et annet formål, nemlig å synliggjøre fagkunnskapen. Vår analyse av lærernes beskrivelse av praksis i forbindelse med labarbeid stemmer godt med den eksisterende forskningen på dette området: Lærerne beskriver hovedsakelig lukkede forsøk hvor hensikten nettopp er å formidle fagkunnskapen (Hofstein & Kind, 2012; Högström et al., 2006; Welzel et al., 1998). Vår analyse viser riktignok også at lærerne tenker at elevene kan lære om metode ved å delta i delta i slike forsøk som hovedsakelig har til hensikt å illustrere fagkunnskapen. Flere forskere anbefaler at man skiller tydelig mellom ulike mål med labarbeidet (Hodson, 2014; Séré, 2002). Grunnen til dette er blant annet at dersom forsøk er veldig åpne, er det ikke sikkert at elevene kommer frem til den fagkunnskapen læreren har planlagt. Er de derimot for lukket, slutter de å likne på måten forskere jobber på, og dette bidrar til å gi et forenklet bilde av naturvitenskapens egenart (Hodson, 2014). Vår analyse viser riktignok at lærerne integrerer aspekter ved naturvitenskapelige praksiser og tenkemåter selv om forsøkene handler om å reprodusere resultater som er bestemt på forhånd. Begreper som opprinnelig kommer fra en naturvitenskapelig diskurs, får dermed en ny funksjon i denne lærerstyrte praksisen. Dette stemmer med tidligere funn gjort av Gyllenpalm og Wickman (2011a, 2011b) som ser dette i sammenheng mellom en sammenblanding mellom undervisningsmetoder og naturvitenskapelige metoder (Gyllenpalm, 2010). I forskningssammenheng betyr *hypotese* en tentativ forklaring (Chalmers, 1999), men i praksisene Sonja og Kari beskriver i gruppeintervjuet er hypotesene åpenbart ikke tentative. Sonja reflekterer litt rundt dette når hun sier: *også får vi håpe at det bekrefter hypotesen da, hvis ikke er det noe galt med forsøksoppsettet*. Gyllenpalm, Wickman og Holmgren (2012) beskriver en *hypotesefrykt* som oppstår når elevene må prøve å gjette hva som er den rette hypotesen i slike forsøk. Dette tyder på at elvene forstår at dette spillet egentlig handler om å gjette, eller vite, den *riktige* hypotesen. Våre resultater tyder også på at begrepet labrapport får en ny funksjon i lærernes praksis i forbindelse med labarbeid som skiller seg fra meningen i en naturvitenskapelig diskurs. Labrapporten har sin opprinnelse i den eksperimentelle rapporten hvor strukturen reflekterer stegene i forskningsprosessen (Martin, 1992). Knain (2015) påpeker at elevene må rekonstruere den naturvitenskapelige sjangeren i en skolekontekst når de jobber med rapporter og har også vist at dette kan være utfordrende for elever (Knain, 2005). Våre resultater viser også at lærerne bruker mye tid på å lære elevene å skrive i denne sjangeren og at sjangeren kan være forvirrende og utfordrende. For eksempel sier Sonja at elevene blir litt forvirret når de må gjenta hypotesen i konklusjonen, men at hun forteller dem at det er greit at de gjentar seg selv litt her.

Våre resultater peker på utfordringer med å overføre naturvitenskapelige praksiser og tenkemåter fra en naturvitenskapelig diskurs til en skolediskurs. Ifølge Gyllenpalm, Wickman og Holmgren (2011a) kan sammenblandingen mellom utforskende arbeidsmetoder og naturvitenskapelige metoder hindre lærere i å ta opp aspekter ved naturvitenskapens egenart eksplisitt i undervisningen. Fra vårt teoretiske perspektiv er det også et viktig poeng at vi lærer *gjennom* språk, hvor den sosiale og kulturelle konteksten utgjør en viktig del av læringen (Halliday, 2003, Knain, 2015). Fra dette teoretiske perspektivet på språk og læring vil vi derfor si at det elevene først og fremst lærer, er en slags *skolevariant* av naturvitenskapelige praksiser og tenkemåter som er ganske annerledes enn i den naturvitenskapelige diskursen. Denne skolevarianten kan karakteriseres som en egen sjanger. Et viktig spørsmål blir: Hva lærer egentlig elevene av denne «skolevarianten» av naturvitenskapelige praksiser og tenkemåter? Og i hvilken grad forberedes de på fremtidig deltakelse i andre diskurser? Knain (2015) påpeker at elevenes tekster kan ses på som en indikasjon på om læringskonteksten er passende. Dersom elevenes tekster likner tekstene i den naturvitenskapelige diskursen, er det altså et tegn på at læringskonteksten er god. Våre resultater tyder riktignok på at en hovedutfordring for lærerne er å designe passende kontekster for å få frem naturvitenskapelige praksiser og tenkemåter. Lærerne i vår studie etterlyser også nettopp kunnskap om design av undervisning og konkrete eksempler på undervisningsopplegg. I Norge har vi nå fått en ny læreplan hvor naturvitenskapelige/biologiske praksiser og tenkemåter skal prege arbeidet med de andre kjerneelementene i fagene (Utdanningsdirektoratet, 2019). Våre resultater tyder på at dersom lærerne ikke får støtte i dette arbeidet, er det en fare for at dette blir implementert i tradisjonelle undervisningsmetoder hvor naturvitenskapelig praksiser og tenkemåter får en ny mening. Lærerne i vår studie etterlyser didaktisk kunnskap generelt og mer spesifikt kunnskap om gjennomføring av lab- og feltarbeid i skolen. På grunn av denne mangelen i mange læreres utdanning blir det derfor opp til lærerne selv å overføre kunnskap og erfaring med labarbeid fra universitetet til undervisningsmetoder i skolen. Vi har særlig pekt på utfordringer med å overføre praksiser og tenkemåter fra en naturvitenskapelig diskurs til en skolediskurs. Resultatene våre viser at den rene biologiutdanningen ser ut til å spille en viktig rolle for lærere; de beskriver den faglige tryggheten og erfaring med lab- og feltarbeid som særlig nyttig for jobben som biologilærer. Det finnes riktignok ikke så mye forskning på hva som egentlig foregår i de *rene* naturvitenskapelige utdanningene. Det finnes noe forskning på labarbeid på universitetsnivå som tyder på at labarbeid gjennomføres på samme lærerstyrte måte som i skolen (Séré et al., 1998). Likevel vil vi si at dette er et område hvor det er behov for mer forskning. Slik biologilærerutdanningen er nå, tilbringer studentene mesteparten av tiden sin som studenter ved de *rene* naturvitenskapelige institusjonene. Kunnskap om hva som egentlig foregår her, er derfor svært viktig for å forstå lærernes utfordringer og hvordan lærerutdanningsinstitusjonene kan støtte den kulturelle overgangen fra en naturvitenskapelig kultur til en skolekultur.

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Errata

p. viii Table of contents. Summary of findings. 5.3. Title of article 3 changed to correspond with correct title in the article. Changed from 'Students conceptual sense-making through modelling in molecular biology: the role of drawings, gestures and material artifacts' to 'Students' model-based reasoning in immunology: the role of drawings, gestures and material artifacts'. This changed is done throughout the extended abstract all places where it was written this way.

p. viii 5. Summary of findings, 5.2. Title of article 2 changed from 'Undergraduate students multimodal reasoning through representation construction in immunology' to the correct title: 'Undergraduate students multimodal reasoning: representation construction in immunology the laboratory'. This change is done everywhere the title is written this way.

p. ix Article 1, 2 and 3 changed to Article I, II and III. This change is done throughout the extended abstract.

p. ix Article 3. 'Manuscript submitted to Science Education, manuscript submitted for review' changed to 'manuscript to be submitted for review in Research in Science Education'.

p. 4 1st paragraph. Colon in reference (…Nersessian, 2008: Osborne, 2014) changed to semicolon.

p. 13 3rd paragraph. Line 5. 'representation' changed to 'representations'

p. 43 My coauthor written 'Tone Fredsvig Gregers' is changed to 'Tone Fredsvik Gregers'

p. 44 5.2 Article 2… '(manuscript submitted for review) Science Education' changed to '(manuscript to be submitted for review) Research in Science Education'