Acknowledgments

This master's thesis in science didactics at NTNU in Trondheim marks the end of a five-year education in teaching.

As someone who is interested in almost anything 'scientific', and especially those topics that are counterintuitive, it has been a pleasure to research student understanding of electromagnetic induction. Student reasoning can sometimes prove insightful and delightfully elegant, while too much information can sometimes clog the mind. As giving as this study has been, many questions remain unanswered. I would love to keep exploring the subject, teaching many more students about induction, but unfortunately time constraints put a stop to this.

As the work on this thesis now comes to an end, an uncanny melancholy resides in me. Perhaps weary of the future, I feel myself reflecting on the past. If someone would have told me 10 years ago that today I would be finishing a master's thesis in science didactics, I would not have believed it. Five years of demanding work have resulted in this book, something that makes me incredibly proud.

I wish to express my thanks to my supervisor Nils Kristian Rossing, who has contributed both creatively and professionally. I am grateful to my fellow students in the study room, for always being there to offer some advice, or simply listen to my problems. I also wish to thank my brother for proofreading the thesis. I thank anyone else who, directly or indirectly, has helped my completing this thesis, either professionally or emotionally. This includes the cafeteria staff at the Moholt campus, who were always ready to serve some 'risengrynsgrøt' on Fridays.

My greatest gratitude, however, goes out to my loving wife and children. Without you, this work would have never even started. I apologize strongly for my absence these last months, and thank you for being so patient.

Trondheim, 22nd of May 2017

Jorn de Vlieger

Sammendrag

Emnet til denne masteroppgaven er undervisning av elektromagnetisk induksjon til ungdomsskoleelever. På tross av at elektromagnetisk induksjon er blant fagene som blir oppfattet som mest utfordrende blant både elever og lærere, er det blitt gjennomført relativt få studier som omhandler didaktikken angående elektromagnetisk induksjon. De fleste av studiene som omhandler faget har blitt gjennomført med fokus på forståelsen av universitetsstudenter. Forskningen angående yngre elever er dermed mangelfull. Denne studien diskuterer resultatene av et utforskende undervisningsopplegg med to grupper av tre elever. Undervisningsopplegget bruker konkrete materialer som elevene kan undersøke for å øke forståelsen sin. Studien bruker en blanding av grounded theory, case- og quasieksperimentdesign, og samler data gjennom observasjoner og intervjuer etter opplegget. Formålet med studien er å definere viktige faktorer som påvirker ungdomsskoleelevers forståelse når de lærer om elektromagnetisk induksjon.

Studien har funnet at, selv om annen forskning har påpekt fagets kompleksitet, en konseptuell forståelse av elektromagnetisk induksjon er mulig for ungdomsskoleelever å oppnå. Noen faktorer som påvirker elevers læring ved undervisningsopplegget har blitt observert. For det første spiller det magnetiske feltkonseptet en viktig rolle i elevers læring av konseptene involvert i elektromagnetisk induksjon. I motsetning til det meste av litteratur på emnet, har elevene ikke bare forstått feltkonseptet, men har også funnet og beskrevet det gjennom utforskning. Elevenes forståelse var derimot begrenset, i tillegg til indikasjoner på konstruerte feiloppfatninger. For det andre bekrefter studiet at små kognitive forstyrrelser er mer effektiv for læring når elever har lite forkunnskaper, som er tilfellet ved unge nybegynnere. Spesielt kunnskap om elektrisitet virker å være hjelpsomt. Det bidrar til bedre utforskning og tolkning av observasjonene. Et annet funn er at den konseptuelle, utforskende tilnærming bidrar til at elevene bygger relativt omfattende kognitive strukturer om elektromagnetisk induksjon. Elevene i studiet kunne koble flere elementer angående elektromagnetisk induksjon sammen i deres forklaringer, noe som viser forståelse av nøkkelrelasjoner. Til slutt, den praktiske utforming av undervisningsopplegget kan påvirke utfallet betydelig. Studentene blir lett distrahert av trivielle elementer ved materialet brukt for utforskning.

Abstract

The topic of this master's thesis is the teaching of electromagnetic induction to secondary school students, approximately 15 years old. Despite the electromagnetic induction being amongst the subjects experienced as most challenging by both students and teachers, there have been relatively few studies on didactics regarding electromagnetic induction. Almost all the studies that have been done on the subject have focused on the understanding of university level students. Thus, a lack of research with younger students exists. This study discusses the results of an exploratory lesson with two groups of three students, using concrete material to investigate phenomena and gain a conceptual understanding. The study approaches the subject through a mix of grounded theory, case- and quasi-experiment design, using observations and interviews to gather data. This study aims to define important factors affecting secondary school students' conceptual understanding when learning electromagnetic induction.

This study found that, although research has emphasized the complexity of the subject, a conceptual understanding of electromagnetic induction seems possible for secondary school students. Some key aspects affecting student conceptual learning during the lesson were observed. Firstly, the magnetic field concept proved a very effective tool for learning the concepts of electromagnetic induction. Contrary to most literature on the topic, the students not only understood the concept but also found and described it through investigation. The students' understanding was limited, however, and indications exist of constructed misconceptions. Secondly, the study confirmed that small, cognitive perturbations are more effective for learning when learners possess little prior knowledge, as is the case with young novices. Especially knowledge of electricity seems to be helpful, allowing for better investigation and interpretation of observations. Another finding is that the conceptual, investigative approach allows the students to build a relatively comprehensive cognitive structure of electromagnetic induction. Students in the study were able to connect several elements involving electromagnetic induction in their explanations, revealing an understanding of key relationships. Lastly, the practical outline of the lesson can greatly affect the outcome. Students were easily distracted by trivial elements involving objects used for investigation.

Contents

Table of Figures

Table of Tables

Chapter 1: Introduction

Electromagnetism is full of counterintuitive phenomena, which can almost seem as magic. The contactless interactions are fascinating to many students. Electromagnetism is among the fundamental forces known to man, such as gravity. This means, that the existence of these forces cannot be explained, only observed. They are the forces at the end of every explanation, where our understanding of reality stops. Additionally, magnetism and electricity are intertwined in a way that few people thoroughly understand, if anyone at all. They are, in fact, two sides of the same coin, which is why the forces can interact. Electromagnetic induction is of huge importance to our society, as it allows us to generate and distribute electricity on a large scale.

1.1 Problem statement and purpose of this study

Electromagnetism is amongst the most difficult subjects for university students. Despite of this, "studies have been sparse and separated" (Thong & Gunstone, 2007, p. 31). The research that has been done on the subject reports mainly of fragmented knowledge among students. Students also struggle with the complex nature of the subject, as it is composed of abstract concepts, perpendicular relationships that are constantly changing over time. It is exactly this abstract nature which makes it difficult for teachers to educate students. Studies on student understanding are in almost every case directed towards university levels, occasionally senior high school or upper secondary school. Textbooks have received critique for being unable to convey electromagnetism; the mathematical representations are emphasized too much, while underlaying concepts sometimes are neglected.

Vitensenteret in Trondheim has been developing an exhibition on electromagnetism. 'Vitensenter' translates to 'Science center', a museum which focuses on conveying popular science and math to children and adults through experiences. Vitensenteret has also been expanding their role in education; offering experiences for schoolchildren outside of the classroom. Because of the complexity of electromagnetism Vitensenteret wants to implement a complementary workshop or teaching plan to support the exhibition. The educational stance of Vitensenteret has provided the starting point of this study.

Learning by experience has long been an important part in teaching science. An education in science consists not only of learning the facts, but also the concept of scientific discourse. Even though Dewey is famous for the slogan “learning by doing”, he clearly stated that experience alone is not enough, one must reflect upon the experience to learn from it (Dewey, 2012). Inquiry learning, based in authentic settings, can provide the right conditions for students to form a complete understanding.

The idea of a lesson plan on electromagnetism for secondary school students, aged around 15 years, was formed. Secondary school students, however, are not likely to have the mathematic capacity to work with most of the equations involving electromagnetism. Therefore, a lesson on the basic concepts and relationships involved in electromagnetic induction would be better suited.

Based on the above mentioned, this study will analyze the results of an exploratory lesson in the basic concepts of electromagnetic induction. A precise problem statement can be formulated:

What are the key factors in exploratory teaching of basic concepts in electromagnetic induction to students in secondary school?

Three research questions were formulated to aid the discussion of the results:

1. What is the most important prior knowledge needed to understand electromagnetic induction?
2. What is the impact of using concrete material when learning the concepts of electromagnetic induction?
3. How does each step in the lesson contribute to conceptual learning and construction of an understanding of electromagnetic induction?

To this purpose, a lesson plan has been developed based on literature on the subject and the expected cognitive level of secondary school students. The lesson emphasizes independent exploring by students with real objects, divided into several activities, each showing different concepts involved in electromagnetic induction. Together, the activities build towards an understanding of the subject. This study utilizes a qualitative approach; the lessons were videotaped and results were based on observations from the videos, as well as interviews conducted with each group approximately one week after the lesson.

1.2 The structure of this thesis

This thesis starts with a brief review of the current scientific view on the basic concepts of electromagnetism. The concepts reviewed here have been central both in the lesson and in the discussion. In the next chapter, relevant theory and research will be presented. Amongst other topics, inquiry based learning and reported problems in student understanding of electromagnetism will be reviewed. The methodology chapter briefly discusses the research design of the study, and presents the lesson plan. The results of the data collection are presented with observations and direct citations from the lessons and interviews. These results will be discussed with regards to the theory and the research questions. Finally, a conclusion determining some key factors in teaching electromagnetic induction to secondary school students is presented.

Chapter 2: Scientific understanding of electromagnetic induction

In this chapter, a brief review of the fundamental principles needed to understand electromagnetic induction is presented. The theory will be reviewed mostly conceptual, as a more detailed explanation is not necessary. Magnetism is perhaps most commonly known in the form of refrigerator magnets, and electromagnetic induction as induction cooktops. In fact, the phenomenon is widely used and supports our society in various ways, from phone chargers and cooktops to transportation and power supply.

2.1 Magnetism

The force we understand as magnetism is produced by electric charges in motion. As is with the other fundamental forces, such as gravity and electricity, magnetism only effects other objects of the same nature: electric charges in motion. This immediately illustrates the relative character of magnetism. To the observer, a charge only produces a magnetic field if it moves relative to the observer. Otherwise, only an electric field is observed. However, in any reference frame the resulting forces will be alike.

A charge traveling through space at a constant speed produces a steady electric current. This steady, constant electric current produces a constant magnetic field, $\vec{B}$. Magnetic fields are vector

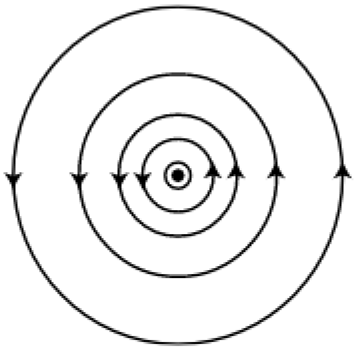

Figure 1: Magnetic field lines of a straight wire with the current pointing out of the page. The strength of the field diminishes as one moves further from the current (Kirkby & Close, 2011, p. 117).

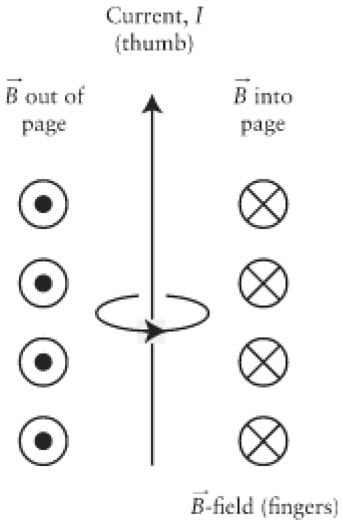

Figure 2: Direction of the current flow and magnetic field ($\vec{B}$-field) using the right-hand screw rule (Kirkby & Close, 2011, p. 117)

fields and can therefore be described with field lines. The field curves in circles in a 90-degree angle to the direction of the current (Figure 1). This stands in contradiction with electric field lines, which can be drawn from positive to negative charges. An infinitely long straight wire produces a magnetic field evenly distributed infinitely along the wire. The direction of the magnetic field can be determined using the right-hand screw rule (Figure 2).

A charge moving through a magnetic field (stationary in the observer's reference frame) will experience a magnetic force, $\overrightarrow{F_B}$. The force on a particle with charge q, velocity $\vec{v}$ in a magnetic field $\vec{B}$ is perpendicular to both $\vec{v}$ and $\vec{B}$:

$$\vec{F}_B = q(\vec{v} \times \vec{B})$$

If the alignment of $\vec{v}$ and $\vec{B}$ is perfectly perpendicular, the particle will therefore follow a circular trajectory, given that $\vec{B}$ is uniform (Figure 3). The direction of the magnetic force can be found using another right-hand rule. The index finger points in the direction of the velocity, the thumb in the direction of the magnetic force and the rest of the fingers represent the direction of the magnetic field. Looking at Figure 3, it is worth pointing out that the moving particle will create its own magnetic field, which is resisting the magnetic field causing the change in direction.

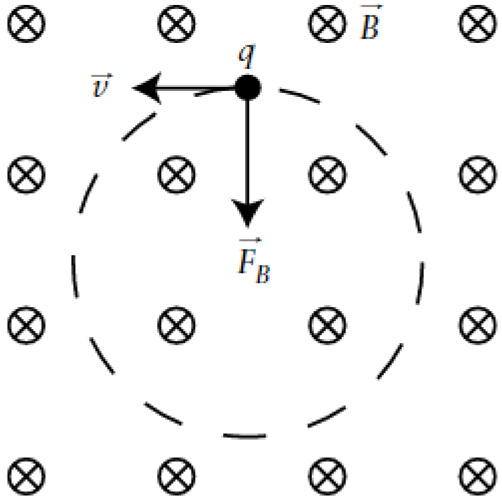

Figure 3: The trajectory of a charged particle q in a uniform magnetic field $\vec{B}$ (Kirkby & Close, 2011, p. 119)

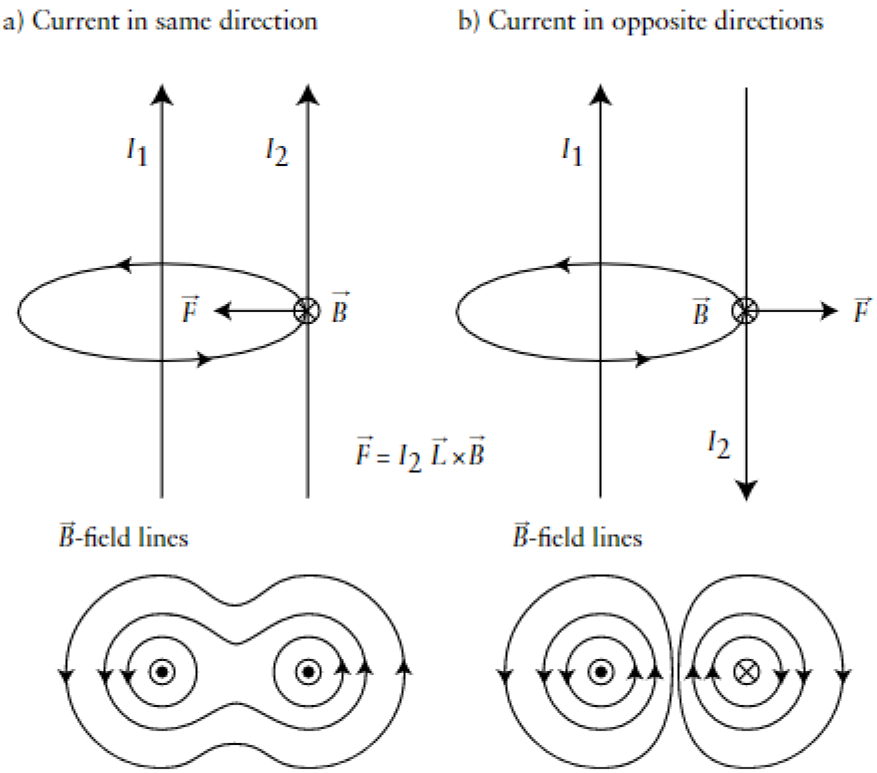

Figure 4: Magnetic forces between two parallel, current carrying wires (Kirkby & Close, 2011, p. 120).

Magnetic attraction or repulsion can be explained using to parallel, current carrying wires, I_1 and I_2 (Figure 4). When the currents are flowing in the same direction (a), it creates an area of lower field density. Trying to reach the lowest state of energy, the wires will pull towards each other. This distributes the magnetic field as much as the system allows. Currents flowing opposite directions (b), will repulse each other due to a higher density of magnetic field between them. Alternatively, one can find the direction of the force that a charged particle moving (I_2) through the other current's (I_1) magnetic field experiences, and vice versa.

A charge traveling in a circular motion will generate a magnetic dipole moment. The direction of the magnetic dipole moment can be found using the right-hand screw rule. In a magnetic dipole, the poles can be identified as the north and south pole, with field lines going from the north to the south pole. Drawing the magnetic field of a magnetic dipole with field lines (Figure 5), it resembles the magnetic field of a bar (solid) magnet. This can be explained by the way magnetism in solid

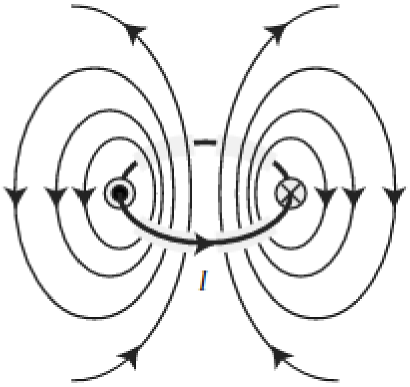

Figure 5: The magnetic field of a magnetic dipole (Kirkby & Close, 2011, p. 127)

magnets is generated. A popular misconception is that electrons circle the nucleus in atoms. In addition, the electron has a spin itself. This means that every electron should generate a magnetic dipole moment, both with its own spin and the orbit around the nucleus. Figure 6 illustrates a hydrogen atom with electron, with dipole moments drawn in. Electrons, however, do not orbit the nucleus, they inhabit orbitals. This means that in larger atoms, depending on the orbital, an electron can either generate or cancel out its own dipole moment. Together with the other electrons of an atom, they create the total atomic magnetic dipole moment. In most materials, the electrons and the atoms themselves are ordered in such a way that the magnetic dipole moments cancel each other out. However, in magnetic materials, a bigger part is aligned parallelly which results in an overall magnetic moment of the material itself.

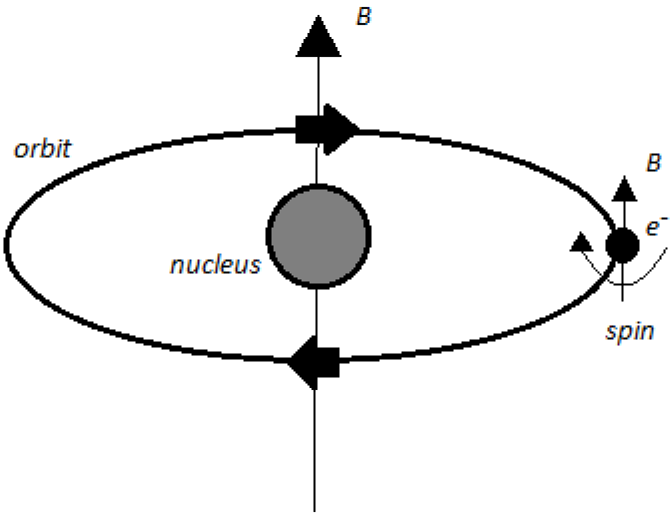

Figure 6: The atomic magnetic dipole moment generated by an electron.

2.2 Electromagnetic induction

A changing magnetic field produces an electric field, and a changing electric field produces a magnetic field. Together, these two phenomena constitute the topic of electromagnetic induction. In 1831, Faraday found that moving a closed loop of wire through the magnetic field of a magnet will cause a current to run in the loop. The changing magnetic flux induces an electric field in the wire. Magnetic flux, Φ_B, is defined as the intensity of a magnetic field through a surface. It can be represented as the number of field lines through the surface. To calculate the electric field induced in a looped wire the change of magnetic flux through the surface area that loop creates is needed. This formula is known as Faraday's Law:

$$\mathcal{E} = -\frac{d\phi_B}{dt}$$

This equation shows a larger change in magnetic flux over a smaller time period will induce a stronger electric field. The induced magnetic field can be illustrated by imagining a section of wire moving through a magnetic field (Figure 7). This is known as a motional electromagnetic field, caused by relative movement of the magnetic field and the charges in the wire. As represented by the first equation shown,

$$\vec{F}_B = q(\vec{v} \times \vec{B})$$

The free electrons in the wire experience a force $\vec{F}_B$ because of their movement through the magnetic field, $\vec{B}$. This causes them to drift towards the left, creating a potential difference along the wire. Therefore, an electric field is induced. The wire 'cuts' the magnetic field lines, which means the situation is alike particles moving through a magnetic field, as described above.

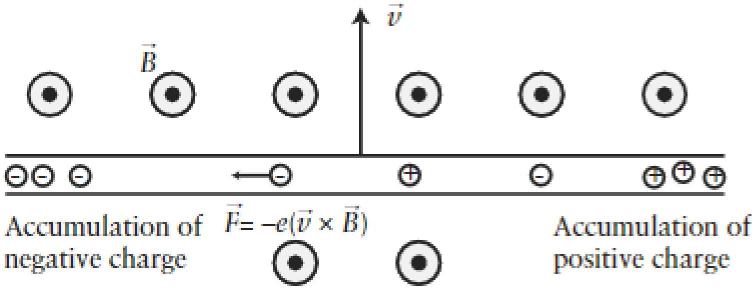

Figure 7: Induced electric field by moving a section of wire relative to a magnetic field (Kirkby & Close, 2011, p. 148)

An induced electromagnetic field is created when the wire is fixed and a changing magnetic flux is used to induce a current. Rather than the wire cutting magnetic field lines, the change in magnetic flux in the area linked by the looped wire is referred to for generating an electromagnetic field. Charges do not differentiate between the moving magnetic field of a magnet and the changing magnetic field of a solenoid, as the two situations are similar in that frame of reference. Note that the magnetic field does not have to go through the wire itself, a changing magnetic flux through any part of the surface area enclosed by the loop will induce a current. However, in the case of a looped wire containing a changing magnetic flux, all charges in the wire will experience a magnetic force. This means that, instead of creating a potential difference in part of the wire as illustrated in Figure 7, there exists an electric field through the length of the entire loop which drives the current.

The wire does not have to be looped only once, it can be looped many times, creating a solenoid, or coil. If tightly wrapped, the number of turns will directly multiply the strength of the induced electric field, given that all turns experience the same magnetic field strength at one moment:

$$\mathcal{E} = -N\frac{d\phi_B}{dt}$$

Each turn of the coil will contribute equally to the induced electromagnetic field. In other words, the voltage induced in the circuit of the coil is directly dependent on the number of turns. Lentz's Law describes the direction of the induce current. It states that the current always flows in the direction that opposes the change in magnetic flux. It is a law of nature to oppose change, the system works to keep the net flux equal. For instance, if a magnet is pushed towards a solenoid, then a current begins to flow that generates a magnetic field in the opposite direction of the magnet's field (repulsing the magnet). When the magnet is pulled away, the solenoid generates a magnetic field in the same direction of the magnets magnetic field (attracting the magnet). This makes it possible to transfer energy into the system, which is utilized by generators. Reversely, electricity can be converted to movement, as is done by electromotors. Essentially, these two are the same thing.

The nomenclature used in static electromagnetism and traditional circuits obeying Kirchoff's law, such as electric fields (caused by potential differences), seems to become unfitting when discussing electromagnetic induction. In a circuit with a current driven by a changing magnetic flux, where is the potential difference? Where is the electric field, if there is no difference in potential? These terms should be avoided if possible when teaching electromagnetic induction.

For further reading, ‘Physics’ by Kirkby and Close (2011) is recommended.

Chapter 3: Theory and relevant research

The following chapter represents a selection of the literature and research most relevant to the research questions.

3.1 Learning science

Vitensenteret's learning principles are grounded in inquiry based learning. Exhibitions at Vitensenter are as open as possible, letting the visitor explore and play with the exhibitions freely. Many of the (inter)active exhibitions are designed by the APE philosophy, Active Prolonged Engagement. Exhibitions should consist of multiple levels in understanding, to make the visitor interact longer with the exhibition and therefore learn more. The perfect APE exhibition draws the visitor in, by looking interesting enough to the visitor. Engagement is achieved by offering a problem that the visitor can solve within the exhibition's framework. Prolonged engagement is achieved by the exhibition having multiple layers, most often multiple solutions. (Tisdal, 2004). The educational approach of Vitensenteret has influenced the thesis to adopt inquiry based learning and student activity in the lesson plan, as the thesis is related to Vitensenteret.

3.1.1 Inquiry based learning

Dewey is often characterized as the father of practical learning, known for the slogan "learning by doing". In his book "Democracy and education", first published in 1916, he argued that learning must happen through experience. Without the correct experience, learning can be meaningless. But, on the other hand, activity alone does not guarantee learning either. According to Dewey, learning is noticing a consequence of change. He exemplifies this with a child burning his finger in a flame. One could try to tell the child that it hurts to put your finger in a flame, but the child cannot truly understand the meaning if it has never burned itself. Neither is putting a finger in the flame an experience, not before the movement is connected to the pain because of it. Afterwards, putting a finger in a flame directly means to burn yourself (Dewey, 2012). In his book "How we think", first published in 1910, he described how scientific thinking can be achieved. The experimental aspect becomes important in learning processes. The problem method is based on the students experiencing a problem which they are motivated to solve. They have to examine the problem, collect data and form hypotheses (Dewey, 1997). Many elements of Dewey's ideas influenced education reformers in first half of the 20th century, with numerous of his texts cited.

Dewey’s scientific methods helped others find support for their theories. With his book “How we think”, Dewey helped to combine curriculum design, psychological research and sociological theory by their scientific method. This produced problem-based curricula (Fallace, 2011). Dewey was a big inspiration for Bruner (Bruner, 1979), who published several influential articles in the sixties and seventies. Bruner based his theories on the thought that every topic has its own fundamental ideas, to which all the facts can be linked to, and which can be shown concrete on the student’s level. He contrived the term scaffolding, which describes how learners work their way towards new knowledge by building on previously learned knowledge. Bruner though that information could be learned by learners of any level, if it is accordingly organized. Bruner emphasized the understanding of the context and the relationship of the topic to be learned. (Bruner, 1966, 1975, 1979). This way of thinking is not unlike Piaget’s constructivist theory, although he describes the process of actual learning. Opposite to Bruner however, Piaget argued that learning potential is genetically connected to the learners age, making it possible for the learner too immature to learn certain topics. Piaget represented an individual’s understanding of the world as cognitive schemes, which are the way knowledge is structured in the mind. Learning happens, as described by Piaget, when the learner witnesses a phenomenon (or information) that creates an imbalance in his cognitive state. This imbalance comes from the learner’s cognitive schemes being unable to explain said phenomenon. If the learner is to understand the phenomenon, it must have a cognitive scheme which can explain it. The learner can assimilate the new knowledge, which means to adjust an existing scheme to fit. If this is not possible, the learner must create an entire new scheme to ‘accommodate’ the phenomenon, and possibly also other knowledge already known (Piaget, in Imsen, 2005).

Today, inquiry based science education is incorporated in most curricula around the world (Abd-El-Khalick, 2004). In 2006, a counsel assigned by the European Union recommended the use of an increase of inquiry based learning methods in science education. With this they hope to raise interests in science (Rocard et al., 2007). However, there currently exists no consensus on the meaning of inquiry for science education (Barrow, 2006). The US National Science Education Standards connect inquiry to the way scientist work. They define the use of inquiry in schools as:

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers,

> explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries (National Research Council, 1996, p. 23)

In this definition by NSES, the use of inquiry in science education can be interpreted as both a method to learn science by, as well as a skillset in its own that students should master. Indeed, a third component can be identified, that of knowledge of inquiry (Lederman, 2006). Minstrell provided a looser definition of inquiry, stating that an inquiry can be considered complete when "we should know something we did not know before we started. Even when our investigation fails to find the answer, at least the inquiry should have yielded a greater understanding of the factors that are involved in the solution" (Minstrell, 2000, i Barrow, 2006, p. 205).

In Norway inquiry in science education is addressed, largely in its entirety, in a main subject area in the curriculum named "Forskerspiren", or in English "The budding researcher". The Norwegian Directorate for Education and Training (Utdanningdirektoratet) defines the subject area as follows:

> Teaching in natural science presents natural science as both a product that shows the knowledge we have acquired thus far in history and as processes that deal with how knowledge of natural science is developed and established. These processes involve the formulation of hypotheses, experimentation, systematic observations, discussions, critical assessment, argumentation, grounds for conclusion and presentation. The budding researcher shall uphold these dimensions while learning in the subject and integrate them into the other main subject areas (The Norwegian Directorate for Education and Training, 2013, p. 3).

In likeliness with NSES' definition of inquiry, this opens for multiple interpretations. Knain and Kolstø (2011) argued that "the budding researcher's" goal can either be understood as students being able to describe the scientific method in scientific processes or as students being able to work with scientific inquiry.

In the concluding comments of reporting on several projects of inquiry, Stavik-Karlsen and Grey (2013) noted that, in order for authentic inquiry to take place, students should feel ownership to their questions. This improves student motivation and interest. The inquiry, however should take place within a clear framework. Inquiry based learning can prove challenging to students, especially those new to the method. Normally used to detailed learning instructions, students can seem doubtful of their own skills (Erstand & Klevenberg, 2011). Cognitive sciences however, state that the capacity of the short-term memory is very limited, capable of memorizing only very few

Table 1: Classification of inquiry, with added shadows (Fradd et al. (2002) and Sutman et al. (1998), in Walker, 2015, p. 19)

Inquiry Level	**Questioning**	**Planning**	**Implementing**	**Concluding**		**Reporting**	**Applying**
			Carrying out plan	**Analyze Data**	**Draw Conclusions**		
0	**Teacher**	**Teacher**	**Teacher**	**Teacher**	**Teacher**	**Teacher**	**Teacher**
1	**Teacher**	**Teacher**	Students/ Teacher	**Teacher**	**Teacher**	Students	**Teacher**
2	**Teacher**	**Teacher**	Students	Students/ Teacher	Students/ Teacher	Students	**Teacher**
3	**Teacher**	Students/ Teacher	Students	Students	Students	Students	Students
4	Students/ Teacher	Students	Students	Students	Students	Students	Students
5	Students	Students	Students	Students	Students	Students	Students

elements (Miller, 1956). Inquiry based learning must account for this, as too much information can confuse and limit the inquiry.

Inquiry in science lessons can be classified according to the amount of freedom students have in their inquiry. One commonly used classification is constructed by Fradd et al. (2002) and Sutman et al. (1998), and is represented (amongst others) by Walker (2015), see Table 1. Although complex, this classification is useful in describing an inquiry based lesson. It is a valuable tool to analyze and improve problem based learning (Walker, 2015).

3.1.2 Inquiry and constructivism

In an article comparing inquiry learning internationally, Niaz (2004) points out not only required to learn scientific facts but also the concept of scientific inquiry. He quotes Rutherford:

> When it comes to the teaching of science it is perfectly clear where we, as science teachers, science educators, or scientists, stand; we are unalterably opposed to the rote memorization of the mere facts and minutiae of

> science. By contrast, we stand foursquare for the teaching of the scientific method, critical thinking, the scientific attitude, the problem-solving approach, the discovery method, and, of special interest here, the inquiry method (Rutherford, 1964, p. 80)

Niaz (2004) states that presently, a discussion of inquiry cannot be separated from the discussion of constructivism, the two being closely related. Furthermore, he argues that

> inquiry and constructivist teaching approaches seem to share many educational objectives, such as emphasizing student construction of concepts and the relationship between student acquisition of concepts and the concepts' development in the history of science (Niaz, 2004, p. 406)

Inquiry based science education can therefore contribute to constructing knowledge. Products of science often considered constructed by humans.

> even in relatively simple domains of science, the concepts used to describe and model the domain are not revealed in an obvious way by reading the "book of nature." Rather, they are constructs that have been invented and imposed on phenomena in attempts to interpret and explain them, often as results of considerable intellectual struggles. (Driver, Asoko, Leach, Scott, & Mortimer, 1994, p. 6)

Therefore, one cannot expect students to readily discovering scientific knowledge by simply observing an experiment. Driver et al. (1994) claimed that a view of individual construction of scientific knowledge alone is not enough. In this view, students in a classroom are engaging with others attempting to construct knowledge for themselves. The teacher's main role is to provide physical experiences and encourage reflection. Driver et al. (1994) pointed out that, if one only sees learning as exchanging one scheme with another, one overlooks the possibility of the existence of parallel schemes related the social situation the student is in. Informal science ideas are often characterized as 'misconceptions' for being too naïve or simply wrong compared to scientific ideas. However, when taught about a subject, a student does not necessarily replace the informal idea with the scientific idea. Indeed, most informal ideas work fine in most situations (which is why they are in use) and will still be available to the student in other contexts than the science classroom. Thus, Driver et al. (1994) argued that learning science involves both personal and social processes:

> Learning science involves young people entering into a different way of thinking about and explaining the natural world; becoming socialized to a greater or lesser extent into the practices of the scientific community with its particular purposes, ways of seeing, and ways of supporting its knowledge claims. Before this can

> happen, however, individuals must engage in a process of personal construction and meaning making (Driver et al., 1994, p. 8).

Science classrooms should be recognized as separate communities, with their own ways to treat and gain knowledge. However, the discourses used in science classrooms differ from the use of scientific inquiry in science community (Driver et al., 1994). Driver et al. (1994) elaborate on use of what Bruner called ‘scaffolding’; how students can create meaning for themselves while inquiring about a new topic. Students can form small pieces of meaning, which they can stand upon to reach new levels of understanding. With help and guidance of a teacher, or more competent peer, learners can slowly form new or changed ontological frameworks about the subject. In one of the examples given in the article (air pressure), the discursive inquiry seemed to make the students able to understand and work with the effects of differences in air pressure. However, when the teacher asked the students after the session if they had any questions, one student expressed to not fully understand the reason for said effects: “Christa's question suggests that although she had been successful (with the support of the adult) in constructing the pressure difference explanation in this case, it may still lack plausibility for her ("Why does air push it down?")” (Driver et al., 1994, p. 11). The students seem to easily understand the symptoms, but not as much the cause. This illustrates that, although the students can believe and work with the effects, the cause of air pressure seems to challenge their existing ontologies of what air is.

3.2 Student understanding of electromagnetism

What ‘understanding’ as a topic, phenomenon or process means, can be challenging to define. As (scientific) knowledge is constructed, it can often be represented in separate ways, such as mathematical formulas or conceptual, qualitative representations. One can also see that it can be hard to delineate any scientific topic independently of others. As such, and understanding of the relationship between topics, in other words an overview, can also be valuable understanding. Mazur (1997) described a common occurrence regarding science students in university, even those doing well on exams. He decided to test his students understanding of the topic taught by asking qualitative questions, that would be regarded by most scientist as simple. Mazur tested them in their understanding of the concepts, the principles of the topic being taught. He was surprised by the results: “For example, after a couple of months of physics instruction, all students can recite Newton’s third law and most of them can apply It in numerical problems. A little probing, however, quickly shows that many students do not understand the law” (Mazur, 1997, p. 4). He blamed this on students learning ‘recipes’, or so called ‘problem-solving-strategies’. It is possible for students to achieve a good grade without understanding the underlying concepts. This can result in inexplicable mistakes, since the strategies are unable to solve every problem (Mazur, 1997). Reversely, however, understanding the underlying concepts does not automatically equate being able to solve any problem. Naturally, students will try to pass any course as effectively as possible, and to pass a course means to pass the exam. Students choosing to understand the concepts will use more time and achieve a lower grade if an exam focuses on numerical problem-solving.

Even though electromagnetic induction and electromagnetism in general includes vital knowledge for modern society, the field has seen relatively little research. Focusing mostly on university students and curriculum, the lion share of studies investigate understanding of a higher level than this thesis. Nonetheless, many of the findings of these studies are transferable to younger students.

The Norwegian curriculum only briefly mentions electromagnetic induction in one of the learning goals to be reached before the students finish Norwegian secondary education (aged 16 by that time): Students should be able to “use terms such as current, voltage, resistance, output and induction to explain results from experiments with electrical circuits” (The Norwegian Directorate for Education and Training, 2013, p. 10). Indeed, induction is only mentioned in relation to electrical circuits. The concept of electromagnetic induction itself receives no attention, not even in the learning goals for the three years of Norwegian college which come after secondary school. One of the learning goals before starting secondary school, however, states that students must be able to conduct and explain experiments with electricity and magnetism (The Norwegian Directorate for Education and Training, 2013).

3.2.1 Difficulties in understanding

Electromagnetic induction is known to be hard to grasp for students, especially those new to the subject. In many cases, even the seemingly much more obvious topic of electricity is not understood well (Bagno & Eylon, 1997; Maloney, O’Kuma, Hieggelke, & Van Heuvelen, 2001), even by textbook authors (Gunstone, McKittrick, & Mulhall, 2006). Saglam and Millar (2006) have studied upper high school students’ understanding of electromagnetism. They constructed a written test which they conducted in two different countries (England and Turkey), and interviewed some of the students afterwards. They found that students from both countries largely identified the same questions amongst the most challenging. This shows that the subject is inherently difficult, with the cultural and teaching traditions being different in both countries. Teachers in a study by Albe, Venturini, and Lascours (2001) mentioned magnetic field, magnetic flux and induction most commonly as concepts students have difficulties in understanding. Allen (2001) stated that the phenomenon's many different elements, three-dimensional structure and causal relations can cause problems in student understanding. Saglam and Millar (2006) also formulated the hypothesis that students who have a good spatial awareness will understand electromagnetism better. They argued that this could be the case; since two dimensional illustrations are often used to teach the subject, requiring the students to see the tree dimensional situation. However, their data did not support this hypothesis.

Students seem to have problems connecting the different basic elements in electromagnetic induction, as well as applying learned knowledge to new situations:

> Even a small move away from the familiar resulted in a marked drop in facility value. This suggests that many students' correct answers may be based on recall of taught knowledge, and that they have limited ability to apply this to other situations or to recognize the situations in which certain "rules" apply. (Saglam & Millar, 2006, p. 555)

This points towards a fragmented understanding of electromagnetism amongst students. If a topic is well understood by students, then answers probing the same understanding should show consistent results. This was not the case in the study Saglam and Millar (2006), showing at least a context specific understanding among students. Albe et al. (2001) came to similar conclusions:

> It seems that the elements of knowledge brought into play constitute "islands" which most of the students do not connect fully, this being an analogy for all the links that make up the basic concepts of electromagnetism. The use of physical knowledge is fragmented and the students are not able to bring together different elements of knowledge. This indicates a lack of conceptual grasp of the basic physics of electromagnetism. (Albe et al., 2001, p. 203)

This suggests that a better conceptual understanding can lead to a more complete understanding of electromagnetism.

Saglam and Millar (2006) identified several problems in student understanding that commonly appeared in the answers for the written test:

1. Some students used inappropriate analogies between electric and magnetic forces when formulating their answers. Magnetic north and south poles can be compared to positive and negative electric charges to illustrate a part of magnetic forces. However, four of six students interviewed afterwards seemed to see the magnetic north or south pole as being factually positive or negative, explaining a magnet's influence on (moving) charged particles in this manner.
2. Some students visualized the magnetic field as flowing from the north to the south pole. This (negatively) affected how they solved certain problems, for example needing the magnetic field to flow through a current carrying coil to effect it.
3. Students seem to struggle with causality regarding electromagnetism. Students appeared to have difficulties regarding the effect of changing certain variables in a problem. The three-dimensional nature of electromagnetism also proved challenging, as many students expected the resulting force to be in the same direction of the cause (i.e. magnetic field lines). (Saglam & Millar, 2006)

These misconceptions provide further evidence that student understanding is fragmented and inconsistent.

Bagno and Eylon (1997) argue that student knowledge of electromagnetism is not properly structuralized. They identified a gap between mathematical and conceptual understanding. In their study, they focused their research on three areas of knowledge representation:

> (1) The structure of knowledge—e.g., realizing the importance of central ideas, such as Maxwell's equations (expressed qualitatively); (2) conceptual understanding—e.g., understanding the relationships between the electric field and its sources; (3) application of central relationships in problem solving. (Bagno & Eylon, 1997, p. 726)

Bagno and Eylon (1997) describe a knowledge structure as a hierarchy of ideas, where the most important ones are placed at the top. They show research that revealed that experts in physics base their hierarchal representation of knowledge on physical principles while novices often refer to superficial features. They suggest this means central ideas, or conceptual understanding, about the topic are important in knowledge structures. A good conceptual understanding is key to solving problems.

> Qualitative reasoning is an important goal at all levels of science instruction, hence another desired feature of the knowledge structure in physics is the qualitative representation of relationships in addition to their mathematical representation. (Bagno & Eylon, 1997, p. 726)

Without a thorough conceptual understanding, qualitative reasoning becomes difficult. “When students become confused, they recite equations which do not mean much to them” (Bagno & Eylon, 1997, p. 730). Hence, when students solve problems they seem to resort to the mathematical equation which fits the quantitative aspects of the problem best (from their memory, not conceptual reasoning. Ultimately, the researchers found five main problems in student knowledge representation of electromagnetism:

> (1) Often, it does not include central relationships (e.g. Maxwell’s equations) in any form, neither mathematical nor qualitative.
> (2) There is an overemphasis of subsidiary information at the expense of more central relationships. For instance, many students consider Ohm’s law to be of central importance and completely disregard electromagnetic induction.
> (3) It seems that students lack a coherent organization of concepts and relationships in this domain to facilitate the process of retrieval. Thus, in tasks requiring a comprehensive search of information, they have difficulty retrieving even the partial information that they store.
> (4) Most students seem to represent the relationships only in mathematical form and do not have access to more qualitative representations that are important in experts’ reasoning. Furthermore, even students who are capable of providing such a qualitative description of the knowledge do not do so spontaneously.
> (5) As in other scientific domains, students hold many inaccurate ideas in electromagnetism and erroneously interpret the central relationships. More specifically, this study highlights some difficulties students have in understanding the relationship of an electric field to its sources, motion of charges in a magnetic field and interpretations of electromagnetic induction. (Bagno & Eylon, 1997, pp. 234-235)

Table 2: Key relationships of electromagnetism (Bagno & Eylon, 1997, p. 727)

	Equation	Key relationship	Symbolic representation
1.	$\oint E \cdot dS = \frac{\sum q}{\epsilon_0}$	A charged particle produces an electric field.	$q \rightarrow E$
2.	$F = qE$	An electric force is exerted on a charged particle in the presence of an electric field.	$E \rightarrow F(q)$
3.	$\frac{dq}{dt} = I$	Moving charges are current.	$q \rightarrow I$
4.	$\oint B \cdot dr = \mu_0 \Sigma I$	Current produces a magnetic field.	$I \rightarrow B$
5.	$F = q \cdot v \cdot B$	A magnetic force is exerted on a current in the presence of a magnetic field.	$B \rightarrow F(I)$
6.	$\oint E \cdot dr = \frac{d\phi_B}{dt}$	A change in a magnetic field produces an electric field.	$\frac{\Delta B}{\Delta t} \rightarrow E$
7.	$\oint B \cdot dr = \epsilon_0 \mu_0 \frac{d\phi_E}{dt}$	A change in an electric field produces a magnetic field.	$\frac{\Delta E}{\Delta t} B$

Bagno and Eylon (1997) repeatedly report the missing of conceptual understanding in student's reasoning in their findings. The authors therefore propose applying a concept map and building a correctly hierarchal knowledge structure and employing active problem solving when working with assignments. They proposed a knowledge structure on seven key relationships (Table 2), involving principles and definitions related to electromagnetism. These relationships were represented in a hierarchical structure which includes several interconnected layers. Bagno and Eylon (1997) created a map of the first layer, which they referred to as "a skeleton of the domain at the most general level" (Bagno & Eylon, 1997, p. 731). It consists of only four of the key relationships. Additional layers can be added to represent progressively more specific information about the concepts and relationships.

Thong and Gunstone (2007) found three major misconceptions in their study involving interviews with 15 first year university students:

- Induced current is proportional to current in the solenoid.

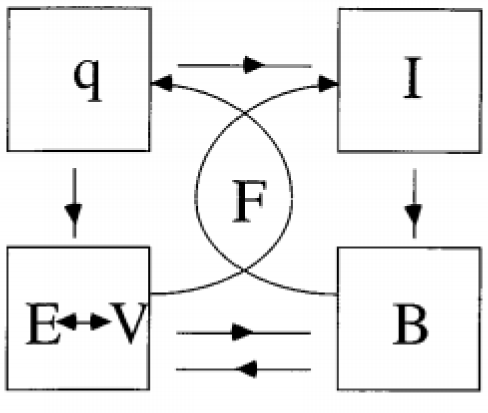

Figure 8: A concept map for electromagnetism (Bagno & Eylon, 1997, p. 731)

- An induced electromagnetic field can be treated as a Coulombic (electrostatic) potential difference.
- Magnetic field lines are treated as real entities. The authors offer this possible explanation: “a view of field lines having a physical reality was likely expressed as a need for ‘real contact’ of the field lines with the external coil” (Thong & Gunstone, 2007, p. 42).

Galili and Kaplan (1997) point out that students’ understanding of magnetism is problematic. They found that textbooks do not emphasize the relative aspect to magnetism and charged particles enough. This leads to misconceptions regarding what the speed is meant to be relative to. Further, the authors point out that the relationship between magnetic and electric force often is forgotten. In another article, discussing an university course on electromagnetic induction, Galili, Kaplan, and Lehavi (2006) argue that teaching on this subject can be insufficient. In their view, most textbooks follow a historical progression when explaining induction. This can lead to the misconception that Faraday’s law is the only way to induce an electromagnetic field. In addition, student understanding of the topic becomes fragmented. The authors therefore propose to start with the micro level before teaching about macro effects. This way, more fundamental forces, such as Lorentz force can be used to explain Faraday’s law.

CSEM (Conceptual Survey of Electricity and Magnetism) is a quantitative pre- and posttest designed to measure first year university students’ conceptual understanding of magnetism and electricity. In their article, Maloney et al. (2001) discuss the CSEM’s reliability and validity, as well as findings from using the test. The authors point out that certain difficulties exist measuring conceptual understanding because of students' lacking in prior knowledge, when compared with other topics, such as mechanic. Despite of this the authors judge CSEM to be a reliable and valid instrument. Using CSEM in the field Maloney et al. (2001) found several aspects regarding electromagnetism that students struggled with. Students' answers indicate that magnetism is an unclear concept to most. Electrical force was confused with magnetic force, as was the direction of force. Most of the students seemed only to consider movement instead of a change in magnetic flux as a cause to electromagnetic induction, even after the course. One interesting finding showed students neglecting Newton's when dealing with electromagnetism. In the answers of one question, regarding the force between to current carrying wires, students often pointed out the wire carrying the larger current as exerting the most force.

3.3 Conceptual understanding and learning

Dega, Kriek, and Mogese (2013) have studied how students' conceptions can change through cognitive perturbation and cognitive. They conducted their research by comparing to groups of first year university students, each using one of the methods. The authors argue that learning through creating a cognitive conflict is more challenging to a student than a cognitive perturbation. The conflict method builds on the view that alternative conceptions are complete theories. Adopting a new conception, therefore, requires the learner to discard the entire old conception. However, Dega et al. (2013) also emphasize other literature which treats student understanding as fragmented and inconsistent, containing of multiple conceptual elements on different levels. Since students are new to the topic, it is not unreasonable to suggest that their cognitive understanding is scattered and diverse. Thus, a small perturbation could ensure an easier transition. Dega et al. (2013) point out that "although there is not yet a consensus on the structure of students' alternative conceptions and the strategies of conceptual change, it is important to examine an effective conceptual change strategy that may enhance students' learning of concepts" (Dega et al., 2013, p. 678). Their findings showed that cognitive perturbations have a better effect for students who possess little prior knowledge than cognitive conflict. Additionally, the latter seemed to have a counterproductive effect regarding students' susceptibility to the new concepts presented.

In their study on the effects of interactive computer simulations on students' conceptual understanding of electromagnetic induction, Zacharia and Anderson (2003) found that the simulations can extend the students' experiences. This is necessary, they claimed, to attain a full understanding of the concepts involved in electromagnetic induction.

3.3.1 Magnetic Field concept

The (magnetic) field is a very useful concept when dealing with magnetism, or other situations where the potential energy of a body differs with their spatial relations to another body (such as gravity). The field concept visualizes mathematical formulae, making a better conceptual understanding possible. However, the concept has proven to be difficult to grasp. Törnkvist, Pettersson, and Tranströmer (1993) researched second year university students' understanding of electrical field line with a questionnaire issued shortly after exams on electricity. Students were shown an illustration containing several fundamentally wrong elements. The authors showed that 85% of their respondents failed to react to crossing field lines. Many of those who did find one or more erroneous field lines offered an incomplete or misplaced explanation. Students used tautological or anthropomorphic reasoning while others offered no explanation at all. Törnkvist et al. (1993) also conducted interviews where students were asked to predict trajectories of particles in a magnetic field. They found (amongst other findings), in likeliness with Maloney et al. (2001) that students failed to connect mechanics with electromagnetism.

The field concept is completely abstract while showing concrete elements, with lines and arrows. This can result in students using field lines as an explanation for magnetic force or considering field lines as physical entities (Saglam & Millar, 2006; Thong & Gunstone, 2007).

Chapter 4: Research Methodology

This thesis focuses on how students can develop a conceptual understanding of electromagnetic induction through an inquiry base approach using models in an exhibition. Since little research is available in this field, a fundamental understanding of secondary school students' perspective on the phenomenon is needed for further research.

4.1 Study design

This thesis takes an exploratory form, allowing for a wider perspective which can be narrowed in during the study. Therefore, a qualitative approach was chosen over quantitative. Quantitative research strategies often build on theoretically established concepts and work inductively. On the other hand, qualitative approaches tend to be inductive, wide in perspective and aim to develop theories or concepts (Ringdal, 2007). Creswell (1998) defines qualitative research as:

> Qualitative research is an inquiry process of understanding based on distinct methodological traditions of inquiry that explore a social or human problem. The researcher builds a complex, holistic picture, analyzes words, reports detailed views of informants, and conducts the study in a natural setting. (p. 15)

This builds on an ontological view of knowledge being socially constructed. Epistemologically, this leads to gathering data with minimal distance to participants. Therefore, an understanding of a phenomenon or problem can most accurately be acquired through analyzing data directly from the informant, in their own words. Creswell (1998) points out five different methods which he views as "distinct methodological traditions of inquiry": biography, phenomenology, grounded theory, ethnography and case study. Since this study is exploratory, and aims to discover new theory, some of the characteristics of the grounded theory method apply to this study design. Due to the limitation of a master's thesis, however, only two groups were studied. Therefore, parts of a case study design also apply. Lastly, some small resemblances with an experiment design may be seen, as the participants are taken out of their normal context. This study, therefore, uses several methods from different study designs. A study design does not always fit into one of the 5 different methods mentioned by Cresswell:

> Some situations may have no clearly preferred strategy, as the strengths and weaknesses of the various strategies may overlap. The basic goal, however, is to consider all the strategies in an inclusive and pluralistic

> fashion-as part of your repertoire from which you may draw according to a given situation to do social science research (Yin, 2003, p. 16)

As there many different situations which may be studied in social science, a study should therefore be flexible and vary a method according to the situation, rather than committing to a single method ideologically.

4.1.1 Theoretical sensitivity

Creswell (1998) explains that the intent of a grounded theory study is to find new theory or concepts. The researcher does this by collecting vast amounts of data, mainly through interviews and observation. This data is then thoroughly analyzed, after which the researcher will present preliminary explanations or a (or multiple) hypothesis to be tested (Creswell, 1998). Strauss and Corbin (1990) note that, to produce new theory, the researcher conducting the study should not be heavily influenced by existing theory on the field. On the other hand, the researcher cannot be completely blank either. Corbin and Strauss call this *theoretical sensitivity.* Too much influence by current theory will render the researcher unable to see data from a new perspective, while too little will not allow the researcher to interpret the data. They present several ways for a researcher to achieve this sensitivity:

- Studying literature on the field,
- personal and professional experience and
- analyzing the data while researching.

As a researcher, I have built theoretical sensitivity by personal experience while teaching (and being taught) and by studying appropriate theory in the field. As mentioned before, this theory is mostly orientated towards the understanding of electromagnetism by older students and will serve mostly as indicators for expected problems. Previous research generally presents possible misunderstandings or problems students can have with the phenomenon. Strauss and Corbin (1990) also state that theoretical sensitivity plays a role in defining the element of creativity in grounded theory studies. However, it does not ensure it. The same researchers write:

> Because there is an interplay between researcher and data, no method, certainly not grounded theory, can ensure that the interplay will be creative. Creativity depends on the researcher's analytic ability, theoretical sensitivity, and sensitivity to the subtleties of the action/interaction” (Corbin & Strauss, 1990, p. 17).

Creativity can therefore be highly personal; two different researchers might interpret the same data differently. Furthermore, a creative result also depends on the quality of the data gathered. While an unimaginative analysis can technically be drawn correctly grounded in the data, one could argue that the researcher did not push data collection far enough or did not ensure its quality (Corbin & Strauss, 1990). Creativity is needed to see patterns in the data, to construct new concepts and build new theory.

A qualitative research strategy allows for more flexible research compatible with an explorative study than a quantitative approach. Even though quantitative research can uncover patterns in student understanding that might be very valuable to this field, this study aims to find conceptual understanding, something that is not easily caught using questionnaires. To ascertain how the students work with the models and how their understanding of electromagnetic induction develops, two methods were used, both of a qualitative nature. The first being observation during the actual lesson with the students, the second being a group interview with the students some days after each separate lesson. Data will be gathered using video and audio recording equipment.

4.1.2 Case study

Due to the nature of a master's thesis, time and resources were limited. Therefore, only two groups with three participants each were selected. Since the study is explorative in nature, and therefore one collects a lot of data. This is one of the features of a case study; the researcher collects large amounts of data from few units, or cases (Johannessen, Christoffersen, & Tufte, 2010). Therefore, some of the characteristics of a case study design have been incorporated in this study design. Johannessen et al. further stated that case studies in social sciences are distinct in two ways; attention in the study is given only to the case in question, and the case is meticulously described.

Yin (2003) offers five rationales for choosing a single case study design, one of them being the revelatory case. Here, the investigator has an opportunity to analyze a phenomenon new to scientific investigation. In this study, since no research on this topic exists, the case can be seen as the two groups learning electromagnetic induction. A single-case design either be holistic, meaning attention is given to the case as a whole, not dividing it into smaller parts. A case that can be divided into several sub units, is called embedded (Yin, 2003). In this thesis, the case is divided into several units, being the two groups. Although different observations between the groups are discussed, the groups are not compared to each other, this would make it a multiple-case design.

Yin (2003) presented five components which are of special importance when designing a case study:

1. The study's research questions and problem statement. The study normally begins with a problem from taken from reality.
2. The study's propositions. This component is like theoretical sensitivity, which is discussed above. The researcher's propositions will affect the outcome of the study.
3. The units of analysis should be defined, in accordance to the problem statement and research questions.
4. The link between data and propositions. A case study can be based upon theory, which directs the study. When no theory is available, a describing case study can by conducted.
5. The criteria for interpreting, depending on their match with the theory in question. Yin states that some data can be difficult to interpret.

These components do apply to this study. However, Yin (2003) did state that a case study design is best suited for problem statements regarding the reasoning behind actions or situations; the "what" and "how" as he calls it. This study, however, focuses more on the practicalities involved when learning about electromagnetic induction.

4.1.3 Quasi-experiment

Both grounded theory and case study designs investigate within, and including, the real-life context of the research object. This study, however, has taken the subjects out of the normal context in which they would be learning about electromagnetic induction, be it either the classroom, or the Vitensenteret. This is to control variables and make the research situation uncluttered from outside influences. These are some of the characteristics of an experiment. However, since other features of a true experiment cannot be met in this study, such as an experimental group and a control group, and repeatability, this part of the study will classify as a quasi-experiment. However, experiments are often done to compare the outcome between the experimental group and the control group. Also, quantitative date is gathered that is easily comparable (Johannessen et al., 2010). This research does not directly compare the two groups, and gathers exclusively quantitative date, which brings the design back to the domains of grounded theory and case study.

4.2 Selection of participants

The participants have been selected on age only. Due to the difficulty of the subject, participants have been drafted from the last years of secondary school (Norwegian: *ungdomsskole*), aged 14 to 16. The selection of this age was for several reasons: First, the participants' age should correspond with the target audience of Vitensenteret. Secondly, students in their last years of secondary school have studied the basics of electricity at least once. They will also be more likely to have experienced other aspects of science, such as experimenting and observing. Together, this will make it more likely for participants to be able to learn from the lesson. Last, a youngest possible age would give an indication on the lower age limit for the final program.

Emails were sent to schools in the Trondheim area, explaining the project and encouraging students to apply for participation. No demands for minimum grade has been used, asking only that students be interested in science. Two groups of three participants were selected. Group one was currently in 10th grade (aged 15 or 16), and were codenamed Grey, Pink and White. Group two was currently in 9th grade (aged 14 or 15), and were codenamed Blue, Stripes and Yellow.

4.3 Lessons

The preliminary lesson plan is based both on literature in the field and experience and documents produced by members of staff of Vitensenteret. Some vital conceptual ideas have been set as achievable learning goals, needed to build an understanding of electromagnetic induction:

1. The magnetic field concept. This is used as a tool to investigate and understand the phenomena encountered during activities.
2. Understand the relationship between charges and magnetism. The students are to see that a moving magnet is able to move a charge (produce an electric field), and, likewise, a moving charge produces a magnetic field.
3. The movement need only be relative between the magnetic field and the charges involved.

These main goals are supported by the goals for each activity, as described in the lesson plan (Table 3).

As this lesson introduces many new concepts through exploration by the students, no emphasis is placed on scientific terms to describe the observations and explanations. While a precise language is extremely useful in science, the use of informal terms will be sufficient within each group. The scientific terms can be presented or clarified during the lesson, if fruitful for the investigation.

A compact version of the lesson plan can be presented, consisting of the various activities the students engaged in:

Table 3: Lesson plan

Lesson part	**Goal**	**Equipment**
1. Introduction 5-10 min - Discuss what students have learned about electricity, with focus on current and what it is. - Discuss general magnetism with students. E.g., what can they pick up with magnets, what are usages in daily life? - Discuss the compass: What is it made for? How does it work? What does it point towards (North Pole = magnetic south)?	- Activate (*and document for research)* prior knowledge -Build collective understanding of the basics - Identify compass as indicator of magnetism	**Magnet** **Compass**
2. Investigating magnets 15 min - Students investigate interactions between compass and magnet. - Students test magnet strength - Students investigate the magnetic field of a bar magnet, using a vector board and compass.	- Identify compass as an indicator of magnetism and direction of magnetic field. - Observe the energy that is available in magnets - Establish the magnetic field concept.	**Magnet** **Compass** **Vectorboard (Figure 9)**
3. Examining copper 15 min - Students use magnets to investigate interactions with various metals.	- Establish relationship between movement and force on the magnet.	**(strong) Magnet** **Metals: Iron, copper, aluminum** **Copper pipe**

- Students use compasses and weak magnets to determine whether copper is magnetic or not. - Students are shown the falling magnet through the copper pipe, and asked to investigate again. Switch to stronger magnets.	- Force acting on the magnet is always opposite the direction of the movement.	
4. Current carrying wire 10-15 min - Before current: Remind students that wires are made of copper. Student test for magnetism. - Current is turned on, students test for magnetism again. - Students investigate the magnetic field of a current carrying wire.	- Establish that a (constant) current creates (constant) magnetic field. - Introduce a circular magnetic field. - See a communality between activity 3 and 4: relative movement of electrons.	**Power source** **Wire demonstration device (Figure 10)** **Compass** **Magnet**
5. Current carrying coil - Students investigate the magnetic field - Students are asked to explain the shape of the magnetic field.	- Similar magnetic field as a bar magnet. - Magnetic field is still circular, magnetic fields can merge.	**Big coil, 10 turns (Figure 11)** **Power source** **Magnet** **Compass**
6. Inducing electricity - Students investigate interactions with solid magnets - Students are to find the most efficient method. - Students are asked to produce a voltage with one current carrying coil	- Continuous movement (change in magnetic flux) is necessary. - ‘Strength’ of the induced electricity is related to speed of the magnet (measured in volts). - The change in magnetic field is what creates the electricity.	**Big coil, 10 turns** **Power source** **Magnet** **Compass** **Voltmeter** **Group two:** **LED assembly** **Coil with 400 or more turns**

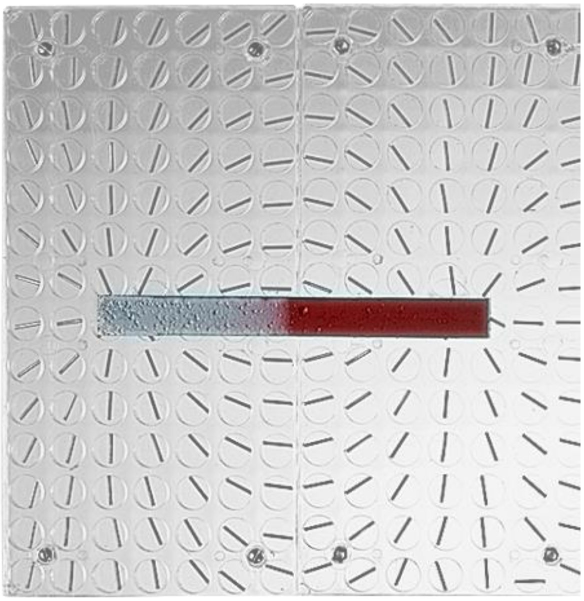

Figure 9: This picture illustrates a vectorboard similar to the one used in this study (A/S Søren Frederiksen).

Figure 10: Device used to demonstrate the magnetic field of a current carrying wire, together with compasses (A/S Søren Frederiksen).

Before the session with group two, some minor changes were made to the lesson plan, based on experiences with group one. After each activity involving the investigation of a magnetic field (activity 2, 4 and 6), the group was shown an illustration of the magnetic field in question. They were shown an illustration of free electrons in metal to help visualize the free electrons. When inducing electricity, they were given an analogue voltmeter, a coil with 400 turns, to increase the sensitivity while investigating. Lastly, they used a LED assembly to while inducing electricity, to indicate the direction of the current.

Some of the devices used require an additional explanation. Vectorboard (Figure 9) will be the term used in this thesis for an acrylic plate with many compass needles or small, iron arrows or rods beneath it. When a magnetic field is in their vicinity, these will adjust to be parallel to the magnetic field lines traveling through their center, thereby depicting the magnetic field. Figure 10 depicts the device used to investigate the magnetic field of a current carrying wire. It features a vertical wire traveling through an acrylic plate, allowing for a compass to held easily nearby the wire. The ten-turn coil is built in the same manner (Figure 11).

4.4 Gathering of data

Observation is a widely-used method of gathering data in social studies. As mentioned earlier in this chapter, the students will be observed while working with the models. Since I will be leading

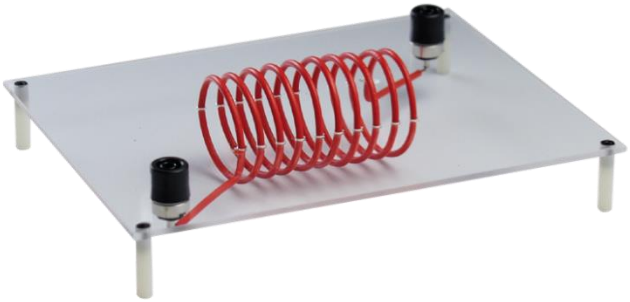

Figure 11: The device that was used to investigate the magnetic field of a coil (A/S Søren Frederiksen).

the lesson and activities with the students, I will be in an appropriate position to observe. However, since I also will be playing the role as teacher, there is a possibility that I will be engaged in typical teacher duties rather than observing, while something interesting develops in the students' work. To assure no important moments are overlooked, the choice has been made to record both audio and video during the session. This will ensure that all data available will reach analysis, both verbal discussions between students and interactions with the model. This means that participants will be observed both directly and via recordings. Additionally, my own input has been recorded to provide an accurate impression of what the participants have been taught before interacting with the models.

Each group was interviewed approximately one week after the lesson, where their understanding was explored by discussing the results. As emphasis is placed on the students own experiences and understanding, the interview was based few questions, although each group was asked about topics and events that were of special interest during the lesson. A basic interview guide (see appendix 3) was developed. Additionally, the interview was used to discuss the students' reasoning during the lesson, to gain insight in the cause for students' actions during the lesson.

Transcripts were made, in Norwegian, of both the lessons and the interviews. They were followingly translated to English for use in this thesis. However, despite best efforts, some meaning may get lost in translation. To accommodate for transparency, the original Norwegian transcripts used in this thesis can be found in appendix 4.

4.4.1 Participant observation

Observation is a natural part of this thesis. Since focus is on how students will work with the models, one must observe students working with the models. By observing participants interacting with the models, as well as engaging in verbal communication with other participants can acquire an invaluable insight in their understandings. However, on many occasions an action can have any number of explanations. Therefore, this thesis utilizes group interviews as well, although the opposite is true for interviews. It is not always true that a participant can (or will) explain their actions. Both methods are therefore mutually complementary. Since participants are unable to predict their understanding of electromagnetic induction after a lesson, the interview will happen after the lesson. After analyzing the data from the lesson, the interview can then be used to have the participants explain any interesting observations.

Video observation is the primary method of observation used in this thesis. Knoblauch, Schnettler, Raab, and Soeffner (2006) explain that video can preserve relevant details of situated action. More precise, video can preserve key dimensions such as:

- Time, the timing and possible rhythm between actions
- Participation framework and interactional space. Instead of focusing too narrowly on only one participants, video can capture the totality of the setting.
- Multimodal details: language, gaze, gesture and more are documented while participants act and react to it. (Knoblauch et al., 2006)

In short, video capturing allows the researcher to analyze every aspect of the session thoroughly. This ensures that possibly relevant details will not be lost. This richness in detail makes video analysis a fitting tool for this research design.

4.4.2 Interview

Interviews are the most common method for gathering data within qualitative research (Johannessen et al., 2010). The purpose of interviews in this thesis is twofold. Firstly, the interviews provide a chance to shed light on interesting events from the lessons. It is a possibility to ask participants about certain actions or statements, either because they are unclear or to find out more. The participants will also be asked about how they experienced the working with the models and the lesson in general. They are invited to talk freely as well. Secondly, the participants will be ‘tested’ on electromagnetic induction. The quality of the participants’ understanding will not be easily measured using written tests, especially since the focus is on conceptual understanding and learning happened in a hands-on environment. Therefore, the interview is a fitting method for this thesis. Johannessen et al. (2010) have pointed out that interviews are particularly well suited to answer describing (research) questions about concrete events or actions, as well as interpreting (research) questions about how informants consider, experience and interpret events and actions.

It is important to maintain balance between a structured nature and an open nature in this interview. Interviewer-related error should be minimalized by developing a sufficiently structured interview. (Fowler Jr & Mangione, 1990). A standardized interview guide allows little room for the interviewer to formulate leading questions or otherwise signal any ‘correct’ answer (Fowler Jr & Mangione, 1990). Additionally, structure provides a backbone to the interview; structured interviews avoid the risk of gathering incomparable data if the interviews follow different paths. However, too much structure can substantially reduce the flexibility of the research, as well as the depth and quality of the data (Johannessen et al., 2010). Indeed, one of the strengths of an interview is the freedom to follow interesting paths. Instead of asking informants about concepts already know, the interviewer can pursue previously unknown phenomena, giving the interview strong inductive power. Therefore, the interview type used was semi-structured to maintain both reliability and validity. Since the research question focuses on conceptual understanding, a too rigid and structured interview will not allow the participants to elaborate on their understanding.

Three interviews were held, one group interview with each group of participants. The interviews were held approximately a week after the lesson, allowing the experiences to settle. During the interviews, both prompts and probes were used. Prompts are used to clarify the topic (Cohen, Manion, & Morrison, 2007), which in these interviews could be showing footage from the lesson or otherwise. Probes are employed to have the interviewee clarify, elaborate or add to their answer, thereby giving the data “richness, depth of response, comprehensiveness and honesty that are some of the hallmarks of successful interviewing” (Cohen et al., 2007, p. 361). The form of a probe can range from a simple pause to a full verbal question (Cohen et al., 2007). See appendix three for the interview guide.

4.5 Validity and reliability

Case studies are especially sensitive to concerns regarding the validity of the findings. Due to the small number of participants in this study, it becomes difficult to be able generalize any findings. Any congruence between the two groups could at best indicate a general rule, but would never overcome the factor of chance. This affects the external validity. Internal validity can be criticized in this study, as there are many elements influence the results of the study. The researcher therefore, sometimes, must infer the cause of a certain observed event, without having observed the actual cause. Another aspect with this study is that each group consisted of three students, each of a different academic level. In this study, the academically strongest participants were most active in their reflections during the activities, as well as the interviews. This means that they are overrepresented in the results, making this study possible more representative for academically strong students.

The way the lessons were carried out may have affected reliability. The groups needed more guidance than expected during the activities. Therefore, the influence of the researcher as a teacher has been greater than first anticipated. Another researcher, with other prerequisites, will influence the lesson differently. A second influence on reliability may be the length of the lesson. Due to some investigations taking longer than anticipated and other aspects during and before the lesson, each group spend almost two hours (regular, not school hours) in the room. Despite the impressive time spend alert and interested by the students, this may have influenced the result during the later activities. Such a long time spend focusing may cause fatigue, and thus reduced cognitive abilities.

4.6 Consideration of alternative methods

Alternative methods have been considered to gather data for this thesis. A quantitative measurement of participants' performance both before and after a lesson is a means to determine a lessons effectiveness. However, due to the nature of the problem statement of this thesis, problems might occur using quantitative methods to measure qualitative understanding. Since focus is on conceptual understanding, rather than the students' ability to complete numerical tasks using formulas, the outcome of a written test will not be valid. In addition, the participants in this study, being newcomers to electromagnetism, have few verbal tools to accurately describe their understanding of the phenomenon. The students will use words or concepts they can relate to, not necessarily know or immediately understood by the researcher. An interview, which in this thesis is semi-structured, offers participants a chance to check if their explanations are understood. If not, they can try again using different words or concepts, as well as gestures, drawings or otherwise. An interviewer also has the possibility to ask the interviewee to elaborate statements.

A different approach to teaching about electromagnetic induction through a lesson-like design has also been considered. For example, student-interactions with models and experiments can be studied by *only* observing these interactions. Again, the participants are newcomers to the field and have little knowledge of the field before participating. Consequently, the interactions will be influenced by any teaching on that area. This thesis focuses not only on student-interactions, but also on what prior knowledge is required for students to actively and productively engage with the experiments. Therefore, it is natural to observe and study the teaching of electromagnetic induction in relation to student-interactions with the models.

4.7 Ethical considerations:

Social research, especially research with children, is inherently full of ethical decisions. Ethics are, contrary to widely held belief, no simple matter of right and wrong. Rather, "Judgements about whether behavior conflicts with professional values lie on a continuum that ranges from the clearly ethical to the clearly unethical" (Cohen et al., 2007, p. 58). Therefore, a researcher must make ethical decisions based on research context and other values. put forth a set of initial ethical considerations when planning research, some of which are applicable to this thesis. However, some guidelines do exist. With regards to this thesis, three key areas can be identified (Cohen et al., 2007; Johannessen et al., 2010): informed consent, protection of the participants and data handling.

Before participating in a study, the participant must have given informed consent. This means the participant should be aware of all information that could possibly influence his or her decision to participate in the study. This includes the participants' right to withdraw from the project at any time, without stating a reason. In this thesis, both the participants and their caretakers have read and signed a declaration of informed consent explaining thoroughly the projects subject, intent and means of data gathering, as well as the participants right to withdraw (See appendix 2, Norwegian).

Participants should be protected regarding their identity and consequences of participating in the study. Therefore, participants have been completely anonymized, including gender, only area and age as remaining identifiers. The teacher of the participants helped in selecting students that would not be uncomfortable during the study. As some participants missed class during the study, we collaborated to find classes that the students could afford to miss. The participants were warned of the physical dangers of working with strong magnets, such as minor crush injuries and the influence on magnetized objects (i.e. memory cards or credit cards).

Due to the gathering of possibly sensitive data of the participants, in the form of video and audio files, this project has been reported to the NSD (Norwegian Centre for Research Data), see appendix 1.

All participants in this study are offered a season ticket to Vitensenteret as a reward. This reward functions as an incentive to participation. While this may ease the recruitment process, it also creates a slightly higher threshold to withdraw from the project. However, the incentive is not a direct payment, nor is it exchangeable for money. While a reward, the season ticket is judged as too invaluable to be a significant factor if the participant should feel uninclined to complete the study.

Chapter 5: Results

5.1 Prior knowledge

In the lessons the students' pre-existing knowledge was examined. Original transcripts in Norwegian can be found in appendix four.

5.1.1 Group one

Although they had heard of induction cooking tops, the first group showed little to no knowledge regarding electromagnetism, being unable to explain the concept of electricity. Only when asked about words such as "volt", "ampere" and "electron" did they reply to have heard of these words. However, no student offered a definition of these words.

On the microlevel of atoms and electrons, again, the group only remembered the word "electron" when the interviewer asked of it. Subsequently, the interviewer proceeded to explain briefly the concept of electricity.

On magnetism, the group seemed to be somewhat familiar with the polarity of (permanent) magnets, although Grey referred to the poles as positive and negative, while Pink stated that those terms belonged to batteries. As there seemed to be some disagreement on whether positive and negative are the correct terms for magnets' polarity. The interviewer explained the difference in terminology. However, all students in the group continued to use positive or negative when referring to one of the poles of a magnet. Later in the discussion, Pink stated that two of the same sides will not attract each other, remembering magnetic trainsets.

Later in the lesson, when working with several types of metals, all students seemed to act on the knowledge that magnets will pick up iron, with any pole. However, they did not explicitly express this.

On compasses, all the students knew that a compass will point towards the earth's north pole, while only Grey was aware that this is because of magnetism, with the others expressing they did not know that.

The interviewer then proceeded to explain how a compass always points towards the north, anywhere on the earth. The group did not have any conception regarding a magnetic field or the field concept in general.

5.1.2 Group two

The second group had just had an exam on electricity, and therefore had a better understanding prior to the lesson than group one. Yellow had been to "Newtonrommet"; an outside of the classroom learning arena where his class experimented with making a lightbulb glow using a magnet. This experience seemed to have given him a slight advantage when working with coils later in the lesson. The others had not been to "Newtonrommet", but had heard of induction cooking tops in the kitchen.

The students expressed some prior knowledge regarding electricity, as they described electricity as electrons moving in a circuit. They also knew that electrons are electrically charged, however, the interviewer needed to correct the students when they were unable to recall the charge of electrons. In the interview, it became clear that a misconception existed in Yellow's understanding, if he had a conscious conception, regarding free electrons in metals. When talking about how electrons move through the wire (by a magnetic force in this case), Yellow stated:

> Yellow: You often draw atomic centers with circles around it. And also, you have the shell model, with dots everywhere. It's more like that, because it jumps this way and that.
> Interviewer: Yes.
> Yellow: Between… some jump into this one shell, and then others have to jump back again. (Transcript 1)

This connects to a wondering question asked by Yellow during the lesson:

> Yellow: Are there electrons in this plastic? There have to be. So really, if I drag the magnet past quick enough, will it become magnetic? (Transcript 2)

After this statement in the interview, the interviewer explained there exist free electrons in metals, which are the electrons in an (normal) electric current.

On magnetism, like group one, group two also used positive and negative as terms to describe the north and south pole of magnets. Stripes also pointed out the fact that one side attracts the other side only.

Although Yellow initially corrected the group by saying north and south pole instead of positive and negative, later in the lesson he gave an explanation on why the poles are positive and negative based on the coloring of the magnet (white and red).

Blue: Yellow, is this end positive and this end negative, or?
Yellow: I really don't know, I never remember which is positive and which is negative. I would say that this one is positive and this one is negative.
Blue: This one is positive and this one is negative?
Yellow: Because we see warmth as red and cold as blue.
Blue: ooh, right.
Stripes: Yes. (Transcript 3)

Yellow's explanation sounded logical to the others, and they accepted it. When questioned about their misuse of these terms later in the lesson, the group claimed that their teacher insists that these are the correct terms for magnetic poles. However, they were aware that another teacher tells their students to use north and south pole. The interviewer subsequently explained that the terms are nomenclature, but are not to be confused since the terms do not relate to the same phenomenon.

The students knew that a compass will point towards the earth's magnetic north pole. Yellow pointed out that a compass consists of a tiny magnet which is attracted to the earth's magnetic field. Later in the lesson, Yellow showed extensive knowledge of the earth's magnetic field. He could draw and compare the magnetic field of the earth to that of a bar magnet. The rest of the group did not have a conception regarding a magnetic field or the field concept in general.

5.2 Activities, group one

5.2.1 Investigating magnets

During lesson one, a problem with one of the bar magnets was discovered. One of the poles seems to have moved approximately one quarter of the length of the bar magnet inwards. Grey expresses this first.

> Grey: Look at this, right here there was like some resistance. *She tries with both magnets.* Ok, maybe not. *Attaches both magnets to each other along the long sides.*
> White: Yes, both sides work.

> Pink: It doesn't matter.
> White: No… (Transcript 4)

This causes all the students to immediately move away from their statement about different poles attracting each other. However, they seemed to accept the interviewer's explanation regarding the age of the magnet without question.

Exploring the strength of the strongest magnets seemed to make a big impression on all students. Pink described the feeling as if there was a wall between the two magnets. During the interview, this experience was discussed. The students described it as an interesting and exciting experience. When asked were they imagine this force comes from, White expressed she sees it as some invisible force or part of the magnet, while Pink suggested more general ideas such as force and energy. When challenged to provide a deeper explanation.

> White: There has to be some… You can attach it as well, so there has to be something which is like, around the magnet. It has to send out something.
> Pink: It has to have energy then.
> White: There has to be something in between, because when we attach them then they move at once. So, there has to be something there. There has to be something that, like, pushes them away from each other. (Transcript 5)

It is possible White is thinking of a magnetic field, which was not brought up until after this discussion.

Exploring how the magnets behaved opened for play as well. The magnets were put on different objects, onto each other in many ways. In combination with compasses both groups found the same activity independently; to get the compass needle to spin round as fast as possible using a magnet.

However, actual systematic exploring with magnet and compass proved harder. Group one especially needed guidance from the interviewer to examine the relationship between the compass and the bar magnet.

5.2.2 Magnetic field

Group one were then given the vectorboard the investigate with. After establishing that the small iron pieces acted like compasses, the group was asked to investigate and describe the patterns the saw with the magnet flat on the board.

> White: I’m thinking that, all those on the red side, they point towards it, and those [in the middle] don’t.
> Interviewer: No.
> White: Those point=
> =Grey: Away from it.
> White: They still point to the red side. And those further away more towards the white side and these ones [on the white side of the magnet] point inwards [to the white side].
> Interviewer: Good observation.
> Pink: These [arrows in the middle of the magnet] point towards both here and here [ends of the magnet]. (Transcript 6)

Even though group observed the different directions of the vectors, they were unable to identify lines, or generalize the idea of a field more. They were given a magnet in a casing filled with liquid and iron filings. Upon shaking, a three-dimensional magnetic field can be observed. After studying the model, the students then proceeded to try to influence the iron filings in the casing with other magnets. This developed into play, where they tried to gather as much iron filings as possible with the outer magnet.

5.2.3 Examining copper

After exploring how the magnets interacted with various metals, the group quickly stated that copper and aluminum do not interact with magnets. Initially, there was some confusion as some of the compasses seemed to turn when investigating the copper plate. This disturbance was soon attributed to nearby magnets. After establishing that copper was nonmagnetic, the interviewer showed the group a magnet falling through a piece of copper piping. The group seemed very surprised, and immediately started to offer explanations.

> Pink: It probably goes back and forth. (*She hears the magnet ticking while falling)*
> White: Yes, because it is like a little magnetic, maybe.

> *Grey tries and looks into the pipe while the magnet falls.*
>
> White: Because there is some magnetism in it. It goes much slower than it would have gone normally. (Transcript 7)

Immediately, two explanations are offered. Pink suggested that the way the magnets tumbles in the pipe is affecting the fall time, while White proposed the copper might be slightly magnetic. After looking carefully at the magnet in the pipe, Pink confirmed the movement. However, none of the members of the group, including Pink, seemed content with the tumbling as an adequate explanation. Therefore, they discussed a plan, to vary the number of magnets (they were using small, cylindrical magnets), and continued to investigate. The group arrives at the conclusion that two magnets fall faster than one. By varying the number of magnets, they have also confirmed that it is magnetism which is causing the long fall time, although not stating it explicitly. When the investigation stops moving forward, the interviewer asks them about their thoughts.

> Interviewer: What is your theory, why would it fall so slowly?
>
> Pink: It is a little magnetic, so it will like stick a little bit, that is why it goes tickticktick.
>
> White: I think… It can also be repulsive, so it pushes it from one side to the other.
>
> Interviewer: Yes… no…
>
> White: Maybe, but it doesn’t stick to the outside either, so… (Transcript 8)

Pink sees her observations as pointing towards magnetic attraction. White, on the other hand, seemed to see a complexity here. She has noticed that the magnet brakes, but does not stop or attach itself to the copper. The interviewer then invited the group to replicate the movement of the falling magnet with a slate of copper and a strong magnet in hand. The students immediately noticed the braking force acting on the moving magnet. Students were then asked to find out more about this phenomenon. Pink mentioned that if a magnet were to ‘attach’ itself, it would be stuck. This made White propose friction as the cause, and tries to move the magnet without touching the plate.

> White: *Tries it.* There might be something there, yes.
>
> Grey: Are you sure?
>
> White: Yes, so maybe it is not friction, then. Yes, feel it, it’s like something repulsive or something. (Transcript 9)

Her they dismissed the only other cause they could think of, friction. The students continue to explore the phenomenon. They begin to move the magnet faster along the copper to get more effect, but do not verbalize their thoughts until asked.

> Interviewer: So, what do you think, when is it heavy and when isn't it?
> White: Ok, it is a little heavier when I do it quickly. It's like…
> Pink: More resistance.
> White: This [slow] actually goes without something stopping it, but this [quicker], then it becomes, like ugh [heavy]. Look, now there isn't a lot of resistance, if I do it slowly. (Transcript 10)

When asked to explain what is happening, none had an answer. They seemed to accept simply "magnetism" as an explanation, even though none of their previous experiences with magnets could account for this. The interviewer subsequently explained the students about free electrons in metals, and charges reacting to magnetic fields.

5.2.4 Current carrying wire

When investigating the wire, students were encouraged to use compasses. While turning the current on and off, the students quickly announced the wire to be magnetic when the current was running. However, while Pink did indicate some short of relationship between electricity and magnetism, she formed alternative conception regarding the wire's magnetism.

> Pink: Yes because, this [compass] points towards magnets, and there is a magnet in here [wire]. Because I think current and magnets are the same thing.
> Interviewer: But it doesn't point towards it now.
> Pink: What if you turn it off? *Turns off current.*
> White: Hmm I didn't quite get that.
> Pink: Because it points here, and this is where the current goes. But if you turn it off… So, I think there is a magnet in it.
> White: It is off now.
> Pink Yes, but then there is a magnet in here [wire]. And when you turn it on, the current will stop the magnet. (Transcript 11)

This appears to be due to random circumstances and a misunderstanding of the magnetic field concept. The compass was pointing towards the point where the wire was connected when there was no current flowing. When the current was turned on, it might have looked like the compass was deflected. The device used appeared to distract both the students from seeing simplicity, and the compasses would react to other parts of the device. The students were investigating connections in the device itself. When asked about this in the interview, the students expressed they were not sure why. They mentioned they could have seen the whole device as a magnet, or that the coloring of the wires could have played a role. Therefore, the device was taken out of the circuit, and the group was presented with only two wires connected to each other. When the interviewer asked the students to investigate the magnetic field of the wire, they did not try to establish a direction with the compass. Instead, they assumed various places to find a north or a south pole.

> White: Ooh right, is it because, this is coming from the positive one. Does it have anything with that to do? Maybe not… But it pointed here, when there was no current. (Transcript 12)

When the interviewer directed the students towards focusing on the wire, the students discovered that the magnet always points across the wire. This became apparent while the students moved the compass along the wire where it was curved.

> White: Ooh
> Pink: Oh, it points like one way all the time, into the wire.
> Interviewer: Mhm
> Pink: Oh, here it turns.
> Interviewer: It might just be a little confused, because there are two [wires].
> White: Yes, but it points out from the wire. (Transcript 13)

Grey correctly predicted that the compass would point the other way if the polarity of the wire was to be switched. While the students are watching the compass change direction while the power source is being turned on and off, White seems to wonder why the compass does this.

> White: But why does it do that?
> Pink: Because there is a magnet in the current, or in that [wire].
> Interviewer: Yes, because before, we talked about electrons, right? And when a current

> runs, there will be electrons going through the wire.
>
> White: Ooh, so it will be the same as this! *Points towards the copper plate.* Because it goes fast, electrons go fast trough the wire.
>
> Interviewer: Mhm.
>
> Grey: Ooh. (Transcript 14)

With some help from the interviewer, White connects the wire with the copper plate. She sees that both scenarios involve relative movement of electrons.

The device was put back in the circuit to further investigate the shape of the magnetic field of the wire. The students used the same technique as with the bar magnet, following the direction of the compass. They seemed amazed to find that the compass would keep circling round the wire.

> Interviewer: So, can we find north and south here?
>
> White: No, it like has a center. And it goes around. (Transcript 15)

White describes the magnetic field as to have a center, with the compass going around, but never in.

5.2.5 Current carrying coil

The students were asked to investigate the magnetic field of a current carrying coil.

> White: Oh, it wants to go in here!
>
> Grey: Ooh!
>
> *The students follow the compass*
>
> Grey: Does it want to go back now?
>
> White: No, here [where to compass comes out of the coil] it just wants to go around.
>
> *Follows the compass around the outside of the coil.*
>
> Pink: It only wants to go in here.
>
> *Students try to guide the compass past the 'entrance' of the coil.*
>
> White: Here, it like, wants to go in.
>
> Grey: But it wants to… It doesn't want to go in this way here.
>
> White: No, it doesn't.
>
> Pink: No, but then you have to switch the current.
>
> White: Yes, it only wants to go in this one way, but not back. Can we try to witch the

> current? *Current is reversed.*
> Grey: Look, now it does want to go in there! (Transcript 16)

The students describe their observations to each other. They test their idea that the compass only points through the coil from one side. Pink makes the connection with the single wire, where they learned that reversing the current will reverse the magnetic field, and proposes to change the polarization to make the compass go in from the other (physical) side of the coil. The students are happy to see their prediction is right. When the interviewer asked if the students could explain the shape of the magnetic field, Grey expressed she had noticed a relationship between the shapes of the wire and the shape of the magnetic field.

> Interviewer: But how does this happen? Didn't we see that the magnetic field of a single wire is round? Then why is it suddenly straight now?
> White: Because now it [the wire] is round.
> Pink: Ja?
> Grey: Before it [wire] was straight, then it [compass] wanted to go around. Now it is round, and it wants to go straight.
> Interviewer: Yes, but why?
> White: Well… I don't know. (Transcript 17)

Grey had only described an observation, but not in fact offered an explanation. The interviewer then asked the students to think about the shape of the magnetic field of the wire, and how it would look if the same wire would be curled. White suddenly visualized the turns of the coil sharing a magnetic field.

> Grey: It [compass] just goes around and round.
> Interviewer: Yes, but what if there would be another [wire], straight after this one?
> White: Oh, it wants to goa round that one too, but then comes the next and the next until it comes out. It [turn] pushes it [compass] in a way along. (Transcript 18)

5.2.6 Inducing electricity with coil and magnet

When the students were freely investigating the coil and bar magnet, they initially held the bar magnet vertically, while the center of coil was parallel to the table. It seemed as if they were trying to find a spot where the bar magnet would begin to produce electricity, like a battery. Pink's first comment might indicate this. White is holding the bar magnet, while Pink is monitoring the voltmeter.

> Pink: Maybe it will become negative when you put it here and positive there? (Transcript 19)

The students continued to place the magnet on several places of the coil, without effect. After a while, Pink suggested to put the magnet through the center of the coil, but the magnet was too big and White had to switch to a smaller magnet. When White put the magnet in the center of the coil, it seems as if Pink missed the voltmeters registration or the movement was too slow for the voltmeter to register. This causes the group to change back to holding the bar magnet vertically again for a while, before switching to stronger magnets. Suddenly, White starts to move the magnet.

> Pink: Ah, if you do it quickly you get something. *Takes the magnet.*
> White: Did you get two [referring to the voltmeter]?
> Grey: Wow.
> White: Come on, Pink! *Pink tries harder.* (Transcript 20)

At this point, Pink was moving the bar magnet too fast for the voltmeter to register it properly. This caused White to consider slow movements, but after a test she discarded the notion.

> White: No, go in slowly again.
> Grey: Wow, four, five, six!
> White: Try to go in slowly. *Tries herself.* No, slowly doesn't work, but… You have to do it fast.
> Grey: Wow.
> Interviewer: Mhm.
> White: Is that it? The same as with the copper?
> Interviewer: Yes, in a way. (Transcript 21)

Possibly because of the movement involved, White makes the connection between the copper plates and the wire. However, they were unable to comment more on this connection.

5.3 Activities, group two

5.3.1 Investigating magnets

When asked to investigate the interactions between a compass and a magnet, the students engaged with the magnets and compasses first individually. Stripes appeared to be engaged in play, trying to make the compass needle spin round as fast as possible. Yellow placed several compasses around a magnet, but makes no comment about it. Blue meanwhile made a comment about the compass needle vibrating when the magnet is moved. Then, Yellow also got into play, trying to make the compass needle go around fast. Blue started flipping the bar magnet along the long axis, essentially switching the north and the south pole, and noticed that the compass needle would turn 180 degrees. Yellow and Blue discuss their initial findings and seem to have found the same results. It is here that the discussion took place regarding the nomenclature of the poles, as mentioned in section 5.1 Prior knowledge. This part of the conversation has been taken out here.

> Yellow: It attracts it here and repulses it there, the arrow, look when I come closer.
> Stripes: Yes.
> Blue: So, it attracts north, simply. So, the compass needle, it turns=
> =Yellow: That is, if this is positive, the arrow is positive, so…
> Stripes: No, look here, here. *She finds the pole at ¾ of the magnet.*
> Interviewer: Yes, this one is a bit strange.
> (…)
> Yellow: But, do you see that the arrow is attracted by this one and repulsed by the other?
> Stripes: Mhm. (Transcript 22)

Here, the ‘faulty’ magnet also comes into play, although, like with group one, it does not seem to be a problem to the students. Unlike group one, this group was not as easily thrown from their conception that opposites attract, but treated the confrontation with the faulty magnet as curious. However, they readily accepted the explanation provided by the interviewer, and seem to work fine with the idea that this bar magnet is just an exception.

5.3.2 Magnetic field

The students were quick to grasp the idea of the vectorboard, although, like group one, they assumed the metal pieces were compasses or magnets. The interviewer subsequently explained that there were no magnets, but pieces of iron that are shaped like arrows. There were no questions related to why they would work in the same manner as a compass.

The students continued to investigate, holding the bar magnet vertically on the board and moving it. Asides from describing all the arrows as pointing towards the magnet, Stripes and Yellow noticed that, once the magnet moved on from an arrow, it would remain in the same position. Yellow commented that turning the magnet has no effect on the arrows.

After being asked by the interviewer to find some patters that the bar magnet makes, Blue suggested to lay the magnet flat on the board. Yellow started to describe his observations.

> Yellow: Here, those in the middle don't really know what to do. Because… The pole has moved a little more to the middle so it is about here [3/4], and the other is here [at the end].
> Blue: Ja.
> Stripes: Mhm.
> Yellow: So, the middle is about here.
> Blue: Mhm.
> Yellow: So, this row here, it points at both.
> Interviewer: And those between the middle and the poles?
> Yellow: They point a little more her [closest pole] than here. (Transcript 23)

It seems as if the students are having trouble seeing a pattern, other than the direction of each individual vector. They are describing each vector with its relation to the poles. The students were asked if they could draw any lines based on the vectorboard.

> Interviewer: How would you draw lines, if you would connect all [arrows]?
> Blue: One here and one here. *Draws arcs with her hands.*
> Interviewer: Mhm.
> Blue: And one straight out here and here [poles].
> Interviewer: And those that are here, how do the ones a little on the side look?
> Blue: A little like this. *Draws a straight line at an angle with the magnet.*
> Yellow: If I look at this like the earth, then they would look like this, and this, and this.

> *Draws bigger and bigger arcs resembling field lines.* There will be more and more circles farther out. (Transcript 24)

Yellow connects this to his knowledge about the earth's magnetic field. When asked, he draws out a nearly correct representation of the magnetic field. Afterwards the students were shown an illustration of the magnetic field. The students were then challenged to see what happens when they follow the magnet with a compass.

> Yellow: If I start here [at the side of one of the poles], it will move far away. *Follows the compass further away from the magnet.* Here, it must have lost contact. *Is half a meter away from the magnet.*
> Interviewer: No, go on. Just be very careful to follow where the needle points.
> *The compass finds its way back to the magnet.*
> Yellow: It moves like an arc! (Transcript 25)

The students seemed to be amazed that the compass was affected by the magnet from such a distance, and the fact that something physical could follow the field lines.

5.3.3 Examining copper

The students were asked to examine different metals with magnets and compasses. They soon discovered that, while iron is attracted by magnets, the other metals presented, aluminum and copper, seemed unaffected by magnets. Using a compass, they found other, confusing results. The students seemed to be unable to decide whether the metal was magnetic. However, a magnet was positioned close by, affecting the compasses. This made Yellow suspect the copper to be slightly magnetic. However, after the interviewer pointed out the nearby magnet, the group changed tactics and tried magnets again. They were sure they saw no attraction at first.

When the group was handed the copper pipe, Yellow immediately put in a magnet, which fell out slowly. This made Yellow suggest friction at once. Blue took the magnet and looked in the pipe while it fell. As the falling magnet does not touch the pipe a lot, she suggested it was magnetism instead of friction. This experience makes the group rethink their thoughts about coppers magnetic abilities, now claiming that it must be magnetic. Regardless, the friction was tested with a plastic pipe of the same dimensions, and the students agreed that friction was not the cause. The students returned to investigating the magnetic nature of the copper pipe, using the compass.

> Blue: It is a little magnetic, because the needle turns a little right there.
> Stripes: It looks like it.
> Yellow: *Puts the magnet on and takes it off the copper.* I feel… It feels like there is something here.
> Stripes: *Tries as well.* Yes, a little maybe. (Transcript 26)

Blue saw movement of the compass needle, which she interprets as a sign for a magnetic field of the copper. Yellow commented he feels something while he puts the magnet on and takes it off the pipes surface repeatedly. The group switched to a stronger magnet, and using a piece of copper plating instead of the copper pipe. This made the effect more noticeable, and the group confidently stated the copper to be magnetic.

> Yellow: It has to be magnetic!
> Stripes: Yes!
> Blue: Can I feel? Yes.
> Yellow: There is a magnetic field around there.
> Stripes: Yes=
> =Blue: Yes. (Transcript 27)

All members of the group now agree that a magnetic field exists around the copper plate. The students may have felt satisfied with their findings, and stopped their exploration of the phenomenon. The interviewer than tried to make the students reflect on the nature of magnetism of copper, by asking exactly when it is magnetic. A discussion between Yellow and the interviewer ensued.

> Interviewer: Now I would like to ask an important question. When is it magnetic?
> Yellow: It attracts magnets. This one also does it, just that the magnetic field is a little…
> Interviewer: If it gets attracted like a magnet, shouldn’t it be repulsed on the other side?
> Yellow: I would say it works like with iron. It isn’t magnetic, but can be attracted by magnet.
> Interviewer: Yes, yes, I see what you mean. But how can we test this? (Transcript 28)

Yellow connected his observation with his knowledge about iron, which is ferromagnetic, stating that copper might slow the magnet down in a likely manner. After not responding when the interviewer asked how Yellow could test this, the interviewer showed the magnet falling onto the copper, which ‘brakes’ the magnet, so it drops softly onto the copper. The interviewer subsequently asked if this would happen if the copper would act like iron. Yellow recognized this discrepancy, but seemed flustered by it.

> Yellow: It brakes it as well… *He starts to lift the magnet faster and faster. Switches to a small copper plate, and manages to lift it into the air a little.*
> Yellow: You can’t say that it isn’t attracted by the magnet!
> Stripes: It is attracted a bit, yes. (Transcript 29)

The students did not seem to be able to make sense of the situation, and initially ignored the braking, still holding on to attraction when removing the magnet as a comparison to the way iron reacts to magnets. To make the testing similar to the falling magnet through the pipe, the interviewer asked the students if they could think of any other directions in which they could move the magnet. The students then begin to move the magnet along the surface of the copper plate. They begin to move the magnet faster and faster almost automatically, without commenting either to the interviewer or each other. When he is moving the magnet so fast the copper plate started sliding on the table, Yellow exclaimed:

> Yellow: Ok, now I’m not even touching it! (Transcript 30)

After this, the interviewer asked again when the copper plate seems to be magnetic. The following discussion ensued.

> Interviewer: So, what do you say, when is it magnetic?
> Stripes: When you pull them away from each other.
> Yellow: When you pull the magnet over it. Eh, this is induction, isn’t it?
> Interviewer: Yes, that is what it is all about, but we are not there quite yet.
> Blue: *Moves the magnet along the copper plate.* It gets heavier the further you get.
> Stripes: Let me try. Yes.
> Blue: But it doesn’t get easier on the way back, that is a little strange.
> Yellow: Well, when I push it this way, there is something that catches me.
> Stripes: Yes, there is like resistance there.
> Interviewer: And the other way?

> Yellow: It is the same.
> Stripes: Mhm.
> Blue: *Tries it.* Now I tried it the other way, and is became the opposite.
> Yellow: *Starts to move the magnet faster.* Well, the faster I move it, the more it gets.
> (Transcript 31)

Several paths of reasoning seem to go on at the same time here. Blue's initial statement (pushing the magnet gets harder further down the plate) was immediately questioned by herself, saying that if this was true, the way back should be easier, which it is not. She later tries the same movement with the magnet reversed, and seemed to be confused when this seemed to confirm her first statement. Meanwhile, Yellow has been thinking about the resistance that he observed. It appears as if he connects lifting the copper plate and moving it on the table with the magnet. He tests out this idea, and states that the quicker he moves the magnet the more resistance he feels. After a brief explanation, the lesson had to move on due to time constraints.

5.3.4 Current carrying wire

After a brief investigation, the students concluded that the wire was not magnetic when not carrying a current. When the current was turned on, the students were asked to investigate further. However, the group did not make any progress. In the interview the group commented that they had expected the whole wire to be one magnet, with north and south poles at the positive and negative connectors of the power source. The interviewer decided to provide some direction to the investigation, and asked the students to pay attention to the magnets while the current was turned on and off. The group then claimed the wire was magnetic when a current is flowing.

The group had now observed magnetism due to the current in the wire. The interviewer now established with the group that an electric current in a copper wire means there are electrons moving through it. After reminding the students of the existence of free electrons in the copper plate with an illustration, the interviewer asked the students to compare this situation with the previous situation (magnet moving over the copper).

> Interviewer: So, there are electrons here [plate] and here [wire], the only thing we do here is connect the positive and negative side, and the electrons start moving=
> =Yellow: Yes, off course, off course=
> =Blue: Does the magnet affect the copper here=

> =Yellow: Yes, because if el… If electrons… They are attracted by the protons, those are positive. If this her [magnet] is positive, or actually, negative because then it repulses them, if I hold it in the middle, all the electrons will move to the outside. That means if I do this (*moves the magnet up and down the plate*), then all the electrons will either move to or from the magnet. That means a lot of electrons are moving. (Transcript 32)

Yellow wrongly connects the charge of the electrons with the poles of a magnet, even though the difference between north and south pole and positive and negative has been pointed out several times throughout the lesson. His explanation does not take in account the neutral overall charge of the plate, nor the recently discovered copper has on a moving magnet. However, he does envision the situation on a microlevel, and mentioned the movement of electrons. Blue proposed an experiment to test Yellow's idea.

> Blue: *Balances the copper plate on the edge of the table.* If it is correct, what you said, that this [magnet] repulses electrons, then this [copper plate] should maybe fall down if I move back and forth. (Transcript 33)

The group pursued this for some time with varying, inconclusive results. The interviewer directed the students' focus back to the movement of electrons, and similarities between the two situations.

> Interviewer: Ok, but what is happening here [wire] then? We talked about moving electrons, right?
> Yellow: Yes.
> Blue: Or, that it is magnetic when the electrons are moving?
> Interviewer: Yes, and what happens when I do this? *Moves the magnet back and forth over the copper plate.*
> Yellow: The… The mag… it moves!
> Interviewer: What moves?
> Yellow: The magnet?
> Interviewer: Yes, but what's in here?
> Yellow: Eh, copper. And electrons.
> Interviewer: Ok, so if we do this (*moves copper plate over the magnet that is resting on the table*), how does that look for the magnet?

> Yellow: Eh… Like that? *Points to the wire*. Then the electrons are moving, because for the magnet, they are going back and forth. (Transcript 34)

With some help, the group arrives at the conclusion that movement of electrons is the cause of the observed magnetism. Yellow also states that the movement only has to be relative between the magnet and copper.

The students were then asked to investigate the magnetic field of the current carrying wire. As with group one, they act on their expectations to find a north or south pole somewhere on the wire. They start with holding a compass close to the wire's connections with the power source, as well as where the two wires are connected and some bare metal is showing. When asked, the group expressed that they are looking for a point where the compass would change direction.

The students seem to have the perception that a current carrying wire will act like a bar magnet. The initial investigation proves this idea wrong, however, the students struggled to find a new direction. The interviewer therefore made the students reflect on what they learned on magnetic fields. When this failed to lead to fruitful investigation by the students, the interviewer offered a new perspective on the matter.

> Blue: But, what? I don't understand anything.
> Interviewer: Where is it going? Try to describe what you are seeing.
> Blue: Ok, it is not pointing straight towards the red one, but it is like… hard to explain.
> Interviewer: Earlier, we saw, with the normal magnet, that we could follow the compass. But if we follow it here, what happens?
> Blue: Hmm, if I follow the compass, then… No, I don't get it.
> *Yellow tries.*
> Interviewer: Where is it going?
> Yellow: I'm taking it round, and it goes like, I take it…
> Blue: It points neither to or from the wire.
> Stripes: Mhm.
> Blue: It points like this [past the wire].
> Interviewer: Yes… where are north and south then?
> Yellow: Eh, here and here.
> Interviewer: Are they? (Transcript 35)

It proved hard for the students to simultaneously hold the compass level, move it in the direction of the needle, keep it close enough the wire and reason with the evidence. Even though the students saw the compass in various positions around the wire, and even moved it in a circular motion, they seemed unable to unable to accept or process this information. Questions arose from the students about whether the actual shape of the wire (square or round) under the isolation could affect the magnetic field. After discussing this, the interviewer guided the group further in their investigation.

> Interviewer: If you hold it on one side, then it points this way, but if you hold it on the other side it points the other way. Wherever you hold it next to the wire, where does it point?
> Yellow: Past the wire.
> Stripes: Mhm.
> Interviewer: And if you would follow it?
> Yellow: It just goes around… (Transcript 36)

This proved enough for Yellow to connect the evidence and state that the magnetic field was circular. The other students tested and confirmed this afterwards.

5.3.5 Current carrying coil

Before turning on the current in the coil, the interviewer asked the group how they thought the magnetic field would look. The group offered no suggestions. They were then asked to investigate the magnetic field. Briefly into their exploration, the group immediately connects their observations to the magnetic field of a bar magnet, with the compass being able to travel through the coil in addition. It seems, however, as though Yellow sees a discrepancy. He remembers the shape of the magnetic field of a current carrying wire, and points out that the shape of the magnetic field of the coil may only look this way. To test this out, the 10-turn coil was changed for a single turn. As Yellow is investigating the magnetic field in all places of the single turn coil, Blue is confused about the direction of the electrons and the direction of the magnetic field.

> Blue: But I'd say that here, maybe, the wire goes around like this [turn]. Or inside the wire, the electrons go around like this, or not? *Draws horizontal circles in the air.*
> Interviewer: What did you say? Here?
> Blue: Inside the wire.
> Interviewer: No, the electrons move from the negative to the positive side.

> Blue: Yes, but do they like go around inside as well? Or is it just…
> Interviewer: No, they move mostly straight forward.
> Blue: But then, how does the magnetic field move like we saw?
> Interviewer: Ah, that was a very good question! (Transcript 37)

She is asking if the electrons have any movement other than the circular motion when following the coil, possibly to justify the direction of the magnetic field. Meanwhile, Yellow has reached the conclusion that even the single turn appears to have a north and a south pole. He then tried to understand the 10-turn coil's magnetic field. It seems as if he tried to understand how the curling of the wire would affect the magnetic field. Blue engaged in Yellow's reasoning, stating that there might be a difference between the straight wire and the curled wire.

> Blue: Eh, does the magnetic field go, like, this way [through the coil]? Because, in a way… It is more like, it turns more this way, into the wire. Because, it there isn't really a difference between this wire and that. *Points on two turns in the coil.* There something that is different between the curled one and the straight one.
> Interviewer: Well=
> =Yellow: I wouldn't say that. Because, the wire here [connecting the coil to the power source], that [magnetic field] goes around like this, right?
> Interviewer: Yes.
> Blue: Mhm.
> Yellow: So, if I curl it, it will keep going around.
> Blue: Yes, but=
> =Yellow: That means that, as well as going around like that, so it goes… It means it [magnetic field] goes around like this. It is the same here [coil], it just goes around. So, it is actually the same, just that one is one straight line and the other is many.
> Blue: Yes, that is wat I mean, this and this one [the two wires in question], the same happens with the compass, either we hold it here or here. So, there is a difference between this [coil] and the straight wire. Something happens when you curl it like that.
> Interviewer: Do you mean something is different inside the wire?
> Yellow: No!
> Blue: No, when you curl it.

> Stripes: When you roll it.
>
> Yellow: The straight one always guides around, also when it is bent. And here [coil], if I curl it round all, it will always have the same… It will always guide around. So, it will go around all.
>
> Blue: But why does it become different from the straight wire?
>
> Interviewer: But is it different?
>
> Yellow: If you imagine that, this wire here, actually is the same except only one.
>
> Blue: Yes, that is true.
>
> Yellow: Only, when they are together, it works better. (Transcript 38)

Here, Yellow showed his understanding of the phenomenon by correctly explaining it to the other students. He also saw that the proximity of the turns in the coil will make the compass travel through the entire coil before circling back.

5.3.6 Inducing electricity with coil and magnet

In contrary to group one, group two worked with coils with several hundreds of turns instead of the 10-turn coil model. This resulted in easier observations for the students. When handed a coil connected to two LED's and a bar magnet, the group immediately knew what to do.

> Stripes: What if I do like this? *Moves the magnet in and out of the coil.* It didn't light.
>
> Yellow: Yes, it did.
>
> Stripes: Yes!
>
> Blue: Oh, the light is red.
>
> Interviewer: What did I say about LEDs?
>
> Blue: Eh, they only light when the current is going one way.
>
> Interviewer: Yes, and what are you seeing right now?
>
> *Stripes moves the magnet slowly in, and quickly out, and tries the reverse.*
>
> Stripes: Oh, it works… Like, this one lit then, and then both. It works like…
>
> Blue: We have to, like…
>
> Stripes: This one only works when you put it in, the other only when you take it out. (Transcript 39)

Stripes observed that each LED will only light when moving the magnet one way. She tested her idea, and when it was confirmed, stated a generalized rule. Yellow then tested that the movement only has to be relative to each other. He placed the magnet on the table and moved the coil up and down instead.

The LED's were taken out and an analogue voltmeter was put into the circuit. The students soon found the most effective way to induce a current, without much discussion. Yellow tried to turn the bar magnet along its long axis while in the coil, with insignificant effect. Stripes moved the bar magnet to and from the coil, without putting it in, which had some effect. Blue tried to move the magnet on the side of the coil, which had negligible effect. The interviewer then asked for their conclusions.

> Interviewer: What… Which way is most effective, then?
> Yellow: Like this, in and out. Because then more turns react to it.
> Interviewer: Yes… And because, if you look at the magnetic field it looks like?
> Stripes: A magnet.
> Blue: Mhm.
> Interviewer: Yes, and they are strongest?
> Stripes: At the tips. (Transcript 40)

Yellow points out that moving a magnet through a coil will engage the most coils in the activity. The interviewer guided the students to connect their observations with the shape of the magnetic field.

Group two was also challenged in the lesson to induce a current using only two coils, one with a current.

> Interviewer: How can you get a current to run in the other coil, without using a battery or something like that?
> Stripes: We can use a magnet.
> Interviewer: And what if we don't have a magnet, only these two coils?
> *Yellow takes the current carrying coil and moves it up and down the other coil.*
> Yellow: Yes, we got some, we got some.
> *Yellow moves the coil in all possible directions as a joke.*
> Interviewer: But now you have to think before you just fling it around. How does this magnetic field look?

> Yellow: It was like this, like a magnet.
>
> Interviewer: So how can you make the most current?
>
> Yellow: By putting it in. *Places the coil on top of the other.* Wait, we got some.
>
> Blue: Oh, let me try! *Moves the coil op and down like a magnet.*
>
> Yellow: You can see it move [voltmeter needle]. (Transcript 41)

Even though initially joking, the students were surprised to find that a current carrying coil could be used as a bar magnet to induce a current in another coil.

5.4 Learned and understood concepts

During the interview the students were asked some questions about main concepts in the lesson.

5.4.1 Group one

When directly asked what they know about magnets, the students of group one only mentioned the more superficial characteristics. The students mentioned a north and a south pole, and White remembered that the north pole is often colored red. Grey mentioned that different strength magnets exist. Pink expressed a thought that magnets could have something to do with making energy, which caused White to discuss some of the details of electromagnetic induction.

> Pink: You can make energy?
>
> Interviewer: Mhm, is it the magnet that makes energy, or?
>
> Pink: No, there is something in between… No, I don't remember.
>
> Interviewer: Yes, you are on the right track.
>
> White: It was when something… Copper or something like that, either moved or the magnetism moved, like, quickly over it so the electrons started to move. Then, there could come electricity? Electricity, I think. (Transcript 42)

Then, the discussion went to which metals could be picked up. All students knew that iron could be picked up, and all recollected the strange effect a magnet has on copper or aluminum. However, none of the students offered an explanation for this fact. The group was asked what they remembered of magnetic fields. White seemed to accurately recall the shape of the field.

> White: It was like, I don't completely remember how, but it was around them. Also, they were pulled to either one side.
>
> Interviewer: What did we use?

> White: Huh?
>
> Interviewer: You were talking that something was pulled to either one side?
>
> White: Yes, that were those compass things, they were pulled to each side. Those that were closest to north were pulled towards north and those that were south to south. So, in a way they were pulled to the sides, not the middle, or something like that. It was like around the magnet, that was pulled in. In a way, it was a magnetic field. (Transcript 43)

The interviewer asked White to draw what she meant. While she was drawing, both Grey seemed to remember more and helped complete White's drawing with several suggestions on the shape of the field. It is also White that took the lead when discussing the copper plate and magnet.

> White: Mhm, in a way when we dragged it along the copper plate slowly, it felt quite normal in a way, there wasn't a lot of… counterforce. But if we began to do it quickly, like moving it back and forth quickly, then there was a lot of this…
>
> Pink: Resistance.
>
> White: Resistance, because there was something…
>
> Grey: There were some electrons that started to work or something like that.
>
> White: So, it became hard to move them, the quicker they in a way moved towards each other, quickly.
>
> Grey: It was like, just like something was holding it, a bit. When I moved it away. (Transcript 44)

Again, Pink and Grey also contributed after White had started explaining. It seems as if Pink and Grey are recollecting knowledge from memory, while White is trying to express her understanding. When asked, White was also able to connect the copper plate to the copper pipe.

> Interviewer: How does this all connect, any ideas?
>
> White: It is like… Because it… The magnet is moving quickly through the pipe, really, and when it moves fast, there is more resistance, because of the copper and this [magnet] moving towards each other. Then it will take longer for it to come down. (Transcript 45)

When discussing the magnetic field of the current carrying wire, all students clearly remembered the compasses pointing the other way when the direction of the current was switched. All students seemed to have trouble recollecting the actual shape, however. White first expressed that the compass would always go around the wire. Immediately afterwards she said she does not remember if the compass pointed around or to the wire.

After the interviewer provided an illustration of a wire coming out of the paper and a compass both left and right of the wire, White remembered the movement of the compasses. She connects this to the coil.

> White: Ooh, now I remember, it was a little… It didn't point in, in a way it just wanted to go around, so in a way it showed where the field was.
> Interviewer: Mhm.
> White: Because when we did it where we went through [the coil], then it pointed where it wanted to go. It didn't point to any current.
> Interviewer: Mhm.
> White: So, in a way, it pointed where the field went and were it wanted to go in again. (Transcript 46)

The group was also challenged to generate a current in a coil using only another coil carrying a current. This was not covered in the lesson. Even though the students recollected the shape of the magnetic field of a current carrying coil to be similar to that of bar magnet, none connected the two. The only suggestions before guidance were related to somehow connecting the wires of the two coils. Only after the interviewer reminded the students of the similarity between a bar magnet and a current carrying coil did White mention the idea of moving the coil. However, the field concept appeared not completely understood. Pink and Grey suggested that the two coils could be put on top of each other, with the turn touching and the holes parallel. They said it would put the wiring closer together and therefore enlarge the induced current. While the interviewer was trying to guide the group to an understanding, it became apparent that the concept of inducing electricity was poorly understood. While talking about the concept of inducing electricity from one coil to another, the interviewer asked the students how the compass moved through the coil.

> White: First, it went in here and then it went out here, and around like this and back in again.
> Grey: It just wanted to go one way.
> Interviewer: Mhm.
> White: That means the current is coming out there. (Transcript 47)

It seems as if White thinks that the current comes out of the coil like the compass, and is thus transferred to the other coil.

5.4.2 Group two

When asked what they know about magnets, the group firstly answered north and south poles. The groups views regarding the composition of (solid) magnets was discussed, as this came up during the lesson. The group, or at least Yellow, seemed to have an understanding that the north and south poles of magnets can be found throughout the length of the magnet. It appears as if they see the magnetism of each individual magnet melting into one as the magnets are put together. Yellow stated the north and south pole to be part of the bigger whole (of the bigger magnet). No mention of a magnetic field was made, until the interviewer asked the group to use the field concept to explain adding magnets to one bigger magnet. Blue showed understanding of how fields can interact with other fields.

> Blue: But… Isn't it like, the small magnetic fields cooperate in a way to make one big?
> Stripes: Yes…
> Blue: When you can put several magnets together to form one.
> Stripes: Yes.
> Interviewer: Can you compare it to something?
> Blue: Yes, maybe you can compare it to that with the coil? Can't you?
> Interviewer: Yes.
> Blue: It has to do with those small magnetic fields that cooperate, in the red wires.
> Stripes: They became one big one, yes. (Transcript 48)

She has connected the question with her understanding of how a coil generates a magnetic field and uses it to explain the situation.

All students seem to remember the magnetic field of a single current carrying wire. Stripe mentioned that one magnetic field magnetic field will form around multiple current carrying wires. Yellow added that each wire pushes the magnetic field along. Upon asking, the group explained that the current must be in the same direction for all wires.

> Yellow: Ehm… The would have to go the same way, wouldn't they?
> Blue: Mhm.

> Yellow: Because, otherwise… They would collide.
> Stripes: Yes, that would have collided.
> Yellow: They want to… Well, if they go this way they would just send along, but the other way they would crash into each other.
> Stripes: Yes, if they go like this they just crash into each other.
> Interviewer: If to come towards each other?
> Blue: Yes.
> Stripes: Then, nothing can get any further. (Transcript 49)

The group uses magnetic fields in the interview to explain the force they felt when pushing matching poles together. Yellow puts the thought into words that the whole group seemed to have.

> Yellow: Because, if you assume that things move this way, from north to south. The one you are holding also goes from north to south, but is facing the other way. And then… They [magnetic field] will always collide into each other.
> Interviewer: Mhm.
> Stripes: If they are going different ways, they will always…
> Yellow: Collide.
> Stripes: Yes, collide.
> Yellow: And repulse each other.
> Blue: They only want to cooperate with other magnets if those magnets are going the same way.
> Stripes: Yes. (Transcript 50)

The group seems to understand the magnetic field as something that can either collide or cooperate.

Regarding the copper plate, the group clearly remembered the relationship between the speed of movement of the magnet and the resultant ‘braking’ force. Yellow and Stripes were able to explain this force with movement of electrons. When interviewer asked if this relates to the current carrying wire, the group vaguely stated a connection between electron movement and magnetism.

All students could easily state the most efficient way to generate a current using a coil and a magnet. The group also considered other options, such as moving a magnet past the hole of a coil. However, no explanation is offered until the interviewer asks.

> Interviewer: Can you explain why, with the tools we have. Try to explain it with the field. Why do some ways work better than others?
> Yellow: Because, in there they are tightly packed.
> Stripes: Yes, they were probably denser in the middle.
> Yellow: I’m going to say something strange here, but, well, in there the magnetic lines are tight, so it is more powerful there. But on the outside, they are further away from each other.
> Stripes: Yes.
> Interviewer: And the magnet itself, the one you are using?
> Yellow: That has… Tightly packed her [poles] and… Yes.
> Interviewer: So, what was the best way to make a current?
> Yellow: Like this. *Takes the magnet in and out of the coil.*
> Interviewer: Because?
> Yellow: There is the most magnetic field there.
> Stripes: So, you can push the hardest there. (Transcript 51)

Yellow explained the effectiveness by magnetic field lines. He showed understanding that the stronger a magnetic field involved, the larger or stronger a current is generated. When the interviewer asked how the coil could be seen as having a magnetic field before a current started flowing, all students also showed understanding that electrons only have to move relative to the magnet. The interviewer probed the group about the perpendicular relationship of the movements and forces involved, however, no student viewed this as directly peculiar.

The group also remembered that a coil can induce a current in another coil. However, they only state moving one of the coils as if it were a magnet and coil. When challenged to induce a current with both coils unmovable, no suggestions were offered other than connecting them with wiring.

Chapter 6: Discussion

In this chapter, the results will be discussed considering literature on the subject. Every activity will be discussed separately first, before discussing the lesson as a whole. Through the research questions, the discussion will be attempt to shed light on the problem statement. The research questions are as follows:

1. What is the most important prior knowledge needed to understand electromagnetic induction?
2. What is the impact of using concrete material when learning the concepts of electromagnetic induction?
3. How does each step in the lesson contribute to conceptual learning and construction of an understanding of electromagnetic induction?

The most direct references to the transcripts are marked with that transcripts' number. However, that discussion might refer to several other transcripts or observations additionally.

6.1 Activities

The discussion of the activities will focus on the role of prior knowledge for this activity, how the investigation progressed and how the activities connect to each other.

6.1.1 Investigating magnets

In this activity, the students were asked to investigate the interaction between magnets. At their disposal were bar magnets and compasses (essentially magnets).

The importance of prior knowledge and confidence in this knowledge can be directly observed in how the two groups react to being confronted with the "faulty" magnet. The observations from using this magnet seemed to be in cognitive conflict with their conception of magnetic attraction. The first group stated before investigation that only opposite poles attract each other, but immediately retracted this statement when they observed the same end of a magnet attach to the faulty magnet on both sides. Their lack of confidence caused the group to think their statement was wrong at once, rather than critically investigating the matter (Transcript 4). This lack of confidence may have been caused by a lack in experience. Group two, on the other hand, did not dismiss their conceptions as easily. They had recently been taught in electricity, and could also vividly remember their teacher's opinions about a magnets poles being named positive and negative. Therefore, their statement about the concept that opposites attract had a better foundation than group one's, which may not have been more than a guess or a whim. This is exemplary of how not only a good understanding of the fundamental principles is essential for learning of observations found through investigation, but also a strong confidence. As Dega et al. (2013) found, cognitive perturbations have a better effect for learning than cognitive conflicts, when the learners have little prior knowledge. The latter even seemed to have an adverse effect, according to their findings. Even though this cognitive conflict has not been used to evoke learning in this case, the adverse effect for group one is visible. If not corrected, this could have caused a serious setback in learning, or in the least have been time-consuming to resolve for the students on their own. They do not have the knowledge or skillset to actively engage in making sense of a total cognitive conflict in this situation. None of the students had any questions regarding the clarification of the interviewer, stating simply that the magnet might be a bit old, without explaining how a magnet's pole might move. The immediate acceptance of the statement by both groups can be due to lack of knowledge or understanding. They simply do not possess any knowledge, conception or experience which disagrees with this statement. In addition, the more school like nature of the lesson might also make the students more inclined to readily accept information from a person in the role of a teacher.

All students in both groups repeatedly used the terms positive and negative when referring to magnetic poles, agreeing with findings by Maloney et al. (2001). Magnetic attraction can certainly be compared to attraction between electric charges, with respect to the polarity. However, in likeliness with findings by Saglam and Millar (2006), the students seemed to overdraw on the analogy. Bar magnets that are colored red on one side and white or blue on the other, might contribute to the misconceptions that these sides are positive and negative. Yellow brought this to light when he explained to the other students in his group, essentially linking color to temperature to positive or negative (Transcript 3). He reasoned that red is often thought of as hot and thus positive, while white is thought of as cold and thus negative[*]. But even after being corrected several times during the lesson, Yellow stated that electrons are being pushed by the pole of a magnet, since electrons are negative and the south pole of a magnet is negative as well (Transcript 32).

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[*] In Norway, it is common for students to refer to the polarity of electricity as plus and minus, and is therefore more easily connected to temperature as might be for English speakers.

This misconception seems particularly resilient, as all students repeatedly confused the terminology throughout the lesson, also after being corrected and explained the differences. As (Driver et al., 1994) pointed out, it is possible that two learning schemes exist within the student, one scientific and one related to personal belief. If any of the students uses this idea as their personal scheme, this would explain the resilience of the misconception. However, with enough evidence supporting the scientific scheme, the personal might be discarded eventually. This misconception also seems to be one of the only prior conceptions (together with "magnets attract metals" and "magnets attract only one side of other magnets") the students had, other than Yellow, related to the subject.

6.1.2 Magnetic force

Trying to push the same poles of two magnets together proved to be an exciting experience for all members of both groups. As this was an interesting activity, it will have helped raising and keeping students' interests in the matter. This was meant to be an important part in the lesson, designed to make the students realize the strength magnets can have. Although not explicitly stated by Bagno and Eylon (1997) in their list of key relationships of electromagnetism (Table 2), the element of force is central in their map (Figure 8) of the domain of the most general level. Seeing that magnets and their magnetic fields possess the ability to exert strong forces proved to be a key factor to understand that magnets can be used to generate electricity later in the lesson. Experiencing this physically might have contributed to the students remembering, as they all were able to recall the event vividly and expressed enthusiasm when retelling.

6.1.3 Magnetic field

The magnetic field concept was presented to the students in two ways. It was introduced using the vectorboard, and further investigated with compasses. The magnetic field concept proved to be a vital tool in the next steps in the lesson, as it can be used to explain certain effects and phenomena. The students of group two even used the concept actively in relation to magnetic force and electromagnetic induction, especially Yellow (Transcript 40, amongst others). This is understandable, as Yellow already had an understanding of the (magnetic) field concept prior to the lesson. However, as useful as the field concept was, it is unsure how well the students understand it. When White talked about what causes magnets to push each other away in the interview, it can be thought that she implicitly means the magnetic field when she said that the magnet sends out something, something that is around the magnet. Group two's explanation of the same event in the interview was rather like group one's. Here, Yellow and Stripes actively used the magnetic field concept and even the direction, as they stated that the magnetic fields collide when traveling in different directions (Transcript 49). This is congruent with one of the findings by Saglam and Millar (2006), who found that some students understand the magnetic field as flowing from the north pole to the south pole. It can also be compared to a finding from Thong and Gunstone (2007), who stated that magnetic field lines can sometimes be treated as real, physical entities by students. Group two seems to visualize magnets to be prevented from reaching each other by their respective fields. Since they used the word "collide", it seems likely that they envision the magnetic field as moving, or flowing, from the north pole to the south pole. If the magnetic field is seen more as a physical object than an abstract representation by the students, then this can easily explain why the two magnets would repel each other. Indeed, if one would envision two garden hoses pointing straight towards each other at full power, it is easy to understand that they would push each other away. As Thong and Gunstone (2007) proposed, this view of the magnetic field being something concrete, offers the students a ”real world" explanation for their observations. However, magnetic attraction is not as easily explained with this metaphor. An explanation offered by Blue in the interview, which the rest of the group concurred with, simply stated that the magnetic fields cooperated when going the same way (Transcript 50). Törnkvist et al. (1993) have shown many problems students can have with the field concepts, especially crossing field lines. Few students in their study regarded crossing field lines as problematic at all. It is unclear how Blue and the rest of the group visualize how multiple magnetic fields might react to each other, but they were reasonably effective in explaining the magnetic field of a current carrying coil from a single current carrying wire. Their use of the terms "cooperate" and "collision could insinuate that a crossing of field lines would not occur, as they would react to each other. The magnetic fields would either be colliding or cooperating, therefore flow the same way. However, the student's conception of the field concept is not nearly developed enough to be able to comment more deeply.

The following of the compasses may have contributed to an understanding of the magnetic field as flowing. As the compass needles used were shaped as an arrow, both groups talked about the magnetic field as having direction, although only group two used it actively in a discussion. The direction of the magnetic field is important in electromagnetism, as it determines the way charges react to it and defines the poles.

6.1.4 Examining copper

In this activity, students were asked to investigate interactions between magnets and copper. First, they investigated without guidance freely, and would conclude that copper is not magnetic. Then, the interviewer would show students a falling magnet through a copper pipe. Further investigation would ensue, to establish the relationship between movement and force.

The investigation of the interaction between magnets and copper was memorable for the students. All could easily recite the relationship they observed doing this activity. The activity directly shows the relative aspect of magnetism, since the magnet and the copper must move relative to each other. This part of the lesson builds the idea that movement is necessary for magnetism to transmit energy. As reported in the literary review, some research (Zacharia & Anderson, 2003) suggests that a focus on experiences may resolve some of the difficulties university students are having in the subject. This activity does not give the students experience in solving or working with electromagnetism quantitively, but rather offers the physical experience of the copper braking (taking away energy from) the magnet. This may have strengthened the students' understanding of the possibilities of magnets, as with the experience of magnetic force. Feeling something pull (or push) on the magnet *without* the copper moving gives rise to the notion that the magnet can affect something inside the copper. This is an important part in understanding electromagnetic induction. As the forces involved when actually inducing a current often are unnoticeable for learners, this activity might contribute to understanding the phenomenon as natural. Another possibility might be to show the students that a current flows in the metal, by offering them a preview of a magnet inducing a current in a coil and lighting a lightbulb.

None of the key relationships described by Bagno and Eylon (1997) in focus during this activity were specifically mentioned by the interviewer, even though he students were urged to explain their observations. Since the students had close to no knowledge of electromagnetic induction, their explanations were based solely on their understanding of magnetism. Therefore, misconceptions such as the copper being only slightly magnetic were constructed by the students during the lesson, despite compasses showing no magnetism when examining the copper plate beforehand. The lack of magnetic poles was also not enough to prevent this. It proved hard to debunk this misconception, as the students possessed no other knowledge or experience to disprove the simple statement that the copper is slightly magnetic. It seems that slight magnetism was the only possible explanation conceivable for the students.

Again, we see that creating a cognitive conflict and allowing students to investigate it does not automatically lead to (correct) knowledge. The students do not have an adequate understanding of the surrounding concepts to deal with the conflict. However, the cognitive conflict can be used to stimulate wonder and interest. The falling magnet did amaze the students and encourage them to find out more about the phenomenon. Indeed, the lack of explanation did not hinder the students in understanding and describing the relationship of the forces involved; namely the faster the movement, the greater the force.

Investigation on the matter seemed troublesome for both groups. Students in both groups were quick to propose friction as a possible cause for the slowly falling magnet, and subsequently rule it out. However, they had difficulties directing the investigation into new paths when on a dead end. In addition, when a hypothesis or idea was tested once and the test confirmed it, students would often quickly accept it as true, disregarding deviant observations. If the contradictory observations were pointed out, the ‘theory’ would be dropped again. This may be because previous observations are (momentarily) forgotten. Since the short-term memory has limitations, too many impressions, which cannot be immediately categorized, will prove troublesome (Miller, 1956). Guidance was needed from the interviewer to make the students experiment more, differently or think about other observations. When not corrected, the groups could spend a long time testing their ideas, without progressing. This can be explained by the students’ lack of prior knowledge and general understanding of electromagnetics, and therefore are unable to choose and structure the investigations effectively. Another factor could be how experienced and skilled the students are in performing practical scientific work. However, it cannot be expected that students will find the right answers by themselves, simply by engaging in an activity even when skilled in it. In accordance with (Dewey, 1997), learning does not come from the experience itself, but from reflecting upon it. To be able to reflect on an experience means the learner must connect several observations and induce a generalization. In science, the way one interprets an observation can be strongly dependent on one’s knowledge of the subject. Therefore, learning by inquiry or investigation is dependent on prior knowledge and understanding. This activity was therefore meant to create questions rather than answers.

Interestingly, despite literature generally commenting that the relative nature of movement in electromagnetism (among many other aspects) causes problems for learners (Albe et al., 2001; Galili & Kaplan, 1997), this aspect seemed hardly an issue for students in both groups. Indeed, Yellow even grasped the concept intuitively and explained it to the rest of the group. Students repeatedly showed their understanding during the lesson and interview. However, Yellow was the only student who tested this while inducing electricity; he held the magnet stationary while moving the coil. He seemed pleased to see that the result was identical to moving the magnet.

6.1.5 Current carrying wire

In this activity, the students were presented with a single wire, connected to a power source. After establishing that the wire showed no magnetism without current, the power source was turned on and the students investigated using compasses.

Other than discovering that the current carrying wire was magnetic, clearly indicated by the compass needle changing direction upon turning the power source off and on, the students had difficulties finding patterns and structuralizing their investigation. As the wire was lying flat on the table, with a magnetic field around and perpendicular to the wire, a compass orientated on the same plane as the table will not point in the correct direction, but rather the component of the vector in the plane of the table. This resulted in some students thinking that the magnetic field pointed inwards to the wire, a misconception that White repeated in the interview, even though the lesson focused on the magnetic field to be circling the wire. In addition, some practicalities regarding the shape of the wire, as well as the device used, seemed to be distracting in the students' search for the magnetic field (Transcript 11). The earth's magnetic field should also be taken into consideration. Should the direction of the magnetic field randomly be directly towards the earth's geographical north pole, the needle of a compass will remain unmoved when the current is turned off, potentially causing confusion. As inquiry based learning can be challenging enough for students (Erstand & Klevenberg, 2011), these distractions should be kept to a minimum. Too much input can leave students confused and unable to make inductions or deductions regarding the material to be learned. The investigation by the students would be incredibly time consuming or even impossible if the material used makes it difficult to make clean and concurring observations, particularly since the students in this study had enough troubles with investigating already.

The three-dimensional nature of electromagnetism also became a hinder for investigation. Since the wire was flat on the table the magnetic field was perpendicular to the wire and therefore not correctly displayed by the compasses used by the students. The students showed no spatial thinking, only when initiated by the interviewer. They did not move the wire from the table, or even moved the compasses over or under the wire. These findings seem to correspond with Saglam and Millar's (2006) hypothesis; that a learner's spatial awareness might effect learning within electromagnetism. The hypothesis was, however, not supported by their findings. The importance of the student's special awareness in this activity can be argued upon. With their hypothesis, Saglam and Millar (2006) intended the learner's ability to understand three-dimensional situations from two-dimensional illustrations found in textbooks. This was not asked from the students in this thesis. In this activity, students were required to hold the compass the current carrying wire in different orientations to correctly find and describe the magnetic field. However, this demands a conscious understanding that compasses only work in a single plane, combined with understanding the magnetic field as fully three-dimensional. As most of students had only just learned of the field concept, they will not have developed a full understanding of the concept. The student's only experience with the three-dimensional nature of magnetic fields was a bar magnet surrounded by fluid suspending iron filings, which the students interacted with after finding the magnetic field of the bar magnet. Moreover, as the students never investigated the magnetic field of the bar magnet with compasses in any other plane than the table's, it is not surprising that they did not either with the current carrying wire. Only group two had placed the bar magnet vertically on the vectorboard, but this did not seem be of influence when investigating the current carrying wire. Therefore, lack of spatial awareness is probably not the cause, although spatial awareness was not tested for. Rather, it is possible that more focus on the three-dimensional nature of the magnetic field when first presented will make learners more inclined to investigate the current carrying wire in all dimensions.

The circular magnetic field illustrates a cognitive perturbation of the student's new-found understanding that a magnetic field will go from north to south, involving the compass traveling from one point of the magnet to another. Additionally, a circling magnetic field seems to be cognitively conflicting with the more general conception that magnetism always involves two points (north and south pole), as does electricity. Indeed, this was observed when the students were investigating freely, before guidance. From explanations by the students given in the interviews, it became clear that the students were looking for some area where the compass would point towards, or some area where the compass would point away from, as we saw with the bar magnets. Initially, when starting to observe indications of the magnetic field circling the wires, students did not readily believe their observation were correct. Rather, they seemed to be thinking they were doing something wrong, and may have still been expecting to find a north or a south pole. Only after the interviewer asked the students in both groups to simply describe what they were observing, a student insecurely stated that the compass seemed to be pointing around the wire. Not before the interviewer confirmed this statement did the students accept this. It was easily tested and confirmed after this. If the students have operated with an analogy of electric charges until now (consciously or subconsciously), a circular magnetic field will likely be unreconcilable with this analogy. Electric dipole moments are created by opposite (point) charges, while magnetic dipole moments are created by charges moving in a circular motion (Figure 5). Considering Piaget’s views, this additional information would create a cognitive imbalance. Depending on the student’s existing cognitive schemes, the additional information can either be assimilated into an existing scheme or accommodated into a new scheme (Piaget, in Imsen, 2005). It can seem as if separate schemes for magnetism and electricity will be helpful in student understanding. Students should not be assimilating magnetic phenomena into schemes for electricity or vice versa. In other words, students should not learn to understand magnetism explained by analogies or as part of electricity. At the academic level normally seen in secondary school, the understanding of both electricity and magnetism will generally be too low for students to see any common ground. However, the key relationships as defined by Bagno and Eylon (1997), and the interconnected nature of these relationships involves both schemes. The learner is therefore required to accommodate both electrical and magnetic understanding into a new scheme, electromagnetics, at some point in their learning in order to progress understanding. Exactly how the students in this study have ordered the subjects cognitively is hard to say. Some indications, such as the continuous misuse of the terms positive and negative, show that the students do not fully differentiate between magnetism and electricity. The lesson might have contributed to creating unclarities for the students around the difference between electricity and magnetism. Indeed, showing that a current carrying wire is magnetic blurs the line between electricity and magnetism. However, this is necessary to further develop understanding of magnetism and electromagnetic induction.

This activity was meant to be connected to the previous activity, interactions between a magnet and a copper plate. As covered in the previous subsection (examining copper), this activity generated more questions than answers. If the two scenarios are compared, they are quite similar: In both cases electrons move relative to a magnet. This produces a magnetic field[*] which can be observed by the way the magnet reacts to it. With some guidance from the interviewer, one student connected the two activities, White (Transcript 14). After she had expressed her thoughts, the rest of the groups seemed to grasp the concept. The current carrying wire provides an explanation, or more accurately confirmation, for key concepts in focus during the copper plate activity. These concepts being (1) the movement of a charge (current) creates a magnetic field, (2) this movement being relative to the elements involved and (3) this works both ways, i.e. a current produces a magnetic field and a moving magnet produces an electric field and with that a current if possible. Three relationships presented by Bagno and Eylon (1997, p. 727) are in focus here; "a moving charge is a current", "a current produces a magnetic field" and "a magnetic force is exerted on a current in the presence of a magnetic field" . In the lesson, only "a current produces a magnetic field" was explicitly mentioned. The lesson focused on the more generalized, or simple, concept mentioned above; movement, relativity and reciprocity. By letting the students experience and discover these concepts, they can begin to build a concept map for electromagnetics. Since there was no focus on electric field or single charged particles in electromagnetic fields, the students' concept map built during the lesson will consist the right hand side of the map, as illustrated by Bagno and Eylon (1997, p. 731). During the lesson, students might have built understanding of a relationship between a current and a magnetic field. Depending on their prior knowledge, and therefore the existence of a concept map of electricity, it is possible that some students have understood to a degree relationships on the microlevel, such as between a magnetic field and a single charged particle. For instance, Yellow has attempted and succeeded in describing and explaining events on the microlevel (Transcript 34), as have White (Transcript 42) and Blue (Transcript 33). Galili et al. (2006) proposed that teaching in electromagnetism should start with

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[*] In the copper plate scenario, the copper moving relative to the magnet is not the actual current producing a magnetic field that brakes the magnet. However, it does allow the electrons to be affected by the magnetic field, and start swiveling around in the copper. These movements are known as Eddy currents, and these do produce a magnetic field which brakes the magnet.

the microlevel, as it might make learners more easily see a common cause for the concepts. While this might be true for university level learners, it requires thorough understanding of concepts such as particle movement, fields, charges and the concept of a particle itself. This prior knowledge is probably not mastered by secondary school learners. Moreover, to learn about the microlevel one depends on an abstract representation, which makes it unsuitable for beginners as well as use in the Vitensenteret. One of the marvels of electromagnetism is exactly the counterintuitive nature, which leads to unexpected outcomes such as slowly falling magnets. These can interest learners and therefore engage them in the activity. As only the general concepts and relationships were in focus during this study, a microlevel explanation was not always needed. Where it was needed and used, as in the connection between this activity and the copper plate activity, the lack of prior knowledge caused problems. Students possessed at best a fragmented understanding of the behavior of atoms and atoms in solid metals like copper. A better understanding could have made the investigation less time-consuming and less dependent on the interviewer. However, it is difficult to assess the true form of the concept map of any individual student. The lesson was meant only as an introduction to electromagnetic induction and its general concepts. The concept map of Bagno and Eylon (1997) can be compared to Piaget’s (in Imsen, 2005) cognitive schemes. The concept map as illustrated by Bagno and Eylon can be viewed as a normative illustration of the cognitive scheme of an individual that fully understands electromagnetics. However, as Piaget points out, each learner must construct a scheme individually, there is no guarantee that the learner constructs the same cognitive scheme as the teacher.

6.1.6 Current carrying coil

Students goal of this activity was for the students to be familiarized with the magnetic field of a current carrying coil. Students were presented with a current carrying coil and asked to investigate freely.

As all students in both groups were now used to using the compasses, the magnetic field was easily found and described. The students also quickly pointed out the similarities between this magnetic field and the one of the bar magnet. However, the discussion quickly turned to how this is possible. As all the students remembered the circular magnetic field around the single current carrying wire, this situation might have caused another perturbation in their understanding of the field concept. In correlation to the findings by Dega et al. (2013), the perturbation seemed to provide a learning opportunity, or at least an incentive for an adjustment in the students' understanding of the magnetic field concept. As the students are beginning learners of the field concept, they will have a fragmented or deficient understanding. This perturbation seems to challenge the students just enough. The shape of the magnetic field of the coil is not in direct conflict with anything the students have learned so far, but rather shows a new side of the field concept. Indeed, it is probable that the students did not think about how multiple magnetic fields would react to each other up to this point. However, it can still be seen as a perturbation, since the students seemed quite surprised to see the shape of the magnetic field compared to that of a single wire. Simply the incongruity between the magnetic field of the single wire and that of the coil, while a coil essentially is built from a single wire (or multiple single wires) challenges the students existing understanding of the (magnetic) field concept.

The way students in both groups found an explanation for the shape of this magnetic field is quite different. Firstly, Grey observed an interesting relationship between the shape of the wire and the shape of the magnetic field, stating that when the wire was straight the magnetic field was circular (Transcript 17). Now the wire is circular and the magnetic field is straight. Even though the circular motion of the charges in the coil does generate the magnetic dipole moment, it is the length of the coil that causes the magnetic field to be straight inside the coil. The coil can be any shape. This statement is therefore exclusively descriptive and shows little understanding. However, from observations made during the lesson, it seems highly likely that Grey only intended the statement to comment on an interesting observation and not as a valid explanation. White, on the other hand, did show some understanding while trying to construct meaning from the observations. After some guiding questions by the interviewer to make students reflect, she proposed the explanation that each turn in the coil effectively "pushes" the compass to the next turn (Transcript 18). This seems to indicate that White has some notion of the magnetic fields of each turn to cooperate. It is unsure, however, to which degree her understanding agrees with the scientific representation of the magnetic field of a coil. It may be possible that White imagined the circular magnetic fields of each turn as wheels, all turning in the same direction and thus pushing the compass through the coil. Unfortunately, this was not further pursued during the lesson. Group two followed a different path. Yellow questions the nature of the shape of the magnetic field, stating that it might only look like a bar magnets. He appeared to form a hypothesis or idea, though he did not state it explicitly. He quickly finds a way to investigate this further, as he started to investigate the magnetic field of a coil with a single turn, while the interviewer is in a discussion with another student. This directed and structured investigation stands in contrast with investigation during the other activities. Inquiry based learning requires the learner to have a certain amount of prior knowledge to be able to direct the inquiry. In this case, it seems as if Yellow is able to utilize his newly gained understanding magnetic fields to independently investigate the matter and ultimately provide an explanation (Transcript 38). Although he had some trouble expressing himself, he concluded that a single turn produces a north and south pole and implements this in the ten-turn coil. He showed his true understanding when he later explained the behavior of the magnetic field to the other students. The other students seemed to quickly understand as well, as the all reacted at the same time when the interviewer asked a question. Although most students in both groups seem the agree that the turns in the coil are cooperating in one way or another, it remains uncertain how precise their understanding is, considering the troubles even university students have with the field concept (Törnkvist et al., 1993). However, as the last step towards constructing an understanding of electromagnetic induction, this activity does seem to have been effective in helping the students to understand the magnetic field. If in fact all students understand the reasoning done by White and Yellow, they would also have to have a basic understanding of the concepts of the other activities.

Although the same key relationships apply her as well as in the activity with the single current carrying wire, they are not in focus here. While the equations listed by Bagno and Eylon (1997) do take direction into account, it is the unique shape of the coil which allows for the effective induction of an electric field. Therefore, if the students understand the magnetic field of a single wire, they can explain the magnetic field of a coil using only logic, as Yellow has done.

Interestingly, Blue is the only student who has noticed the discrepancy between the direction of the current and the direction of the magnetic field (Transcript 37). Although she was not able to describe the perpendicular relationship, she did react to it. Sadly, there was no time nor possibility in the lesson to adequality explain this to Blue. Even though electromagnetism is described by most as extremely complex, Blue showed that it is possible to uncover the complexity by student investigation. Had the material and possibility been there, Blue could have investigated the matter further.

6.1.7 Inducing electricity

During this final activity, the coil was connected to a voltmeter instead of the power source. The students were given a bar magnet, and simply asked to produce a current. The activity was somewhat different for group one and two. Group one used the 10-turn solenoid model that was used when investigating the magnetic field with a digital voltmeter. As this produced a very low voltage that was difficult to detect with the voltmeter, group two was presented with solenoids consisting of several hundreds of turns. Furthermore, group two used a led assembly to highlight the direction of the current in addition to an analogue voltmeter. These differences resulted in a slightly easier investigation for group two, as their equipment was more responsive than group one's.

Group two had the advantage that Yellow had prior knowledge of inducing electricity, and they immediately found the most productive method. Group one did not have any experiences with inducing electricity, and initially placed the bar magnet vertically on top of the coil. They seemed to expect the magnet to just make a current flow, almost like a battery, indicated by Pink commenting that the voltmeter might show positive figures when holding the magnet on one side of the coil and negative while holding it on the other side. Despite of most of the lesson focusing on the relative movement, the students tried out various places on the coil, holding the magnet stationary on the spot. The students might have seen this activity as unrelated to the other activities. As this activity took place late in the lesson, the students had already spent a long time learning about electromagnetism, explaining a (temporary) loss in concentration. Moreover, the students had been exposed to many new concepts and cannot be expected to consider these instantly in every new activity or situation (Miller, 1956). Eventually however, one student noticed a response from the voltmeter while moving the magnet towards or away from the coil, which quickly led to the students trying to produce the highest voltage by moving the magnet away and to the center of the coil. The magnet was too big to fit inside the coil, as the coil had acrylic glass in the middle to show magnetic field lines using iron filings. Additionally, the voltmeter used was unfortunately not responsive enough for the faster movements of the magnet, causing the students to consider slower movements. This shows the importance of well working equipment for inquiry based learning. If the students had a coil available with more turns and a more responsive voltmeter, their investigation might have been more successful. Instead of merely finding one method to induce electricity, they could have investigated how other movements of the magnet effect the induced voltage. As group two was provided with better equipment, they were indeed able to perform a broader investigation. They tried several methods of inducing electricity, such as moving the magnet in and out of the coil and moving the magnet over the center of the coil, and ranked them according to effectiveness by looking at the induced voltage. This indicates that investigation with real objects can be difficult if the equipment does not contribute to learning.

Mechanically, this activity is easy to understand for all students. How the newly learned concepts all work together to induce a voltage in the other coil, however, seems difficult for most. Most students in group one, for example, appeared to understand most of the concepts in the lesson adequately. In accordance with Driver et al. (1994), the students seemed to understand the symptoms of the phenomena, but struggled to understand what causes it. The actual activity of inducing electricity seems to have involved too many unfamiliar elements for the group. Even though White correctly links induction to electrons (probably referring to the previous activities involving movement of electrons), she is unable to comment further. During the interview, it became apparent that White had the misconception that the current from one coil is somehow carried through the magnetic field and in that way induced in another coil. When the interviewer said that the magnetic field of a coil was pointing a certain way, White stated that this is where the current is coming out (Transcript 47). This is can be compared to the results of Saglam and Millar (2006), who found that some learners seem to need a physical connection to explain some of the interactions. Although Saglam and Millar stated this in relation to magnetic field lines, White seems to envision the current physically moving from one coil to another, as if they were connected by a wire. She appears to have assimilated the phenomenon into her cognitive scheme for electricity, instead of into a scheme for magnetism. She therefore may not have accommodated the concepts learned in this lesson in their own scheme, but instead tried to mentally explain the observations electrically. This might be due to the reliance on electrons to explain the observations, which learners at their age primarily link with electricity. Had the students had more prior knowledge on electricity, this misconception could be negated by showing that the current and voltage change accordingly with the ratio of the number of turns in each coil.

As group two had better equipment, they reached a more refined conclusion. However, as with group one, most of these were related to the mechanics of the activity, primarily describing the movements of the magnet and the related efficiency. This could be for the same reasons as with group one. When using the LED-assembly with the coil and magnet, Stripes stated that each LED only lights when the magnet is moving a specific way (Transcript 39). The group did not comment directly on the direction of the current. The group could describe the effectiveness of several different techniques to induce electricity in the coil with the bar magnet. However, only Yellow mentioned that it was related to the relative movement of the electrons to the magnet, but did not comment further. Upon asking why the effect is strongest when moving the magnet in the center of the coil, Yellow offers the explanation that more coils will be effected when moving the magnet that way (Transcript 40). While the goal for the activity was to understand that the magnetic fields for both the magnet and the coil (while carrying a current) are strongest in those places, Yellow's approach is not completely wrong. However, it might suggest that Yellow views each turn to have an independent magnetic field, despite of the group having been shown an illustration of the magnetic field of the coil. During the interview, on the other hand, both Yellow and Stripes use the density of the magnetic field lines to explain that both the magnet and the coil will have the strongest magnetic fields at the ends, as explained by the interviewer during the lesson. Whether this is reflective of their understanding or merely a reciting from memory can be hard to say. Stripes did elaborate on the statement, saying this is the point where one can "push" the hardest. It seems as if she has connected the concept of denser field lines with her experiences during the lesson. Previously during the interview, the group explained magnets resisting each other using field lines (Transcript 50).

6.2 The lesson as a whole

This lesson easily fits into the two broader definitions of inquiry by larger educational organizations mentioned in the literary review (National Research Council, 1996; The Norwegian Directorate for Education and Training, 2013). Both definitions have been criticized for being possible to interpret in several ways (Knain & Kolstø, 2011; Lederman, 2006), one of them being learning science by methods like those that scientists use. This lesson involves observations from (quasi)experiments, logical and critical thinking, and the formulation and testing of explanations. With this, the lesson qualifies as inquiry based. However, inquiry based learning has been categorized into various levels of openness by several authors (Walker, 2015). When analyzing the lesson by this categorization, it falls into some of the least open or inquiry based categories. The structure and goal for this lesson have been set by the researcher. Although the students were free to investigate, a set conclusion needed to be reached for each activity. Otherwise, the lesson wouldn't be able to move on to the next activity. So, while the students have been free to explore to a certain degree, they were guided towards a preordained conclusion by the researcher. This lesson would classify as an inquiry level of two by Fradd et al. and Sutman et al. (1998) (in Walker, 2015). The lesson seems to offer little freedom for the students, since they are required to reach a certain conclusion. The freedom of investigation alone, despite that the students did not have much influence the framework of the lesson, offers good possibilities for building a conceptual understanding.

6.2.1 Prior knowledge

There was a fair amount of difference in prior knowledge on electricity between group one and group two. As group two had just completed at test on electricity they naturally had more extensive knowledge of the subject than group one. In fact, the benefit group two had from this prior knowledge did not show as evidently in the lesson as might be expected. In fact, group two seemed more prone to relate or contribute their observations to electricity, such as Yellow thinking that one pole of a magnet is negative, and therefore would push the electrons in a copper plate to one side. On the other hand, group two's better understanding of electricity meant they did not need certain topics explained during the lesson, thereby leaving more time for exploration. For instance, as group one had close to no understanding of electricity, the concepts of current and voltage had to be explained to them during the lesson. Intricate knowledge of electricity, however, seems unnecessary to learn the concepts of this lesson, which are exclusively of a qualitative nature. Both groups needed copious guidance to reach the desired conclusion in most of the activities. Some subjects outside the realm of electromagnetism seemed almost equally decisive. The students lacking knowledge of the structure of metals for example, proved deterring to the exploration for both groups.

The possession of prior knowledge alone is not always enough. As we saw during the first activity, group one's lack of confidence in their knowledge that opposite poles attract caused them to discard this knowledge instantly after the first contradicting observation. Group two, on the other hand, seemed to be more confident in their knowledge and understanding of science in general, which might explain their (occasionally) more structured investigations.

It is important to stress that prior knowledge is directly related to the goals of any learning session. The more prior knowledge a learner has on a subject, the higher the goals can be. As discussed above, a better understanding of electricity could have helped White's understanding of one coil inducing a current in another. However, this would extend the lesson's goals into transformer theory. Therefore, as described by Bruner (1960), the concept of scaffolding applies. Scaffolding happens during the lesson, as each activity is based on the (presumed) knowledge of the students at the start of the activity. Additionally, scaffolding also applies to the lesson as a whole. Goals can be set according to the expected cognitive level and potential of the student. With that, the entire lesson can be seen as a scaffolding step. A next lesson could (ideally) be built on knowledge gained from the first lesson.

6.2.2 Investigation

A described above, the investigation of the students was sporadic at best. Some ideas, such as friction being the cause of the slowly falling magnet, were easily discussed and tested. Other times, both groups would be unable to even formulate an idea to test. Finding the magnetic field of a current carrying wire is an example of the students being unable to continue the investigation. This can be related to the students' knowledge on the situation at hand. The concept of friction would be more familiar to the students than most of the concepts related to electromagnetism, as they would be more experienced with the phenomenon of friction. Therefore, the students can think of a method to test the idea that friction causes the braking. Whereas when the students have little knowledge or experience, they would have no way of knowing which factors are important for the outcome.

Another explanation for the students' troubles with exploration can be what they are used to from their everyday classroom. Learning by inquiry requires training, it is not something that comes natural to a student if they have not done it before. This becomes evident by the students in both groups looking for the interviewer's confirmation continuously throughout the lesson, as if they were answering a question from their teacher in a classroom. Unfortunately, the discourse used in the students' science classroom was not discussed during the study.

Earlier in this chapter, the lesson was classified as barely being inquiry based, due to the restricted freedom the students have while exploring the subject. However, contrary to the 'traditional' teaching methods used in science classrooms, such as learning only from textbooks or other second hand sources, this method uses concrete material. The students are therefore experiencing the concepts to be learned firsthand. While investigating, the students still had to use many aspects of scientific inquiry, which helps building a skillset emphasized in many curricula around the world (Abd-El-Khalick, 2004). Furthermore, constructing an complete understanding of a concept is not something which can be learned from a textbook. Niaz (2004) argued that inquiry and constructivism are closely related. Considering the many different cognitive schemes each student has, providing a realistic situation in which students can inquire themselves can help them build and adjust their schemes according to their preconceptions. Learning from real phenomena provides the students with an opportunity to test any idea and be presented with a realistic outcome. The authentic situation helps students feel ownership to their inquiry, which will improve students motivation and interest (Stavik-Karlsen & Grey, 2013). What they learn from this will depends on how they interpret their observations, and the framework of the lesson.

The equipment used proved to be of substantial significance to the progress of the investigation. As discussed while reflecting on the activities, both the immediate surroundings and the equipment used affected the observations of the students. Based on this, some improvements can be recommended:

1. The workspace for every activity should be as uncluttered as possible. A separate workstation for each activity would be preferable.
2. Any devices used to investigate magnetic fields, such as current carrying wires, should be big, providing enough room for the students to investigate without other elements disturbing observations. Additionally, any connections or other disturbing elements should be hidden.
3. Any devices used to obtain observations, such as compasses and voltmeters, should be as sensitive as possible and provide immediate feedback. To provide better observations, instead of a normal compass, a ball compass could be used. This compass would be able to point in the direction of the magnetic field regardless of the plane it is held in.

6.2.3 Activities and the construction of an understanding

The students can be said to have reached the learning goals set by The Norwegian Directorate for Education and Training (2013). They can explain that moving a magnet in a coil will induce a current which can be used to power electrical appliances such as LEDs. Students from group two might even be able to inform that the current will be alternating, although this was not in focus during the lesson.

All activities contribute to constructing an understanding of electromagnetic induction, as they all show distinct aspects of the phenomenon. As Mazur (1997) pointed out, understanding can mean different things. He noticed a difference in mathematical understanding and conceptual understanding in his students. It is hard to say which is preferable over the other. The understanding the students have constructed during this lesson is purely conceptual. One could argue that some of the simpler equations could be used in the lesson, to provide a mathematical foundation. However, as most of the literature on the subject points out, a mathematical understanding and the ability to solve mathematical problems does not necessarily mean a complete understanding. Therefore, this lesson offered the students an experience which might connect different sides of electromagnetism in general, and therefore contributes towards a more complete understanding of electromagnetic induction. Even though the understanding probed during the interview varies from student to student, it is highly possible that they have learned something other than what was intended by this study. Some students have at best reached a questionable understanding of electromagnetic induction, but an inquiry, by the looser definition as provided by Minstrell (in Barrow, 2006), might be considered successful when something is learned.

The activities were also meant to build on each other, thereby helping the students to construct an understanding of electromagnetic induction. Considering the complex nature of the subject, with many different elements involved (Allen, 2001), most activities seemed to connect well to each other, with the students being able to connect observations from several activities. Two activities, however, seemed to connect badly to the rest, as the students had more trouble with them. The first being the current carrying wire, the second being inducing electricity. Additional steps or improved activities can be considered to better connect these two activities. As discussed, investigation during the current carrying wire activity might be improved by an increased focus on the three-dimensional aspect of the magnet field. The inducing electricity activity however, seems harder to improve. More focus in the movements of electrons during the copper plate activity might emphasize that charges are affected by a moving (changing) magnetic field. This, however, requires knowledge of single charged particles in a magnetic field. Perhaps that a better understanding of electricity, and with that the electric field concept, would have helped. Then, students could have been explained that the changing magnetic field induces an electric field along the wire of the coil.

The importance of the magnetic field during the lesson was somewhat surprising. Since many studies have shown the difficulties learners can have regarding the field concept (Saglam & Millar, 2006; Thong & Gunstone, 2007; Törnkvist et al., 1993), it was expected that the students would struggle more with the concept. These studies, however, focused on understanding of the field concept in higher academic levels than secondary school students. The understanding of the magnetic field concept was certainly incomplete in all students participating in this study. However, most could use the concept to explain observations and phenomena. On the other hand, the lack of focus on the nature of the field concept during this lesson may have contributed to the rise of certain misconceptions. For instance, many indications can be observer in this study where the students seem to refer to the magnetic field as being solid, flowing or both.

Chapter 7: Conclusions

As little to no research has been done regarding secondary school students' conceptual understanding of electromagnetic induction, this study has been mainly exploratory. For this reason, the purpose of the study was to uncover key factors in student learning of the concepts of electromagnetic induction. The findings of this study exposed some key aspects in student conceptual learning: The magnetic field concept, the use of cognitive perturbations with respect to prior knowledge and cognitive structure building through experience.

7.1 Findings

The success of the magnetic field concept came somewhat unexpected, as much of the prior research indicated that the field concept is badly understood by students. Students in this study, however, managed to find and describe the magnetic fields of a solid bar magnet, a current carrying wire and coil by investigating themselves. While their understanding may be limited compared to requirements for university students' understanding of the field concept, the students in this study were able to actively use the field concept in explanations. The magnetic field concept seems to be a helpful tool in constructing an understanding of electromagnetic induction. On the other hand, some misconceptions might have been born, such as observations indicating that some students understood the magnetic field as something physical.

When building an understanding of electromagnetic induction with novices to the topic, cognitive perturbations have worked better than cognitive conflict in this study. The perturbations were less demanding of the students, as they only challenge part of their understanding. Their remaining knowledge can subsequently be used to investigate and test out ideas, and with that replace part of their understanding. The students' prior knowledge greatly effects this process, as little prior knowledge seemed to impede the students' investigation. A cognitive challenge that seems a small perturbation for a student with a lot of prior knowledge, can seem more conflicting to a student with little prior knowledge. This study found that prior knowledge of electricity contributes to more directed, independent investigation and better interpretation of observations.

The lesson was developed to help the students build a cognitive structure, with each activity linked to the others. By being able to investigate freely during the lesson, students could test ideas and thoughts in an authentic setting. This can improve relational understanding of the concepts involved in electromagnetic induction. The students in this study could quickly apply newly learned concepts in new scenarios, pointing towards a working cognitive structure. The students appeared to understand at least part of the relationship between the various elements involved in each concept and learned to interpret and categorize their observations, contributing to a complete conceptual understanding. However, the students sometimes had trouble investigating, which seems to be related to lack of experience in inquiry based learning. The transition to the last activity was challenging, with students mostly describing the mechanics instead of the concepts. It seems as if an additional activity, focusing on the induction of a current on a single wire could be helpful. On the other hand, a lack of focus due to the length of the lesson can be an explanation as well.

This study also found that, in congruence with literature, the three-dimensional nature of electromagnetic inductions caused problems for the students. Especially while investigating the magnetic field of the current carrying wire, whose magnetic field was directed perpendicular to the plane the students were used to investigating in. Special care should therefore be taken to introduce the three-dimensional aspect to learners.

7.2 Recommendations for future research

As this study was meant to explore a previously unchartered scientific territory, inconclusive findings are to be expected. Future research could benefit from a more detailed approach, perhaps studying a single concept at depth.

The small selection of participants in this study means that the findings cannot be generalized. However, the key factors highlighted by this study could be employed to provide direction to a quantitative study, or a qualitative study with a greater selection.

The teaching method utilized by this study has undoubtedly greatly affected the outcome. The research methodology and results provide no possible justification for the choice to let students explore the subject. Other teaching methods should be considered, and a comparative study involving these methods could be conducted.

The benefits from experience can be hard to identify when and if these students start studying physics. Certainly, this lesson alone will not be enough to make a difference. Continuous, authentic experiences with electromagnetism might make the subject more intuitive, and therefore contribute to a complete understanding of electromagnetism. The knowledge a learner gains from experience is hard to measure, because it is unpredictable and difficult to test. But this does not mean that it is useless.

As the following quote, often accredited to Ralph Waldo Emmerson, eloquently puts it:

I cannot remember the books I've read any more than the meals I have eaten; even so, they have made me.

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Appendix

Appendix 1 – Approval from the Norwegian Social Science Data Services

Nils Kristian Rossing
Program for lærerutdanning NTNU

7491 TRONDHEIM

Vår dato: 05.12.2016 Vår ref: 50925 / 3 / AMS Deres dato: Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 02.11.2016. Meldingen gjelder prosjektet:

50925	*Undervisningsopplegg i elektromagnetisk induksjon i samarbeid med ViT (Vitensenteret i Trondheim)*
Behandlingsansvarlig	*NTNU, ved institusjonens øverste leder*
Daglig ansvarlig	*Nils Kristian Rossing*
Student	*Jorn de Vlieger*

Personvernombudet har vurdert prosjektet og finner at behandlingen av personopplysninger er meldepliktig i henhold til personopplysningsloven § 31. Behandlingen tilfredsstiller kravene i personopplysningsloven.

Personvernombudets vurdering forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/meldeplikt/skjema.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 31.05.2017, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Kjersti Haugstvedt

Anne-Mette Somby

Kontaktperson: Anne-Mette Somby tlf: 55 58 24 10

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

NSD – Norsk senter for forskningsdata AS Harald Hårfagres gate 29 Tel: +47-55 58 21 17 nsd@nsd.no Org.nr. 985 321 884
NSD – Norwegian Centre for Research Data NO-5007 Bergen, NORWAY Faks: +47-55 58 96 50 www.nsd.no

Appendix 2 – Declaration of informed consent to the participants

Forespørsel om deltakelse i forskningsprosjektet

Bakgrunn og formål

Jeg heter Jorn de Vlieger og er masterstudent i naturfagdidaktikk hos NTNU. I samarbeid med Vitensenteret i Trondheim skal jeg skrive en masteroppgave som skal undersøke hvordan ungdomsskoleelever lærer om elektromagnetisk induksjon. Jeg vil finne ut av hvilken deler av undervisningen bør legges ekstra vekt på. Resultatene fra masteroppgaven skal være med på å utforme et undervisningsopplegg som skal brukes på Vitensenteret.

Til dette formålet trenger jeg ungdomsskoleelever som er interessert i naturfag og vil delta i undersøkelsen.

Hva innebærer deltakelse i studien?

Undersøkelsen bestå av undervisning av små grupper deltakere i elektromagnetisk induksjon og deretter et gruppeintervju. I store deler av undervisningen vil deltakere bli oppfordret til å engasjere seg aktivt i modeller, forsøk eller andre elementer ved undervisningen. Datainnsamlingen vil skje i form av lyd og filmopptak ved undervisningen og lydopptak ved intervjuene. Intervjuguiden kan innsees på forespørsel. Deltakere som har gjennomført undersøkelsen få tilbud på et familieårskort til Vitensenteret i Trondheim.

Hva skjer med informasjonen om enkeltpersoner?

Alle personopplysninger vil bli behandlet konfidensielt. All informasjon fra deltakere vil være anonymisert i den ferdige oppgaven, og ingen enkeltpersoner vil kunne gjenkjennes. Informasjonen samlet inn vil kun benyttes av meg og eventuelt veilederen til å observere tegn på læring og finne forbedringsmuligheter for undervisningsopplegget. Etter innlevering av oppgaven våren 2017 vil all data bli slettet.

Frivillig deltakelse

Det er frivillig å delta i studien, og du kan når som helst trekke ditt samtykke uten å oppgi noen grunn. Dersom du trekker deg, vil alle opplysninger om deg bli anonymisert.

Dersom du ønsker å delta eller har spørsmål til studien, ta kontakt med
Jorn de Vlieger
[redacted]

Veileder: Nils Kristian Rossing
[redacted]

Studien er meldt til Personvernombudet for forskning, NSD - Norsk senter for forskningsdata AS.

Samtykke til deltakelse i studien

Jeg har mottatt og forstått informasjonen om studien, og er villig til å delta.

Navn: ____

Dato:__________________Signatur:____

Jeg har mottatt og forstått informasjonen om studien, og godkjenner at mitt barn deltar.

Navn: ____

Dato:__________________Signatur:____

Appendix 3 – Interview guide

Forkunnskaper

Magneter

Fortell om magneter, hva husker dere?

Noen bruk for magneter?

Fortell om kompasset

Hvordan kunne vi undersøke og beskrive magnetisme?

Hva er et magnetisk felt?

Kobberplata

Hvordan vil dere forklare det vi observerte med magneten og kobberplata?

Gjør det noe om magneten rører på seg eller platen?

Hvordan henger dette sammen med magneten i røret?

Ledningen

Hva husker dere av den strømførende ledningen?

Hvordan så magnetfeltet ut?

Spoler

Hva husker dere om den strømførende spolen?

Hvordan så magnetfeltet ut?

Hvorfor?

Hva husker dere om å få strøm til å gå selv, uten strømkilde?

Hvordan fikk dere mest strøm til å gå?

Hvorfor er det slik?

Appendix 4 – Norwegian transcripts

Transcript 1

Yellow: du tegner jo ofte atomkjernen med sirkler rundt. Også har du den skymodellen med masse prikker overalt. Det er litt mer sånn, fordi den hopper frem og tilbake.
Interviewer: ja
Yellow: mellom.. at noen hopper inn i det ene skallet, og da må noen hoppe tilbake igjen.

Transcript 2

Yellow: er det elektroner i plastikken? det må være det å. Så streng tatt, hvis jeg drar magneten forbi raskt nok, vil den da bli magnetisk?

Transcript 3

Blue: Yellow, er det der pluss og det der minus, eller?
Yellow: jeg har ikke peiling, jeg husker aldri hva som er pluss og hva som er minus. Jeg vil si at det er pluss og det er minus.
Blue: det er pluss og det er minus?
Yellow: fordi vi ser varmegrader som rød og kuldegrader som blå.
Blue: ååja, ja.
Stripes: ja

Transcript 4

Grey: se for den her, den her liksom var det noe motstand. *Prøver selv med begge magneter.* Ok, kanskje ikke. *Fester de på hverandre langside mot langside*
White: Ja, så det går begge
Pink: De har ikke noe å si.
White: nei…

Transcript 5

White: det må jo være noe.. du kan jo feste det også, så det må jo være noe som på en måte er rundt magneten. Det må jo sende ut noe..
Pink: Det må jo ha en energi da.
White: Det må være noe imellom, for når vi fester dem da far de jo sånn med en gang. Så det må være noe her. Det må jo være noe som på en måte dytter dem fra hverandre da.

Transcript 6

White: jeg tenker at, alle den på røde siden, peker jo mot den her, også den her [i midten] peker jo ikke dit.
Interviewer: nei
White: den peker=
Grey: den peker bort fra den.
White: den peker jo fortsatt på den røde sida. Også peker dem videre på den hvite og dem [forbi den hvite siden av magneten] peker innover [mot den hvite siden].
Interviewer: det var en bra observasjon
Pink: den [i midten] peker liksom mot der og der [endene på magneten]

Transcript 7

Pink: den går sikkert sånn frem og tilbake sånn (*hører magneten tikke i røret.)*
White: ja, for den er litt sånn magnetisk kanskje
Interviewer: jeg har en med hull i, så dere kan se. *Henter den*
Grey: prøver selv og ser inn i røret samtidig
White: For den er litt magnetisk i den. Den går jo mye saktere enn den hadde gått normalt da.

Transcript 8

Interviewer: hva er deres teori, hvorfor går det så sakte da?
Pink: den er litt magnetisk, så den heng litt sånn fast, derfor den går tiktiktiktiktik
White: Jeg tror.. en kan også være frastøtende, så den støtes fra den ene til den andre siden.
Interviewer: ja.. nei..
White: kanskje, men for den setter seg jo ikke fast på utsida, så…

Transcript 9

White: *prøver det.* det er for så vidt noe som er der ja.
Grey: er du sikker?
White: ja, så da er det kanskje ikke friksjon akkurat da. Ja kjenn da, det er litt sånn frastøtende ting liksom.

Transcript 10

Interviewer: Hva synes dere da, når er det tungt og når ikke?
White: ok, det er litt tyngre når jeg gjør det fort. Det er litt sånn..
Pink: mer motstand
White: sånn [sakte] går nå egentlig uten nå akkurat imot, men her [raskere] så blir det sånn ugh [tungt]. Se, nå er det ikke så veldig masse motstand, om jeg gjør det sakte.

Transcript 11

Pink: ja fordi at, den [kompasset] peker jo mot der det er magnet, og det er magnet inni den her. Fordi at strøm og magnet er det sammen tror jeg.
Interviewer: men den peker ikke mot den
Pink: men når du skrur av? *skrur av strømmen*
White: hmm jeg skjønte ikke det helt
Pink: for den peker mot her, og det er her strømmen går. Men når du skrur av.. så det er magnet i den, tror jeg.

White: den er av nå
Pink: ja, men da er det magnet inni der [ledningen] Også når du skrur på, så vil strømmen hindre magneten.

Transcript 12

White: ååja, er det fordi at, den her kommer ut fra pluss? Har det noe med det å gjøre? Kanskje ikke.. Men den pekte jo der i sted.. når det ikke var strøm.

Transcript 13

White: ooh
Pink: å den peker liksom en vei uansett, i ledningen.
Interviewer: mhm
Pink: å her så snur den.
Interviewer: her blir den nok litt forvirra, for her er det to [ledninger]
White: ja, men den peker ut fra ledningen.

Transcript 14

White: men hvorfor gjør den det?
Pink: fordi det er magnet i strømmen, eller inni der
Interviewer: ja for i sted så snakket vi om elektroner ikke sant. Og når strømmen går, så går jo elektronene gjennom ledningen.
White: åh, så da for du det samme som her! *peker på kobberplata,* for hvis det går litt fort, elektronene går jo fort gjennom.
Interviewer: mhm
Grey: oohh

Transcript 15

Interviewer: så er det snakk om nord og sør her?
White: nei, den her har på en måte et sentrum. Også går den rundt

Transcript 16

White: oi den vil inni her den!
Grey: ooh!
Elevene følger kompasset.
Grey: vil den tilbake da?
White: nei, her [når den kommer ut av spolen] vil den jo rundt her. *Følger kompasset langs utsiden av spolen.*
Pink: den vil bare inni der.
Prøver å føre kompasset forbi 'inngangen'
White: her vil den også på en måte inni der ja.
Grey: men vil den gå.. den vil ikke gå in veien her.
White: det vil den ikke.
Pink: nei men da må du snu på strømmen.
White: ja, den vil bare gå inn den ene veien men den vil ikke gå inn baklengs. Kan vi prøve å snu dem der [ledningene]?
Grey: se, nå vil den inni der!

Transcript 17

Interviewer: men hvorfor blir det sånn da? for vi så jo at magnetfeltet av en ledning går rundt? Så hvorfor blir det plutselig rett nå da?
White: fordi nå er det en runding
Pink: ja?
Grey: i sted var det en rett strek da ville den rundt, nå er det en runding nå vil den dra i en rett strek.
Interviewer: ja.. men hvorfor?
White: nei.. jeg vet ikke

Transcript 18

Grey: den [kompasset] går jo rundt og rundt
Interviewer: ja, men hva om du da har en til, rett etterpå
White: åh den vil den også gå rundt men så neste og neste til den kommer ut. Den dytter den på en måte videre

Transcript 19

Pink: kanskje det blir minus når du tar den der og pluss når du tar det der?

Transcript 20

Pink: ah, hvis du gjør det fort får du noe. *Pink tar magneten*
White: fikk du 2?
Grey: åi
White: kom igjen, Pink! *Pink prøver hardere*

Transcript 21

White: nei gå sakte inn igjen
Grey: åi 4, 5. 6!
White: prøv å gå sakte inn. *prøver selv. N*ei sakte går det ikke, men.. man må gjøre det fort
Grey: wow
White: er det på grunn av elektronene igjen? Nei?
Interviewer: mhm
White: er det det? samme som kobberet?
Interviewer: Ja, på en måte.

Transcript 22

Yellow: den tiltrekkes den der og den frastøtes den her, i forhold til pila, se når jeg kommer hit.
Stripes: ja
Blue: så den tiltrekker seg nord, rett og slett. Så kompassnåla, så den snur seg=
=Yellow: altså hvis det er pluss, pila er pluss, så…
Stripes: nei, se her, her. (*finner en pol* ***3/4*** *på magneten)*
Interviewer: ja det var den som var litt rar
(…)
Yellow: men du ser jo at pila frastøtes av den ene og tiltrekkes av den andre
Stripes: mhm

Transcript 23

Yellow: her så vet ikke de i midten helt hva de skal gjøre. Fordi.. den polen har flyttet seg litt mere mot midten så den er der sirka [**3/4**] og den andre er der [ytterst].

Blue: ja
Stripes: mhm
Yellow: så midten er der sirka
Blue: mhm
Yellow: så den raden der [ved midten] de peker på begge to
Blue: mhm
Stripes: ja
Interviewer: og de som mellom midten og polene?
Yellow: de peker litt mer der [nærmeste pol] enn der

Transcript 24

Interviewer: hvordan kan du tegne linjer, om du forbinder alle [pilene]
Blue: en der og en der. *tegner buer med hånda*
Interviewer: mhm
Blue: og en rett ut der og rett ut der [polene]
Interviewer: og de som er litt her, hvordan går det med de som er på siden?
Blue: litt sånn. *tegne rett ut i en vinkel med hånda*
Yellow: Hvis jeg tenker sånn på det her som jorda, da går jo det jo sånn og sånn og sånn.. *gestikulerer større og større feltlinjer.* Det kommer bare flere sirkler som går lengre og lengre utover

Transcript 25

Yellow: hvis jeg starter her [på siden av en av polene] så går den jo helt utover. *følger kompasset lenger bort fra kompasset, men fortsett i feltlinjen*. Her tror jeg den mistet litt kontakt. *Er nå en halv meter unna magneten.*
Interviewer: nei, bare gå videre. Du må bare være veldig nøye, at du hele tiden går etter der den peker. *kompasset finner veien tilbake til magneten*
Yellow: det går i en bue!

Transcript 26

Blue: den er litt magnetisk, for nåla snur seg litt akkurat der.
Stripes: det ser sånn ut
Yellow: *prøver å ta på og av magneten*. Jeg føler.. det føles ut som at det er et eller annet der.
Stripes: *prøver også.* Ja litt kanskje

Transcript 27

Blue: den er litt magnetisk, for nåla snur seg litt akkurat der.
Stripes: det ser sånn ut
Yellow: *prøver å ta på og av magneten*. Jeg føler.. det føles ut som at det er et eller annet der.
Stripes: *prøver også.* Ja litt kanskje

Transcript 28

Interviewer: da vil jeg stille et viktig spørsmål. Når er den magnetisk?
Yellow: den tiltrekkes magneter. Det gjorde den her også. det er bare at magnetfeltet er litt…
Interviewer: hvis den blir tiltrukket av magneter, må den da ikke bli frastøtet på den andre siden?
Yellow: jeg ville ha sagt at det fungerer på samme måten som jernet der. At den ikke er magnetisk, men at den tiltrekkes av magneter.
Interviewer: ja, ja jeg skjønner hva du mener. Men hvordan kan du teste det ut?

Transcript 29

Yellow: den bremser den jo også..
Yellow: begynner å løfte magneten raskere og raskere. bytter til den små kobberplate og får den litt i lufta.
Yellow: du kan ikke si at det der ikke tiltrekkes av magneten!
Stripes: den tiltrekkes jo litt da.

Transcript 30

Yellow: altså, nå er jeg ikke borti den en gang!

Transcript 31

Interviewer: hva vil dere si da, når er den magnetisk?
Stripes: når du trekker dem fra hverandre
Yellow: når du vifter magneten over den. ehm, det er induksjon, er det ikke?
Interviewer: ja det er nå det alt det her handler om, så du er inne på noe men vi er ikke der helt ennå.
Blue: *går langs lengden på plata* det blir tyngre jo lenger dit du kommer.
Stripes: la meg prøve. Ja.
Blue: men det blir på en måte ikke lettere på vei tilbake, det er det som er litt rart.
Yellow: nei altså, når jeg dytter den den veien der så er det et eller annet som mottar meg.
Stripes: ja det er sånn motstand der.
Interviewer: og andre veien?
Yellow: det er samme
Stripes: mhm
Blue: *prøver.* Nei men nå snudde jeg den, da ble det jo motsatt.
Yellow: begynner å gå fortere. Altså jo fortere jeg går jo mer det blir.

Transcript 32

Interviewer: så det er elektroner her [plata] og her [ledningen], det eneste vi gjør her er å sette minus her og pluss her også beveger elektronene=
=Yellow: ja selvfølgelig, selvfølgelig=
=Blue: påvirker magneten det her kobberet=
=Yellow ja, fordi hvis el.. hvis elektronene.. de tiltrekkes av protonene som er positive. Hvis den her [magneten] da er positiv, eller for så vidt negativ fordi da frastøter den, hvis jeg holder den i midten, så beveger alle elektroner seg ut ditover. Det betyr at hvis jeg gjør sånn her (*beveger magneten frem og tilbake)* da drar elektronene enten mot eller fra

magneten. Det vil si at det er masse elektroner som beveger seg.

Transcript 33

Blue: *balanserer kobberplata på bordkanten.* Hvis det stemmer det du sier, at den her [magneten] frastøter elektroner, så burde den [kobberplata] kanskje dette ned når jeg far sånn frem og tilbake.

Transcript 34

Interviewer: ok, men hva skjer her [ledningen] da? vi snakket om elektroner i bevegelse, ja?
Yellow: ja,
Blue: eller at den er magnetisk når elektroner er i bevegelse?
Interviewer: ja, og hva skjer når jeg gjør sånn (*beveger magneten frem og tilbake over kobberplata)?*
Yellow: den.. den mag.. beveger seg!
Interviewer: hva er det som beveger seg?
Yellow: magneten?
Interviewer: ja, men hva var det inni her?
Yellow: eh kobber, og elektroner
Interviewer: ok, så hvis vi gjør sånn (*beveger kobberplata over magneten som ligger på bordet),* for magneten, hvordan ser det ut da?
Yellow: ehh sånn der (*peker på ledningen).* Da beveger elektronene seg, fordi for magneten så går de frem og tilbake.

Transcript 35

Blue: men, hva? Skjønner ingenting
Interviewer: hvor går den da? Prøv å beskriv det du ser?
Blue: ok, den peker ikke rett mot den røde, men den er litt sånn.. vanskelig å forklare
Interviewer: i sted så så vi med den vanlige magneten at vi kunne følge kompasset. Men hvis vi følger den når, hvor går vi da, hva skjer?
Blue: hmm hvis jeg skal følge kompasset, så.. nei, jeg skjønner ikke.
Yellow prøver
Interviewer: hvor går den hen da?
Yellow: jeg tar den rundt, også går den liksom, jeg tar den..
Blue: den peker hverken bort eller mot tråden.
Stripes: mhm
Blue: den peker sånn her [langs ledningen]
Interviewer: ja.. men hvor er nord og sør da?
Yellow: ehh, der og der
Interviewer: men er det det?

Transcript 36

Interviewer: hvis du holder den på den ene siden, så peker den den veien, men hvis du holder den på den andre siden, så peker den den andre veien. Uansett hvor du holder den ved siden av ledningen, hvor peker den da?
Yellow: langs tråden
Stripes: mhm
Interviewer: og hvis du følger den..
Yellow: den går jo bare i runder..

Transcript 37

Blue: men jeg tror at kanskje at her går jo ledningen rundt sånn på en måte [vikling]. eller inni i ledningen, så går elektronene rundt sånn (*tegner horisontale sirkler i luften),* eller?
Interviewer: hva sier du? her?
Blue: inni ledningen.
Interviewer: nei elektronene går fra minus til pluss.
Blue: ja men går de liksom rundt inni også? Eller er det bare..
Interviewer: nei de går mest mulig rett frem.
Blue: men hvorfor går magnetfeltet da som vi så i sted?
Interviewer: aahh det var et veldig godt spørsmål!

Transcript 38

Blue: ehm går magnetfeltet liksom den og den veien her [gjennom spolen]? Fordi.. På en måte.. Det går mer, det snur mer den veien inne ledningen. Fordi, det er liksom ingenting forskjellig ved ledningen her og her (*peker på to vindinger i spolen)*. det er noe med den her og den rette som er forskjellig. *(peker på en del av spolen og ledningen som kobler modellen)*
Interviewer: ja=
=Yellow: Det ville jeg egentlig ikke ha sagt. Fordi, ledningen her [koblingsledning], den går rund sånn gjør det ikke [magnetfeltet].
Interviewer: ja
Blue: mhm
Yellow: så hvis jeg krøller den der, så går det fortsett rundt sånn.
Blue: ja, men=
=Yellow: det vil si at også at den går rundt sånn, så den går jo.. Det vil si at, og den går rundt sånn og rundt sånn. Det er det samme som den gjør der [spolen], den går bare rundt sånn. [alt sirkulært magnetfelt]. Så det er bare samme måte, bare at her har du en lang strek og her har du mange.
Blue: ja men det er det jeg mener at den her og den [begge ledninger] det skjer samme med kompasset om vi holder det her eller her. Så det er en forskjell som ligger mellom den [spolen] og den rette ledningen. Det er noe som skjer når du krøller den sånn
Interviewer: mener du med annerledes at der er noe annet inn i ledningen?
Yellow: nei!
Blue: nei når du krøller den
Stripes: når du ruller den

Yellow: den rette leder jo alltid rundt, også når den er bøyd. Og her [spolen], hvis jeg drar den rundt alle sammen, så vil den alltid ha samme.. Den leder jo alltid rund her også. Så den går rundt alle.
Blue: men hvorfor blir den annerledes fra den rette ledningen?
Interviewer: men er den annerledes?
Yellow: hvis du tenker at, den ledningen her, det er egentlig det samme som bare en av dem der.
Blue: ja det er jo det.
Yellow: det er bare at, nå er de samlet, så det fungerer bedre.

Transcript 39

Stripes: hva hvis jeg gjør sånn her? *beveger magneten inn og ut spolen.* Den begynte ikke å lyse.
Yellow: jo
Stripes: jo!
Blue: åh det er rødt lys.
Interviewer: hva seg jeg om led pærer?
Blue: ehm, de lyser bare når strømmen går en vei.
Interviewer: ja, hva ser dere nå da?
Stripes prøver med magneten i spolen, beveger den forsiktig inn og raskt ut og omvendt.
Stripes: å, den funker.. Liksom den ene vært da, også på begge. Den funker liksom..
Blue: må vi liksom..
Stripes: den der ene fungerer når du tar den inn, og den andre når du tar den ut.

Transcript 40

Interviewer: hva.. hvilken måte er mest effektivt da?
Yellow: sånn, inn og ut. Fordi da reagerer den på flere viklinger.
Interviewer: ja.. og fordi at, når vi så på magnetfeltet til en spole så så den ut som
Stripes: en magnet
Blue: mhm
Interviewer: ja, og de er sterkest
Stripes: på tuppene.

Transcript 41

Interviewer: hvordan kan dere få strøm til å gå i den andre spolen, uten å bruke noe batteri eller slikt?
Stripes: Vi kan bruke en magnet.
Interviewer: enn om vi ikke har en magnet, bare disse to spoler?
Yellow tar strømførende spolen og beveger den opp og ned over den andre spolen
Yellow: å ja det ble litt det ble litt!
Yellow beveger spolene i alle mulige retninger, for å få resten til å le,
Interviewer: Men nå må du tenke før du bare begynner å røske i det. Hvordan så det her magnetfeltet ut?
Yellow: det var sånn, samme som en magnet.
Interviewer: så hvordan kan du lage mest strøm?
Yellow: ved å stappe den ned i. *setter spolen oppå den andre.* Men, den beveger seg.
Blue: å få prøve! *beveger spolen opp og ned over den andre.*
Yellow: du ser den [voltmåleren] beveger seg!

Transcript 42

Pink: Du kan lage energi..?
Interviewer: Mhm, er det magneten som lager energi eller?
Pink: Nei, det er det imellom.. nei jeg husker ikke.
Interviewer: Ja, du er inne på noe..
White: Det var når noe.. kobber eller noe sånt beveget seg enten rundt, eller magnetismen beveger sånn fort over sånn at elektronene begynte å bevege seg.. Så kunne det komme elektrisitet? Elektrisitet tror jeg

Transcript 43

White: Det var litt sånn, jeg husker ikke helt hvordan det var men det var rundt dem. Også ble dem enten dratt til en av sidene.
Interviewer hva brukte du da?
White: hæ?
Interviewer: Du snakker om at det blir dratt til en av sidene?
White: Ja, det var de der kompastingene, dem ble jo dratt til hver sin.. Den som var nærmest nord ble dratt til nord og dem som var nærmest sør til sør. Så dem ble på en måte dratt til kanten og ikke på midten, eller noe sånn. Det var liksom rundt magnet det som ble dratt in. Det er på en måte et magnetisk felt.

Transcript 44

White: Hmhm, det var på en måte at hvis vi tok den langs kobberplata sakte, så var det ganske normalt på en måte, det var ikke så masse.. motkraft. men hvis vi begynte å gjøre det fort, som å bevege den fort frem og tilbake, så vært det veldig masse sånn..
Pink: motstand
White: motstand, fordi at det var noe..
Grey: det var noen elektroner som begynte å jobbe eller noe sånn
White: sånn at det vært liksom vanskelig å bevege på dem, så fortere som dem på en måte beveget seg mot hverandre da, fort.
Grey: det ble litt sånn akkurat som dem ble holdt igjen, litte grannet. Når jeg tok den bort.

Transcript 45

Interviewer: hvordan henger det sammen, har dere noen ideer?
White: Det er jo når.. for at den.. magneten beveger seg fort gjennom røret egentlig, også når den beveger seg fort, så blir det jo motstand, på grunn av at kobberet og den [magneten] beveger seg mot

hverandre. Og da vil det ta lenger tid før den kommer ned.

Transcript 46
White: oohh nå husker jeg det, for det var litt.. den pekte ikke in, den på en måte ville fare rundt, så den på en måte vist hvor feltet var.
Interviewer: mhm
White: for det vi gjorde når vi for gjennom også [spolen] for da pekte den jo hvor den ville gå hen. Den pekte jo ikke inn på noe strøm.
Interviewer: mhm
White: så den på en måte pekte hvor feltet gikk og hvor den ville gå inn igjen.

Transcript 47
White: da for den jo først in her også for den ut hit, også rundt sånn også inn her igjen.
Grey: den ville bare den ene veien.
Interviewer: mhm
White: det betyr at strømmen kommer ut der

Transcript 48
Blue: menn.. er det ikke sånn at de lite magnetfelt på en måte samarbeider sånn at det blir stort?
Stripes: ja..
Blue: i en sånn magnet der man kan sette sammen flere.
Stripes: ja.
Blue: sånn ... jeg vet ikke
Interviewer: ja, kan du sammenligne det med noe?
Blue: ja kanskje du kan sammenligne det med den der spolen? kan du ikke?
Interviewer: ja
Blue: det er noe med sånne små magnetfelt som samarbeider, i de røde tråder.
Stripes: de ble et stort ett, da

Transcript 49
Yellow: ehm.. de må gå samme vei, må dem ikke?
Blue: mhm
Yellow: fordi, eller så.. kolliderer dem
Stripes: ja de ville jo ha kollidert.
Yellow: dem vil jo.. altså hvis dem går den veien da så sender dem bare videre, men hvis dem går der da krasjer dem inn i hverandre.
Stripes: ja hvis dem går sånn her da krasjer de jo bare inn i hverandre
Interviewer: hvis de kommer mot hverandre?
Blue: ja
Stripes: det er ingenting som kommer seg videre da

Transcript 50
Yellow: fordi, hvis du konkluderer med at ting går den veien der, fra nord til sør. Den du holder går også fra nord til sør, men er omvendt. Også.. kommer de [magnetfelt] alltid til å kollidere i hverandre
Interviewer: mhm
Stripes: hvis dem går forskjellige veier så vil dem jo alltid..
Yellow: kollidere
Stripes: ja kollidere
Yellow: og frastøte hverandre
Blue: den vil bare samarbeide med andre magneter hvis de magneter går samme vei
Stripes: ja

Transcript 51
Interviewer: kan dere prøve å forklare hvorfor, med de verktøy som vi har. Prøv å forklar det med feltet. Hvorfor fungere noen ting bedre enn andre?
Yellow: fordi, inni der så er dem tett i tett.
Stripes: ja det var vel tettere midt inni
Yellow: nå kommer jeg til å si noe rart, men altså inni der så er magnetstrekene tett i tett så det er kraftigere der. Men på utsida da er de lenger fra hverandre.
Stripes: ja.
Interviewer: og magneten selv, den som du bruker?
Yellow: den har.. tett i tett her [polene] og.. ja.
Interviewer: så var er den beste måte å lage strøm på da?
Yellow: sånn *tar magneten inn og ut av spolen*
Interviewer: fordi?
Yellow: der er det mest mulig magnetfelt
Stripes: så der kan du dytte hardest.