LINGUISTIC CHALLENGES IN SCIENCE EDUCATION

A CLASSROOM STUDY OF TEACHERS' AND STUDENTS' USE OF CENTRAL CONCEPTS IN GENETICS

KARIN THÖRNE

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Abstract

This thesis examines linguistic aspects of genetics education and is based on the view that language is an essential dimension of teaching and learning. Its objective is to clarify how teachers and students use genetics concepts in real teaching situations. By studying the spoken language used in lessons, I explore how teachers present the subject and the opportunities students have to learn to use the specific language of genetics. These explorations help explain why genetics is such a challenging topic to teach and learn, as shown by previous studies. My study is based on observations and recordings of genetics lessons for grade nine students, i.e. students in the final year of compulsory education in the Swedish school system. Four classes were followed as they progressed through the genetics unit. The corpus was analyzed with different linguistic methods to reveal patterns in the way teachers use and interrelate core concepts such as gene, DNA and chromosome, how they connect the concepts of gene and trait, and how students are involved in dialogue about core genetics concepts. Teachers were found to use genetics concepts with varying meanings and interrelated words in many different ways, resulting in an ambiguous and inconsistent communication of the genetics content in the classroom. The students used the genetics concepts much less frequently than the teachers, and mainly used them in short sentences. This suggests that current teaching practices do not give students enough opportunities to develop the language of genetics. My results demonstrate several aspects of classroom talk that could contribute to the learning difficulties associated with genetics. It will be important to take these aspects into account when seeking to improve the teaching of this subject.

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List of papers

Paper I

Linguistic challenges in Mendelian genetics: Teachers' talk in action
Karin Thörne, Niklas Gericke, and Mariana Hagberg (2013).
Science Education 97(5): 695-722. DOI 10.1002/sce.21075

Paper II

Teaching genetics in secondary classrooms: a linguistic analysis of teachers' talk about proteins
Karin Thörne, and Niklas Gericke (2014).
Research in Science Education 44(1): 81-108. DOI 10.1007/s11165-013-9375-9

Paper III

Does teachers' classroom talk in genetics lessons clarify or confuse? Investigating semantic relations between the words gene, DNA and chromosome
Karin Thörne, and Niklas Gericke.
Manuscript

Paper IV

Teacher-student dialogue in the classroom: does it support students in learning the language of genetics?
Karin Thörne, and Niklas Gericke.
Manuscript

Authors' contributions

The first author planned the studies, conducted the data collection and data analysis, wrote a first draft for all the papers and had the overall responsibility of the research process.

In paper I the second and third authors mentored the process and functioned as valuable discussants. The second author made valuable contributions in the design and writing process. All authors read and approved the paper before submission.

In paper II-IV the second author mentored and contributed to the idea, design and writing processes and functioned as a much-valued discussant. Both authors read and approved the paper before submission.

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Introduction

The overall aim of this thesis is to understand why genetics - which in my opinion is among the most interesting, exciting, and relevant subjects in modern biology - is so difficult to teach and learn. The educational difficulties associated with this subject were first reported in the early 1980s and have been studied extensively, as demonstrated by several reviews (Gericke & Smith, 2014; Knippels, 2002; Wood-Robinson, 1994). In addition, several studies conducted over the past few decades have highlighted the importance of accounting for linguistic factors in science education (Lemke, 1990; Marton & Tsui, 2004; Mortimer & Scott, 2003; Ogborn, Kress, Martins, & Mc Gillicuddy, 1996; Wellington & Osborne, 2001). This thesis contributes to the literature on the effect of linguistic factors in genetics education by shedding new light on teaching situations *in situ* and focusing on talk in science classrooms. Studies on the communication between teachers and students in routine teaching situations are much rarer than for example interview studies about students' conceptions. In theoretical terms, all four articles presented in this thesis treat classroom talk as a central element of teaching and address linguistic aspects of genetics education. However, the four articles approach their subjects from different perspectives and have different foci. Collectively, they provide valuable insights into the complexity of genetics education, showing that the challenge of teaching and learning genetics is in many respects a linguistic challenge.

Background

Why genetics?

This thesis focuses on the teaching of genetics during the final year of compulsory schooling in Sweden. For many students, this will be the last year in which they will study biology. An important aspect of schooling is to prepare students for citizenship (Roberts, 2007); the knowledge of genetics that students acquire during this final year must thus serve as a basis for acting as well-informed citizen participants in socio-scientific debates about issues relating to genetics.

Genetics is a subject with important implications for several areas including agriculture, medicine or forensics. The rapid development of genetic technology has affected modern societies in many ways at different levels; some of its effects act at the personal level and relate directly to individuals' choices and/or opinions. For example, as a citizen one might wish to take a stand on subjects such as how to deal with GMO, genetic screening and insurance issues associated with gene technology, medical issues, prenatal diagnostics, or personal genomics. There is ongoing research and development work in many areas of genetics that have the potential to affect our daily lives to greater or lesser extents. For example, in recent years, Adidas presented a shoe made from spider thread produced by genetically modified bacteria, genetic experiments seeking to produce hornless cattle were undertaken, and there were studies on gene editing in fertilized human eggs and its potential therapeutic applications (Gentekniknämnden, 2017). In addition, increasing quantities of genetically modified food are being introduced onto the market, including apples that do not darken as they age, petunia flowers with new colorings and insect-resistant crops (Gentekniknämnden, 2017).

Similar developments are occurring in human medicine. For example, there are ongoing studies on the possibility of limiting the spread of malaria by sterilizing female mosquitos, an Ebola vaccine is being tested on humans, and the USA approved a genetic therapy for the first time in 2017 – a treatment for patients with a certain eye disease (Gentekniknämnden, 2017). Medical professionals have highlighted the importance of increasing public understanding of genetics to better prepare society to debate and deal with changes of this sort. The increasing importance of genetics in medicine, and particularly in personalized health care, means that caregivers must also develop a deeper understanding of this subject (Gelbart, 2012; Hurle et al., 2013). A review of research on health services concluded that patients have little knowledge of genetics and that consumers need more information to properly understand individual health care issues such as gene testing (Scheuner, Sieverding, & Shekelle, 2008). Personal genomics is a developing field that allows customers to send in a spit sample to a company that uses it to scan the customer's genome for information about their likelihood of developing specific diseases in the future. Ethical concerns about this business model have been raised – among other things, critics have highlighted the uncertainties associated with the tests that such companies use and the possibility that the test results may affect customers negatively (Ransohoff & Khoury, 2010). Despite these concerns, personal genomics firms have continued to extend their services; some now offer testing for IQ (Regalado, 2018), and it has been suggested that the results of such tests could be used to guide educational activities. For example, Plomin and von Stumm (2018, p. 155) argued that:

> A 'precision education' based on GPSs could be used to customize education, analogues to 'precision medicine.

Regalado (2018) notes that many scientists see problems with this approach because academic achievement is affected by a huge number of factors, making such predictions very uncertain. In addition, developments in the field of epigenetics have called the validity of such deterministic perspectives into question by showing that the genome is not simply a fixed collection of information (Allis, Caparros, Jenuwein, & Reinberg, 2015).

New genetic technologies thus offer many exciting possibilities. However, they also raise important ethical issues that societies must evaluate as communities in ways that allow both experts in relevant fields and laypeople with different views and experiences to contribute to public debates and decision-making. A crucial aspect of this is the ability to understand media reports and information from other actors in society. It is therefore important to educate the public of today and tomorrow to ensure that they understand genetics well enough to make decisions about the subject for themselves, to make sense of reports and information about genetics, and to contribute to political and ethical decision-making at the societal level. Striving for this level of citizenship knowledge among students will be a major challenge for schools.

Genetic literacy

It is important that education gives students opportunities to develop enough knowledge about genetics to be well-informed citizens. To this end, it is necessary to define what the minimum necessary knowledge of genetics is. There have been various suggestions about what students should ideally know about genetics after schooling. Important studies conducted by Duncan, Rogat, and Yarden (2009) resulted in the development of a *learning progression* describing what should be taught in genetics lessons and what students should learn as a result. Their work formed the basis for a more recent study on what is required for genetic literacy in modern societies (Boerwinkel, Yarden, & Waarlo, 2017).

Duncan et al. (2009) emphasize the importance of adopting a broad perspective when addressing subject matter in education rather than focusing on irrelevant details. Their framework is based on eight “big ideas” that are identified as being crucial in genetics education (labeled A-H in Table 1). Three levels of understanding are established for each of these ideas, defining a learner’s progression from grades 5-6 (level 1) to 7-8 (level 2) and finally 9-10 (level 3). This framework thus describes a suggested learning path for students from grade 5 to grade 10. In the context of this thesis, the descriptions of level 3 are most relevant; these descriptions are presented in the right-hand column of Table 1.

As can be seen in table 1, big idea A relates to the importance of understanding the relationships between core genetics concepts. Big ideas B and C emphasize the roles of proteins as the link between genes and traits, and the functions of proteins in the body. Big idea D states that while different cells may carry the same genetic information, its use is regulated such that different cells can have very different gene expression patterns. All four of these ideas are related to the question “how do genes influence how we, and other organisms, look and function?” (Duncan et al., 2009, p. 659). The remaining four big ideas, E-H, relate to the question “why do we vary in how we, and other organisms, look and function?” (Duncan et al., 2009, p. 659); they describe the transfer of genetic information over generations, the idea that there are specific patterns in the way this transfer occurs, and how variations come about.

Table 1. The learning progression of Duncan et al. (2009, pp. 660-661). The big ideas (A-F) are listed in the left-hand column and the definitions of a level 3 understanding of each big idea are given in the right-hand column.

Big idea	Level 3, grade 9-10
A. All organisms have genetic information that is hierarchically organized	Genes are nucleotide sequences within the DNA molecule. DNA molecules make up chromosomes that make up our genome
B. The genetic information contains universal instructions that specify protein structure	The genetic code is translated into a sequence of amino acids that makes up the protein. Almost all organisms use the same genetic code.
C. Proteins have a central role in the functioning of all living organisms and are the mechanism that connects genes and traits	Proteins have particular three-dimensional shape determined by their amino acid sequence Proteins have many different kinds of functions that depend on their specific properties. There are different types of genetic mutations that can affect the structure and thus function of proteins and ultimately the traits
D. All cells have the same genetic information but different cells use (express) different genes	All cells have the same genetic content, but what genes are used by the cell (expressed) is regulated
E. Organisms reproduce by transferring their genetic information to the next generation	DNA replication is tightly regulated to prevent errors. During the process of meiosis chromosomes can swap sections and create new combinations of gene versions on a given chromosome, This creates more genetic variation
F. There are patterns of correlation between genes and traits and there are certain probabilities with which these patterns occur	The gene variants differ in their nucleotide sequence resulting in different or missing proteins that affect our phenotype. Dominant and recessive genetic relationships can be explained at the molecular level as a consequence of the function and interaction of gene products
G. Changes to the genetic information can cause changes in how we look and function (phenotype), and such variation in the DNA can serve as a way to identify individuals and species	DNA mutations are the source of genetic variation. Some DNA sequences can vary between species while others do not, therefore, we share some genes with other species (mice, flies). DNA sequences can vary between individuals and allow us to differentiate between individuals
H. Environmental factors can interact with our genetic information	Environmental factors can cause mutations in genes, or alter gene expression

The learning progression was a theoretical construct, but it was revised on the basis of empirical data a few years after it was first proposed. As a result, several levels were added to the original three (Shea & Duncan, 2013). However, the original big ideas remained unchanged. Another empirically based revision of the learning progression was presented by Todd and Kenyon (2016), who added even more intermediate levels to include steps in the progression that they considered to be missing. Once again, the big ideas were broadly unchanged by this revision.

Boerwinkel et al. (2017) led an international panel of 57 genetic education experts that aimed to determine what all modern citizens should know about genetics to support decision-making about genetics-related issues. That is to say, they sought to define genetics literacy. This initiative was based on the learning progression of Duncan et al. (2009), and highlighted three important types of knowledge – conceptual knowledge, sociocultural knowledge, and epistemic knowledge – that I also consider as central for genetics teaching at compulsory school. The conceptual knowledge that the panel identified as important was broadly similar to the big ideas proposed by Duncan et al. (2009), but with some modifications as shown below. The text in italics is from the original text of Boerwinkel et al. (2017) and highlights areas where their proposals deviate from the learning progression of Duncan et al.

1. All organisms have genetic information *in their DNA molecules*
2. Part of the organism's DNA molecules contains genes. Genes are instructions for the cell to make proteins. These instructions are present in a genetic code that is *almost universal* in all life
3. Proteins have a central role in the structure and function of all living organisms and *form the main* mechanisms that connect genes and traits
4. *Most cells* of an organism have genetic information *for all structures and functions*, but different genes are *switched on and off* in different cells
5. During reproduction, organisms transfer their genetic information to the next generation *through their reproductive cells. Each parent contributes a set of genes, leading to a double set in the offspring*
6. *In simple gene–trait relationships*, there are patterns of correlation between genes and traits, and there are certain probabilities with which these patterns occur

7. Changes *that occur in* the genetic information can cause changes in how *organisms* look and function. *Only changes in cells that become gametes are hereditary*
8. Individuals of the same species have mostly the same genetic information. Only a small portion of the genetic information accounts for the variation between individuals
9. *Multiple genes and multiple* environmental factors interact *in the development of most traits*

(Boerwinkel et al., 2017, p. 1090)

This framework does not include intermediate levels because its purpose is not to describe a learning progression but to define the conceptual knowledge of genetics that every citizen should possess.

The words "gene", "DNA", and "chromosome" play a central role in this thesis. They all represent key concepts in genetics as taught in secondary schools. Although "chromosome" is less heavily emphasized than "gene" and "DNA" in some definitions of genetic literacy (Boerwinkel et al. 2017), it is one of the most central words in genetics education at the secondary level. In my experience, the words gene, DNA, and chromosome are always present in the genetics sections of biology textbooks, while other genetics terms may or may not be present.

A key difference between the progression of Duncan et al. (2009) and the framework of Boerwinkel et al. (2017) is that the latter downplays the importance of a understanding the mechanistic foundations of the gene-trait connection whereas the former stresses the importance of understanding this connection as a way of avoiding misconceptions and deterministic views. Boerwinkel et al (2017) do highlight the role of proteins in the gene-trait link, but they do not consider knowledge of the mechanisms of gene expression to be necessary for genetics literacy.

Despite discussions about issues such as whether protein synthesis should be included in teaching there appears to be a consensus regarding the importance of understanding the role of proteins, which is emphasized by Duncan et al. (2009), Boerwinkel et al. (2017), and several other authors (e.g. Allchin, 2000; Duncan & Reiser, 2007; Gericke & Wahlberg, 2013; Venville & Treagust, 2002; Venville & Donovan, 2005). Accordingly, design studies that focus on using proteins as intermediate links between organizational levels have yielded positive results (Haskel-Ittah & Yarden, 2017; Tsui & Treagust, 2007, 2010; van Mil, 2013). Therefore, another major focus of this thesis is on the role of proteins and related concepts in genetics education.

Students' understanding

Although scholars have sought to define basic genetics knowledge that all students should possess upon completing their schooling (e.g. Boerwinkel et al., 2017; Duncan et al., 2009), studies on students' conceptual understanding of genetics have shown that this level of knowledge is not widely attained (Gericke & Smith, 2014; Knippels, 2002; Wood-Robinson, 1994). Many studies on science education over the last few decades have shown that students' understanding of genetics is often inconsistent with the scientific consensus, and that students' difficulties with the subject persist even after being taught (Banet & Ayuso, 2000; Lewis, Leach, & Wood-Robinson, 2000; Lewis & Wood-Robinson, 2000; Venville, Gribble, & Donovan, 2005).

Central concepts: gene, DNA and chromosome

The concepts of gene, DNA, and chromosome are central to genetics and several studies have focused on students' understanding of them (Duncan & Reiser, 2007; Lewis et al., 2000; Lewis & Wood-Robinson, 2000; Lewis & Kattmann, 2004; Marbach-Ad, 2001; Smith & Williams, 2007; Venville et al., 2005). These studies have consistently shown that there is widespread confusion about these basic genetic concepts: students are commonly confused about their structure, function, the location of the corresponding entities within the cell, and the relationships between the concepts.

Difficulties with understanding the gene concept have been observed in students at many stages of their education, from compulsory schooling to university (e.g. Boujemaa et al., 2010; Lewis et al., 2000; Lewis & Kattmann, 2004; Marbach-Ad, 2001; Saka, Cerrah, Akdeniz, & Ayas, 2006; Venville & Treagust, 1998; Venville et al., 2005). Moreover, students' difficulties with the relationships between gene, DNA, and chromosome have been described in several articles (Lewis et al., 2000;

Lewis & Wood-Robinson, 2000; Smith & Williams, 2007). When students in compulsory school describe DNA, gene, and chromosome, they tend to give either structural or functional explanations, i.e. they focus exclusively on one aspect or the other depending on the context and the concept under consideration (Marbach-Ad, 2001). However, both structure and function must be addressed to comprehensively describe any of these concepts. Therefore, the students' focus on structure or function in isolation suggests that they do not fully understand the common ground between the three concepts. Functional explanations are commonly offered when discussing genes and DNA; for example, a student may state that genes determine an individual's traits. Conversely, structural explanations are commonly invoked when discussing chromosomes (Marbach-Ad, 2001). It has also been reported that genes and DNA are seen as different phenomena, with DNA being regarded as something associated with identification whereas genes are seen as relating to traits and inheritance (Venville et al., 2005). A striking example of students' failure to grasp the relationships between these concepts is provided by the work of Lewis and Wood-Robinson (2000), who found that some students believed an organism could have chromosomes without having genetic information.

In addition to separating the three core concepts, when students do see a connection between them, they commonly mix up both the concepts and their relationships. For example, many find it difficult to keep track of what is made of what; students may think that genes are made of chromosomes or that genes are larger than chromosomes (Lewis et al., 2000; Smith & Williams, 2007), see chromosomes as a part of DNA (Marbach-Ad, 2001), or use the concepts gene and chromosome interchangeably (Lewis et al., 2000). Even cells may be confused with chromosomes; some students use the word "cell" interchangeably with both "chromosome" and "gene" (Lewis & Wood-Robinson, 2000).

There is also confusion about where in the body the genetic information is localized (Banet & Ayuso, 2000; Lewis & Wood-Robinson, 2000; Smith & Williams, 2007). For example, some students think that genes exist in specific organs or tissues (Lewis & Wood-Robinson, 2000) such as the brain, stomach or blood (Smith & Williams, 2007). Another common misconception is that each cell contains only the specific genetic information that it needs (Banet & Ayuso, 2000; Lewis & Wood-Robinson, 2000).

Gene function

Another core aspect of genetics is understanding the function of genes, i.e. what the genetic information encodes. Many students are unaware of how genes affects traits (Lewis & Wood-Robinson, 2000). Several reports have shown that students tend to see genes as particles, and to fuse the concepts of genes and traits (Lewis & Kattmann, 2004; Marbach-Ad, 2001; Venville et al., 2005). A study by Marbach-Ad (2001) showed that 8% of the students aged 14-15 years reasoned about genes and traits as if they were the same things, for example by describing genes as being made of traits.

However, another study by Venville and Treagust (1998) shows how students' conceptions of the gene and its function can develop during schooling. The most basic understanding is to view the gene as a passive particle whose main function is to be transferred between generations, while a slightly more advanced understanding entails seeing a gene as an instruction. The most sophisticated understanding involves seeing a gene as an instruction sheet for the production of a protein that contributes to a phenotype. Very few students seem to reach this highest level of understanding (Duncan & Reiser, 2007; Venville & Treagust, 1998), and few students can actually describe the meaning of "the genetic code" (Smith & Williams, 2007).

Is has also been shown that students can be aware that students encode proteins but see this as an alternative function to determining traits. That is, they think that coding for proteins and determining traits are two different functions, and do not see how they are connected (Duncan & Reiser, 2007).

Thus, there is a widespread confusion about the central ideas within genetics, ideas that multiple studies have identified as basic and important for all educated citizens to understand.

Reasons for difficulties

As demonstrated by the preceding discussion, we cannot take for granted that students have acquired knowledge of genetics even after completing all of their classes on genetics during compulsory education. It is therefore important to identify what prevents students from grasping ideas that are considered to constitute the most elementary knowledge in genetics. Some possible contributors to these difficulties are discussed below.

Pre-conceptions

When students are taught about genetics for the first time, they probably already have some kind of conception of what (for example) genes and DNA are. Many children will have heard these words in movies, news broadcasts, or computer games. However, because popular culture rarely concerns itself with adhering to the scientific consensus, few children have a chance to develop an adequate understanding of these concepts. Instead, they develop alternative conceptions that conflict with the scientific consensus and can create a barrier to understanding genetics in school (Venville et al., 2005). For example, TV shows involving forensics typically focus on the use of DNA samples to identify suspects rather than the functional role of DNA in organisms; this may explain the common perception that the function of DNA relates to identification (Venville et al., 2005).

Students can also acquire other alternative concepts that can complicate the understanding of genetics in school. When teaching classical genetics, it is common to use peas or other plants to illustrate inheritance patterns. However, students are not always aware of the characteristics of life, and not all students recognize that plants are living organisms (Andersson, 2008; Banet & Ayuso, 2000). Many Swedish students in grade nine know that animal consist of cells and that they contain chromosomes and DNA, but are less certain about the composition of plants (Andersson, 2008). Not understanding what is alive and what is not can of course be an obstacle for students in their efforts to grasp complex genetic concepts, especially if their teachers are unaware of the situation.

Teaching

The effect of traditional teaching was explored in a study by Banet and Ayuso (2000). Before teaching, 75% of the participating students (15-16 years old) knew that plants consist of cells, and 85% of students aged 16-17 were aware of this fact after being taught. More surprisingly, around half the students stated that plants have chromosomes before being taught, but only 35% said that plants have chromosomes after being taught. It thus appears that the teaching *reduced* the students' knowledge, which is indicative of very ineffective teaching practices.

Teachers must recognize students' difficulties, although they do not always manage to do so. A study conducted almost 40 years ago showed that students at university level found genetics to be one of the most difficult areas within biology (Johnstone & Mahmoud, 1980). About 20 years later, a follow-up study (Bahar, Johnstone, & Hansell, 1999) showed that students still considered genetics to be difficult. In both studies, students and teachers were asked to rate the difficulty of different biological subjects separately. The difficulties assigned by students differed markedly from those perceived by their teachers, showing that the teachers were unaware of the students' difficulties with the subject. If teachers do not recognize students' problems, they will probably not structure their teaching to overcome these difficulties.

Textbooks

Textbooks are another important aspect of teaching, since many teachers rely on them heavily (Nelson, 2012). Gericke and Hagberg analyzed the explanations of gene function in different textbooks and compared these explanation to historical models of the gene and its function, revealing both similarities and differences (Gericke & Hagberg, 2007). Five main models were identified, each of which describes gene function in a different way depending on focus and context. Neither these differences nor the fact that the explanations are models were made explicit in the texts. In addition, the models are mixed models of the sort that Gericke and Hagberg have termed Hybrid models. This is assumed to be one of the reasons for students' difficulties in understanding the gene concept and its function. Gericke and colleagues also found that upper secondary students could not discern or interpret the different scientific models of genetics in their own textbooks after reading them (Gericke, Hagberg, & Jorde, 2013). These results have subsequently been shown to describe textbook discourses in many countries (Aivelo & Uitto, 2015; Gericke, Hagberg, dos Santos, Joaquim, & El-Hani, 2014).

To understand how central words are defined in school textbooks used in compulsory schooling, I examined three commonly used biology textbooks for grade nine students[1]. None of these textbooks had a wordlist with definitions of key concepts, so I performed a simple pre-analysis of the chapters on genetics. I found clear similarities in the presentation of the words gene, chromosome, DNA, and anlag (a word used extensively in genetics education in the Swedish context). Genes are described as parts of the DNA molecule that function as recipes for proteins and which are passed from one generation to the next. DNA is described as a large molecule in the shape of a spiral ladder whose rungs are nitrogenous bases named A, T, C, and G; the order in which these rungs are arranged stores information that serves as a code for the construction of proteins. Chromosomes are defined in relation to DNA - specifically, they are described as consisting of or containing DNA. “Arvsanlag” or its shorter form “anlag” is described as a synonym of gene in the sections discussing Mendelian genetics. In addition, various interrelationships are made between the concepts. While a thorough textual analysis would be needed to fully describe the presentation of these concepts and their interrelationships, this brief discussion captures the essence of how the concepts are presented in the textbooks and the varied connections that are drawn between them.

Different organizational levels

Another factor that contributes to the complexity of genetics is the fact that it requires the simultaneous consideration of phenomena and processes associated with different levels of biological organization (Knippels, 2002). The educational difficulties associated with learning material that requires simultaneous consideration of multiple levels of

[1] Fabricius, S., Holm, F., & Nystrand, A. (2013). *Biologi. Grundbok*. Stockholm: Liber.
Henriksson, A. (2010). *Biologi*. Malmö: Gleerup.
Andréasson, B. (2011). *Biologi* : för grundskolans år 7-9. Stockholm: Natur & kultur.

organization were first described in the early 80s by Johnstone (1982) in a study on chemistry education. Chemists consider phenomena occurring at three levels: the macro level (which concerns visible features and functions of substances), the micro level (which concerns things we cannot see, such as atoms and molecules), and the representational level (to which things such as symbols and formulae belong). Johnstone (1982) found that while professional chemists and teachers move between these levels without any difficulties (and generally do not reflect on the way they do this), the need to operate on several levels simultaneously causes major difficulties for students.

Bahar et al. (1999) transferred the micro-macro model to the context of genetics by relating the macro level to visible traits, the (sub-) micro level to genes and alleles, and the symbolic level to the symbols used in genetics (e.g. the letters used to represent alleles). Like Johnstone, Bahar argued that it was very difficult for students to make mental jumps between these levels whereas teachers made such jumps with ease.
Several researchers within genetics education have since addressed the problem of different organizational levels (Duncan & Reiser, 2007; Duncan & Tseng, 2011; Lewis & Kattmann, 2004; Marbach-Ad & Stavy, 2000; Schönborn & Bögeholz, 2009; van Mil, 2013; Venville & Treagust, 2002). Duncan and Reiser (2007) identified an important related issue, namely that in addition to the hierarchical levels identified by Johnstone, there are also multiple ontological levels to consider in genetics. On one ontological level, genetics is the study of information about genes; one another, it is the study of hierarchically ordered biochemical structures in which the properties of higher level structures are governed by the structures of lower level components. Duncan and Reiser (2007) described these levels as being "hybrid hierarchical" because they differ in both ontological and hierarchical terms. This makes genetics even more complex than was previously recognized.

History of concepts

Genetics is a subject with a long history, extending from Mendel's studies on peas in the 19th century to the remarkable capabilities of modern genetic technologies. This history has greatly influenced the complexity of genetics content and thus the complexity of the conceptual meaning and language of genetics. During the subject's historical development, several different ideas and theories have been presented, and new knowledge has continuously replaced older understandings. However, some old theories and models remain in use, especially in school science. One example is the inheritance model of Mendel, which remains a dominant part of curricula around the world, not least in contemporary textbooks and teaching (Smith & Gericke, 2015)

The words gene, DNA and chromosome were introduced at different times in history and their meanings have changed to differing extents since their invention. In the late 1800s and early 1900s there were many great advances in biology and genetics started to emerge as a field of study in its own right. With the assistance of better techniques and microscopes, it became possible to examine new structures and phenomena. The resulting new findings required a new vocabulary, so many new words were introduced during this time (Craft, 2013).

Chromatin was discovered and named by Flemming in 1880 (Oxford English Dictionary, 2018), and the word chromosome was introduced by Wilhelm Waldeyer in 1888 (Cremer & Cremer, 1988). Several other terms had previously been introduced to describe these already recognized "stainable bodies" in the cell, including chromatic elements, karyosomes, and nuclear segments, but it was Waldeyer's chromosome that became the established term (Cremer & Cremer, 1988).

The word gene were introduced in 1909 by Wilhem Johansen. It was based on the word pangene, which was used 1889 by Hugo de Vries, who in turn was inspired by Darwin's use of pangenesis (Gayon, 2016). Nowadays the gene no longer has a clear-cut definition, as illustrated by the definition given in *A Dictionary of Biomedicine*, which begins as follows:

> A surprisingly difficult term to describe because the meaning has changed with increasing knowledge and the original 'one gene, one polypeptide' definition is no longer accurate. (...)
>
> (Lackie & O'Callaghan, 2010, p. 232)

The acronym DNA is much more commonly used than the full name of the molecule it represents, i.e. deoxyribonucleic acid.[2] DNA was identified by Oswald Avery in 1944 as a "transforming principle", but it was James Watson and Francis Crick who determined its 3-D structure based on X-ray diffraction images acquired by Rosalind Franklin (Klug, 2004).

The historical development of genetics has been accompanied by developments of the associated terminology. Some old words have become obsolete with the passage of time and others have been retained but have lost their original meaning. A notable example is the word "anlag", which is discussed extensively in this thesis. "Anlag" is still used extensively in the Swedish context, especially when discussing Mendelian genetics; it is an old German word, that has acquired many distinct meanings in Swedish. According to the Swedish academy (Svenska Akademins Ordbok, 1898/2018) anlag can mean a pre-disposition (e.g. to a disease) or a potential for development. Nationalencyklopedin (2018) provides another definition, saying that in the context of genetics, anlag is a synonym of *arvsanlag* or *gene*.

Different meanings

The gene concept has changed over time, giving rise to many distinct meanings as discussed by several authors (Falk, 2012; Flodin, 2009; Gericke & Hagberg, 2007, 2010a; Griffiths & Stotz, 2006; Pearson, 2006; Portin, 1993). Gericke and Hagberg (2007) identified five different models of the concept with focus on gene function that have emerged over time: the Mendelian model, the classical model, the biochemical-classical model, the neoclassical model and the modern model. Flodin (2009) also categorized different models of the gene concept used within different sub-disciplines of biology: the gene as a trait, an information structure, an actor, a regulator, and a marker.

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[2] A google search performed on the 20th of April, 2018, gave 145 000 000 hits for "DNA" and 1 490 000 for "deoxyribonucleic acid". A google scholar search performed on the same date gave 4 880 000 hits for "DNA" and 231 000 for "deoxyribonucleic acid."

Words like “gene” that have different meanings that have emerged over time are described as being polysemous (Löbner, 2002). Such words have no single comprehensive definition or description because their meaning depends on the context: “gene” means different things in the contexts of classical genetics, population genetics, and molecular genetics. As Flodin put it, “gene” is: “...a concept that escapes single definitions and ‘drift around’ in meanings” (Flodin, 2017, p. 141). Within individual professions, the gene concept is used with specific meanings, relevant to a given context. This does not pose any problem for professionals but in teaching situations where several different models are used (and potentially mixed), it is likely to create difficulties for novice learners (dos Santos, Joaquim, & El-Hani, 2012; Gericke & Hagberg, 2010a, 2010b).

Flodin (2017) illustrated the different uses of the gene concept in different disciplines, showing that “gene” does not represent a single concept; rather, it stands for many distinct concepts and so its meaning depends on the context in which it is used. Flodin (2017) analyzed five research articles published in the journal *Genetics* representing five different sub-disciplines of biology (transmission genetics, molecular biology, genomics, developmental biology, and population genetics) to find out how the concept’s use varied. She discovered that in the population genetics article, a gene was typically presented as something with a specific location on a chromosome that corresponded to a specific site of recombination. The molecular biology article described a gene was something that was expressed, suppressed, or somehow regulated. This were also true for the genomics article, but in this case the gene was also described as something that produces proteins. In the developmental biology article, the gene was related to a phenotype and a cause of organ formation. Finally, the population genetics article used genes for genetic mapping and thus primarily focused on the order and position of genes on the chromosomes. Research articles thus portray genes in different ways depending on which functions of the gene concept are most relevant to their content (Flodin, 2017).

Extent of terminology

Another aspect of genetics that has been identified as causing difficulties for students is its extensive terminology (Knippels, 2002). These difficulties do not arise solely from the large number of subject-specific terms. In addition to the polysemous words discussed above, genetics is rich in synonymous words and words that sound similar but have different meanings (Bahar et al., 1999; Pearson & Hughes, 1988). Another problem is that some words are used as synonyms even when they are not, such as gene and allele (Pashley, 1994; Pearson & Hughes, 1988; Wood-Robinson, Lewis, & Leach, 2000).

In summary, a large body of research has shown that students find learning genetics difficult and many leave school without an adequate understanding of this subject. Students have difficulty with basic concepts and their relationships, as well as the connection between genes and traits. Some reasons for these difficulties have been identified: students' pre-conceptions can be an obstacle, teachers may not recognize students' difficulties, and genetics is inherently complex because it has a complex language and requires students to consider different organizational levels and models. Thus, many aspects of teaching and learning genetics have been addressed. However, there is one area that has not been well studied but which is, in my opinion, vital to understand if we want to deepen our understanding of the challenges facing teachers and students: the nature and role of classroom talk in regular classrooms during genetics lessons.

Theoretical perspective

This thesis is grounded in a sociocultural perspective. As Jakobsson (2012) notes, there are many sociocultural perspectives, but all of them can be related to the work of Lev Vygotsky in some way. An essential aspect of all sociocultural perspectives is that language is seen as playing a central role in learning and development.

Vygotsky argues that language and thought have different roots and develop separately in young children, but that at these two capabilities meet and merge at a certain point in development such that "speech begins to serve intellect, and thoughts begin to be spoken" Vygotsky (1975, p. 43). i.e. "thought becomes verbal and speech rational" (p. 44). Vygotsky points out that the connection between thought and language does not mean that all thinking becomes verbal or all speech becomes intellectual. We still do a lot of non-verbal thinking, for example in more practically oriented thoughts. However, according to Vygotsky, thought and language are tightly intertwined in higher cognitive processes.

Thus, language should not be seen as something we use to express our thoughts; rather, we think with language. A similar argument was made by Halliday (1993). Halliday claims that all learning is learning how to mean, i.e. a semiotic process. By exploring children's processes of learning language, we can better understand learning in general. He says that:

> Language is not a domain of human knowledge (except in the special context of linguistics, where it becomes an object of scientific study); language is the essential condition of knowing, the process by which experience becomes knowledge.
>
> (Halliday, 1993, p. 94)

Wells (1994) compares the theories of Vygotsky and Halliday, and concludes that there are many similarities in their thinking, and that these common elements must be central to any language-based theory of learning. For example, both authors see language development as something that emerges through interaction with others. Additionally, both were interested in education and how to improve teaching based on knowledge about language development. However, they had different foci: Vygotsky was primarily interested in mental functioning, whereas Halliday focused primarily on language and its organization and use as a social resource (Wells, 1994).

The language of science

The role of language has also been emphasized by many science education researchers (Lemke, 1990; Mortimer & Scott, 2003; Wellington & Osborne, 2001). The language of science differs from everyday language in several respects, and is therefore often considered difficult (Mortimer & Scott, 2003).

Words and concepts

One obvious aspect of scientific language is the abundance of subject-specific words. As discussed in the introduction, students are known to have difficulties with the extensive specific terminology of scientific subjects such as genetics (Knippels, 2002). Concepts can be particularly challenging when they are referred to using words that have a different meaning in everyday language, such as "energy" (Wellington & Osborne, 2001).

Wellington and Osborn (2001) categorized specific scientific words into three main categories: *naming words, process words* and *concept words*. Naming words are words that denote existing objects, which may or may not be visible. These words may be familiar (e.g. "pea plant") or new (e.g. *Pisum sativum*) to students, but they generally refer to familiar or easily observable objects. According to Wellington and Osborne's categorization, "cell" is also a naming word because it represents something that can be observed, albeit only with the aid of a microscope in most cases.

Process words describe things that happen. A process may be observable – for example, combustion is a process (reaction) that a teacher can demonstrate in front of the class. However, there are also abstract processes that cannot be demonstrated in the same way; an important example is evolution (Wellington & Osborne, 2001).

The last category described by Wellington and Osborn is that of concept words, which are the words that create most difficulties for students. These are words that cannot be understood in isolation; they must be related to other words to be understood. As such, they do not simply denote an object and are more abstract in nature. Concepts vary in complexity; Wellington and Osborn describe the color red as a relatively easy concept to understand, whereas the theoretical construct of the "frictionless body" is a more demanding concept.

Wellington and Osborn (2001) also note that a word may develop from being a denoting word to a concept. Definitions are also often not clear-cut, and may be categorized in different ways depending on which aspects are emphasized. For example, when students look down a microscope and see the black little structures in the root cell of an onion, we can denote these as chromosomes and think of the word as a naming word. We can even have students perform a DNA extraction lab and point at the white substance on the wooden stick and say "here is some DNA". However, these phenomena can also be explored on a conceptual level.

Throughout this thesis, I use both words and concepts. Löbner (2002) describes a word as something with a specific sound when spoken and a specific spelling when written, but notes that words do not have descriptions embedded within them. Consequently, if we do not know a word before we encounter it, we cannot determine its meaning simply by hearing or reading it (Löbner, 2002). In contrast, a concept can be regarded as a mental description of a word's meaning (Löbner, 2002). Vygotsky (1975) similarly talks about concepts as the meanings of words, and connects them to verbal thought. Hence, when I use "word", I refer to a specific combination of letters that together form a meaningful unit (e.g. "DNA"). Conversely, I use "concept" to refer to the *meaning* of the corresponding word.

Language development

As discussed in the introduction, several words in genetics were invented during the earliest days of the subject's history, and some of them have evolved in multiple directions, especially the concept of the gene. Vygotsky (1975) discusses language development in children and the development of the language itself in terms of what he calls concept formation. In the beginning, a phenomenon is often named based on one of its attributes which may not actually be an essential attribute of the phenomenon. To illustrate this point, Vygotsky notes that the Russian word for "cow" literally means "horned" even though having horns is quite a peripheral aspect of a cow's nature. Similarly, the word "chromosome" means "colored body" even though color is not an essential aspect of a chromosome's nature. Vygotsky shows how a word's meaning can change over time, and how new meanings can be transferred from one referent with a specific attribute to another referent by some kind of process of association that groups the two together. Vygotsky compares this to a child's concept formation process whereby nonsense words are transferred to new phenomena by chains of association.

Vygotsky (1975) also notes that concepts are components of hierarchically structured systems. He differentiates between everyday concepts and scientific concepts, and discusses their different developmental paths. Everyday concepts are used and filled with personal experience, but it is not until later in development that a child can define a concept or see it from a metaperspective and use it in logical operations. The scientific concepts learned in school develop in the opposite direction, starting with a definition and an explicit focus on the concept itself. The student may be able to define and use the concept, but only in a schematic way. One needs more personal experience and personal use to build on a concept and fill it with meaning through free use in specific situations. In the school context, concepts are introduced in terms of their relationships to other concepts. This stands in contrast to the way concepts are learned in everyday settings, where for example "flower" and "rose" are seen as synonyms for a long time, before the child realizes the subordination of flower (Vygotsky, 1975).

Halliday (1993) also uses the development of language in small children as a point of departure for thinking about the learning of concepts in general, and defines several features that characterize language development. During a child's semiotic development, the ability to generalize precedes the ability to abstract. Generalization in this context means recognizing that a word can apply to a category of objects. For example, "dog" is not a word for a specific dog, but for all animals of that type. According to Halliday, children have no problems with taxonomy itself because words are naturally learned in relation to other words. However, the details of specific classification systems can be demanding. Halliday (1993) also argues that developing a capacity for abstraction is the next important step in language development and is crucial for coping with education and becoming literate. At higher levels of the educational system, including secondary education, students must be able to handle grammatical metaphors. These are common in scientific language – processes of doing and happening are frequently transformed into nouns (Halliday & Martin, 1993). For example, complicated processes can be packed into a single word or phrase, such as "protein synthesis", which than can be used in sentences to increase their information content. This enables a sort of packing of information that increases the "density" of the language, giving rise to a language that is heavily packed with information such that a lot is conveyed using only a few words.

Networks of words

Another feature of the language of science is "interlocking definitions" whereby several subject-specific words are linked because their definitions are mutually dependent (Halliday & Martin, 1993). In a learning situation, this means that students must learn clusters of words. For example, in a genetics context, the words "gene" and "DNA" are tightly connected; a gene can be defined as "a part of a DNA molecule" while chromosomes are "lengths of DNA folded into a structure called chromosome".

The language is thus much more than separate words, and understanding the language of science is more than simply a matter of defining separate words. Halliday and Martin (1993) note that the real challenge is not how words are defined in isolation, but how they are related to each other.

Lemke's framework of *thematic patterns* (Lemke, 1990) describes how the content of science consists of a network of words (or meanings of words) that are connected to each other in specific ways. The specific words in these patterns sometimes vary - for example, different synonyms may be used - but the crucial aspect is how these items relate to each other (i.e. their semantic relations), which remains unchanged. This creates the specific thematic pattern that constitutes the subject matter. Lemke argues that learning science actually means learning how different words relate to each other and becoming able to discern these patterns. Therefore, it is important for a teacher to present the content in a way that makes the relevant semantic patterns clear and consistent. When we know the subject content, we can understand the content, even if a speaker happens to use a word incorrectly. However, when learning a new subject, it is difficult to discern what is important and what is peripheral. Lemke's framework of *thematic patterns* (1990) draws heavily on an earlier theoretical framework known as Systemic functional linguistics.

Systemic Functional Linguistics

The theoretical framework of *systemic functional linguistics* (SFL) is mainly developed by Halliday (Halliday, 1993, 2004). Halliday's theory of language focuses on the function of language and how meaning is created by the different choices we make when we use it. Language is thus seen as a semiotic system with the potential for meaning based on the availability of a range of options (Halliday, 1978). Halliday considers the complexity of language, including the importance of context. He describes language in terms of different strata: *context, semantics, lexicogrammar* and *phonology*, which are all important to be able to say something about the meanings of an utterance. Context is about the setting in which the language is used, semantics concerns meaning, while lexicogrammatics is about what words are used and the order in which they are placed. Phonology concerns the sounds that are uttered to create words. All these strata contribute to the meaning of an utterance (Halliday, 2004).

Teaching and learning the language of science

The Zone of Proximal Development

Vygotsky (1975) discusses the teaching of scientific concepts and the impossibility of simply transferring a word from the teacher to the student. He concludes that it is pointless to try and teach a concept in such a direct fashion because it will only lead to the student parroting the word (or perhaps its definition) without developing the underlying meaning or knowledge. What students need, Vygotsky says, is to hear the word in use in different contexts, and to see it in different sentences in a variety of situations until the student eventually begins to use the word and make it their own. This will enable the first steps towards the development of the concept within the students' intellect.

Vygotsky (1978) emphasizes the importance of communication with others for learning in his well-known concept of the *zone of proximal development* (ZPD). He states that:

> [ZPD] is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers.
>
> (Vygotsky, 1978, p. 86)

According to Vygotsky, the actual development level is what children can do on their own, i.e. functions they have already mastered, while the ZPD corresponds to functions and abilities that are under development, and problem-solving activities that can only be completed with assistance. With practice and familiarity, this will eventually become the child's actual developmental level. From a pedagogical point of view, Vygotsky states that ""good learning" is that which is in advance of development" (Vygotsky, 1978, p. 89). He thus separates development and learning, and says that learning precedes development, which defines the ZPD. Language is crucial in this process: it is first used for communication (e.g. between student and teacher) before being internalized by the students, used in their internal speech to structure their thought, and combined with higher mental functions such as abstract thinking. Vygotsky compares this model to the results of studies on apes, who can learn new things, but not develop their understanding in the same aspect as humans. Humans participate in social processes that stimulate mental development, which would be impossible in isolation. Internalization is thus a process that first occurs at the interpersonal level and is driven by communication between individuals. It then turns inward and becomes intrapersonal, before being internalized and becoming part of the individual's "inner speech". Vygotsky argues that the learning of higher functions and concept formation progresses through these stages (Vygotsky, 1978).

Dialogue

In Bakhtin's theories, dialogue is central and is considered to operate on multiple levels. On a fundamental level, he argues that human life is inherently dialogic, and that we are constantly in dialogue with our surroundings, our past, and the future. Every utterance is thus a response to an earlier utterance, and every utterance requires a response (Bakhtin, 1981). Dysthe (1996) discuss how we in this sense, are inherently dialogic and all utterances are somehow dialogic. However, she also discusses how Bakhtin separates authoritative and internally persuasive discourses (Bakhtin, 1981), and the importance of this difference in teaching settings. Authoritative discourse is monological in that it does not admit any possibility of different answers; instead, there is simply a correct view that is to be transmitted to the receiver.

Bakhtin saw dialogue as central in learning situations and argued that meaning can only be constructed through dialogue; the receiver's response is essential for understanding. Meaning cannot merely be transmitted to a receiver – the listener must actively respond to the message to make it their own (Bakhtin, 1981).

Dysthe (1996) discusses Bakhtin's theories and their applications in teaching settings, arguing that teaching must focus on students' responses to a greater degree than is permitted by the controlling function of typical triadic patterns. This is needed to establish an internally persuasive discourse that will enable students to make the subject matter their own. However, Dysthe also notes that there is an asymmetrical hierarchy between ideas in educational settings – that is to say, there is content that must be taught and learned. However, while the content clearly defines a direction in terms of which ideas we must head towards, we cannot reach them simply by telling the students the "truth"; instead, we must consider their thoughts and they must actively respond to the ideas being taught.

Classroom interactions

Mortimer and Scott (2003) created a framework for analyzing discursive interactions in science classrooms that distinguishes between dialogic and authoritative teaching based on Bakhtin's distinction between authoritative and internally persuasive discourse (Bakhtin 1981). In this framework, teaching is considered authoritative if it is focused on the scientific consensus and disregards other views of the issue at hand. Conversely, dialogic teaching allows different ideas to be considered and elaborated on. In a teaching context this may entail highlighting the different views that students may have about the subject matter, i.e. their alternative conceptions. This could be done by a teacher talking at the front of a class – that is, the ideas in question need not be uttered by students for the discourse to be dialogic. In everyday language we commonly use "dialogue" to mean two (or more) persons talking, but in Mortimer and Scott's framework, the authoritative vs dialogic dimension refers to the sources of ideas rather than to who is talking; they use the terms "interactive" and "non-interactive" to describe situations where multiple people speak and where only one person speaks, respectively. In this thesis, I use the word “dialogue” to denote occasions where students and teachers talk to one-another. However, in my analysis, I use the word “dialogic” to refer to occasions where several views are considered, in keeping with the framework of Mortimer and Scott (2003).

The spoken language

Dysthe discusses how the relationship between written and spoken language has been viewed over the course of history since the time of the ancient Greeks. The spoken word once had a higher status, and its interactive nature was seen as a strength in teaching styles such as the Socratic dialogue, which was used as a pedagogic tool to get the learner to think for herself (Dysthe, 1996). The relative value assigned to speech and writing has changed over time; today, written language has a higher status, as demonstrated by the greater emphasis on written exams in the school system (Dysthe, 1996).

Although talk has a lower status than writing in modern classroom, several authors have stressed its importance in education (Alexander, 2008; Edwards & Westgate, 1994; Lemke, 1990; Wells, 1999). For example, Edwards and Westgate argue that a large part of education is based on classroom talk and that studies on spoken language provide a lot of information that is inaccessible by other means because “so much is constituted in and through [spoken language]” (Edwards & Westgate, 1994, p. 15). Further, they argue that studying spoken language in classrooms can make “‘visible’ the curriculum in both its ‘manifest’ and it ‘hidden’ forms” (Edwards & Westgate, 1994, p. 15).

Alexander’s *Dialogic teaching* (2008) also places great emphasis on talk. He points out the importance of attending to the quality of talk, not just the form, focusing in practices such as offering extended waiting times and asking open-ended questions. He argues that the content of the talk in the classroom is just as important as the structure of the lesson, and that teachers must have a clear conceptual map of what will be talked about and how to manage the classroom talk to ensure students learn the subject matter.

Taking the linguistic theories discussed above as a starting point and foundation, this dissertation examines the spoken language in a range of classroom contexts. The dissertation focuses on the learning of genetics, which has been identified as a source of significant problems in science education, and specifically deals with students' understanding of central genetics concepts and their interrelationships. Hodge (2017) discussed the value of analyzing texts at the level of individual words, noting that while words must be considered in their context, it can be productive to also consider the frequency with which they are used and the way they are combined with other words. Specifically, he argues that paying attention to small-scale phenomena in a text can shed light on higher level issues, and compares this approach to the progress of natural science, in which studies on atoms, microbes, and genes have had crucial impacts on larger scales. Accordingly, he describes words (and in some cases, fragments of words) as "atoms of meanings" (Hodge, 2017, p. 109). Hodge also argues that when analyzing words, it can be beneficial to consider their history; dictionaries are useful analytical tools for this purpose. There are often several meanings ascribed to words, about which Hodge says:

> I understand these as transformations, contemporary traces of transformations carried out by historical agents, whose actions are usually still recoverable as meanings
>
> (Hodge, 2017, p. 115)

I thus concluded that it would be interesting and productive to focus my efforts on specific central words within genetics and to scrutinize their use and realized meanings in classroom contexts.

Aim and foci of the four studies

The general aim of this thesis is to investigate linguistic aspects of teaching genetics, and to improve the understanding of why genetics is so difficult to teach and learn. It was expected that exploring how teachers and students discuss genetics during teaching situations (i.e. how language is used in practice during genetics lessons) would provide insights into linguistic challenges associated with spoken language and detailed information on how genetics content is actually presented to students. It could also shed light on the opportunities students are given to learn to use the specific language of genetics.

The four articles included in the thesis focus on different areas or aspects of genetics teaching in grade nine, which is the final year of compulsory schooling in Sweden. However, all four articles address linguistic issues and focus on specific genetics content. Three of the articles focused on what teachers said, while the last article deals with dialogue between teachers and students, and how students used genetics concepts.

The first article examines teachers' use of the words gene, allele and anlage, the meanings ascribed to them in the context of Mendelian genetics, and the relationship between gene and trait as realized in the teachers' classroom talk. These foci were chosen because Mendelian genetics constitutes a significant part of genetics teaching and because these concepts are components of different historical models and are known to be difficult for students to understand.

The second article focuses on the teachers' talk about proteins and how they used the protein concept as a link between genes and traits. This focus was chosen because of the emphasis on the importance of proteins in genetics education research and the finding that students often have alternative conceptions of gene function and the role of proteins.

The third article focuses on how the teachers use and interrelate the words gene, anlage, DNA and chromosome. These words are closely related and central in genetics, but are also known to be confusing for students.

The fourth article includes students' voices and focuses on the dialogue between teachers and student involving the words gene, DNA and chromosome. Having scrutinized several aspects of how the teachers used and interrelated central genetics concepts, the aim was to see how students were encultured into the language of genetics and what characterized the situations where they did use central concepts.

Three general questions guided the work presented in this thesis: *How do teachers present genetics content? What opportunities are students given to learn the specific language of genetics? Why is genetics such a challenging topic to teach and learn?*

Methods

To explore how teachers and students used the language of genetics, it was crucial to observe genetics lessons and the language *in situ*. This made an observation study the method of choice. An additional advantage of this decision is that it enables the use of a naturalistic approach involving no intervention, allowing classroom situations to be captured in the most authentic environment possible (Robson, 2002).

Context and data collection

All four studies in this thesis are based on the same data set. The data consists of observed and recorded genetics lessons from four grade nine classes in Sweden.

To be eligible to participate in this study, teachers had to have at least five years' teaching experience, to have successfully completed the relevant teacher training courses, and to be teaching genetics to a grade nine class during the data gathering period. In addition, for the sake of convenience, the teachers had to be working at a school that was close enough to my workplace for me to visit them several times per week. Four teachers satisfied the inclusion criteria and volunteered to participate in the study.

The participating teachers worked at two different schools: two female teachers at one school and two male teachers at the other. Both were ordinary public schools with students of average academic achievement from average socioeconomic backgrounds. The teachers all had adequate educations, having passed teachers' exams in biology including courses on genetics. The teachers had worked in secondary schools for between 6 and 12 years and thus had several years of experience.

The Swedish curriculum

This thesis focuses on genetics education during the final year of compulsory schooling in Sweden. The Swedish school system includes nine years of compulsory schooling. Students commonly begin their schooling at the age of 7, but it is possible to begin at the age of 6. Most grade nine students are thus 15-16 years old. Compulsory school is followed by upper secondary school. Students can then choose between different national programs with specializations in different areas. Grade nine is thus the last year in which all students are obliged to study biology.

The data used in this thesis were collected during the years 2009 and 2010. These were the final years of the former Swedish national curriculum, the *Curriculum for the Compulsory School System, the Pre-School Class and the Leisure-time Centre*, also known as *Lpo 94* (Swedish National Agency for Education, 2006). This curriculum had been revised in the year 2000 (Swedish National Agency for Education, 2000).

Lpo 94 was goal-oriented and did not provide detailed descriptions of the contents to be taught. Instead, it specified goals for each subject taught during compulsory schooling, one of which was biology. There were two types of goals: *Goals to aim for* and *Goals that pupils should have attained*. Goals of the latter type corresponded to knowledge that all students were supposed to possess upon completing their compulsory schooling at the age of 15-16. Both types of goals were grouped under three headlines: c*oncerning nature and Man*, *concerning scientific activity*, and *concerning use of knowledge*. The biology syllabus specified nine goals to aim for. These were very general in nature and did not dictate any particular concept of genetics; for example, under the heading “nature and man”, the syllabus stated[3]:

> [The school in its teaching of biology should aim to ensure that pupils] develop their knowledge of the structure of the human body and its functions.

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[3] The citations are taken from the English version of the syllabus, Retrieved July 10, 2012, from http://www3.skolverket.se. (webpage without page numbers)

Under the heading concerning use of knowledge, one of the two goals was:

> [The school in its teaching of biology should aim to ensure that pupils] develop the ability to discuss questions concerning health and interpersonal relationships on the basis of relevant biological knowledge and personal experiences.

The nine goals that pupils should have attained in biology by the end of grade nine were slightly more specific in terms of content. Two of them related to genetics because they included words commonly recognized as genetic, e.g. genes, inheritance or gene technology. One of the goals was under the heading concerning nature and man:

> [Pupils should] have a familiarity with genetic heredity.

The other goal was under the heading concerning use of knowledge:

> [Pupils should] be able to use not only scientific, but also aesthetic and ethical arguments in issues concerning the preservation of different types of nature and diversity of species, as well as the use of genetics.

In addition to these goals, the syllabus provided a description of the character of the subject biology (Swedish National Agency for Education, 2000), i.e. it explained how school biology should be understood. The following text relating to genetics was offered under the heading *The cell and living processes*:

> Scientific explanations for most of the phenomena and functions, which pupils experience and observe within themselves and their surroundings, can be found in a knowledge of cells. This knowledge, and particularly knowledge about a cell's internal processes, has opened up new opportunities in e.g. genetics. These opportunities create change in Man's living conditions, which involves important ethical aspects. An understanding of this change requires a knowledge of i.a. photosynthesis, combustion and the genetic code.

As can be seen, the curriculum was general in its regulations. It was not structured according to established sub-disciplines within biology (and so there was no specific mention of genetics), and was not intended to act as a prescriptive guide dictating what should be taught about genetics specifically. The teachers had to ensure that their teaching content was adequate to allow students to fulfil the goals specified in the curriculum.

Because the curriculum was so vague, teachers had considerable freedom to interpret it as they saw fit, to make choices about the content to be taught, and to structure their teaching in whatever way they thought would best enable students to achieve the specified goals.

Observations

Four grade nine classes (one for each participating teacher) were observed as they progressed through a complete course on genetics. Overall, each genetics teaching sequence lasted for 3-5 weeks. In total, 45 lessons were documented (between 7-13 lessons per teacher). One class was taught for several lessons by a substitute teacher. The observations of these lessons were excluded from the final data set because the substitute had no training in biology (which was very clear from the observations); the intention was to study teachers' communication rather than a layperson's way of talking about genetics. Therefore, one of the teachers was only recorded for 7 lessons.

During the data collection process, I sat at the back of the classroom during the lessons, documenting what happened in the classroom and writing down reflections. Each participating teacher wore a recording device with a microphone that recorded everything he or she said during the lessons, as well as the students' responses. Another recording device was placed at the front of the classroom and used as a backup when the sound quality from the first microphone was unsatisfactory. During the teachers' lectures (i.e. whenever the teacher stood in front of the class and addressed them as a group), I video recorded the teacher.

Analysis

The four articles all focused on language use in science classrooms, but from different perspectives (as shown in figure 1). As such, there were some similarities between the analyses, but also many important differences. In the three first articles, the core of the analysis was to identify semantic relations (Halliday, 2004; Lemke, 1990) between central genetics words so as to discern the underlying semantic patterns

(Lemke, 1990) and the meanings communicated by the teachers concerning the genetics content covered in the classroom. The fourth article focused on teacher-student dialogues. The analysis in that case addressed both form and content, on multiple analytical levels, using a range of analytical tools. All four articles make use of quantitative analysis methods to reveal patterns of classroom communication over the complete genetics teaching sequence. The following sections briefly describe the analyses presented in each article; more comprehensive descriptions are available in the articles themselves.

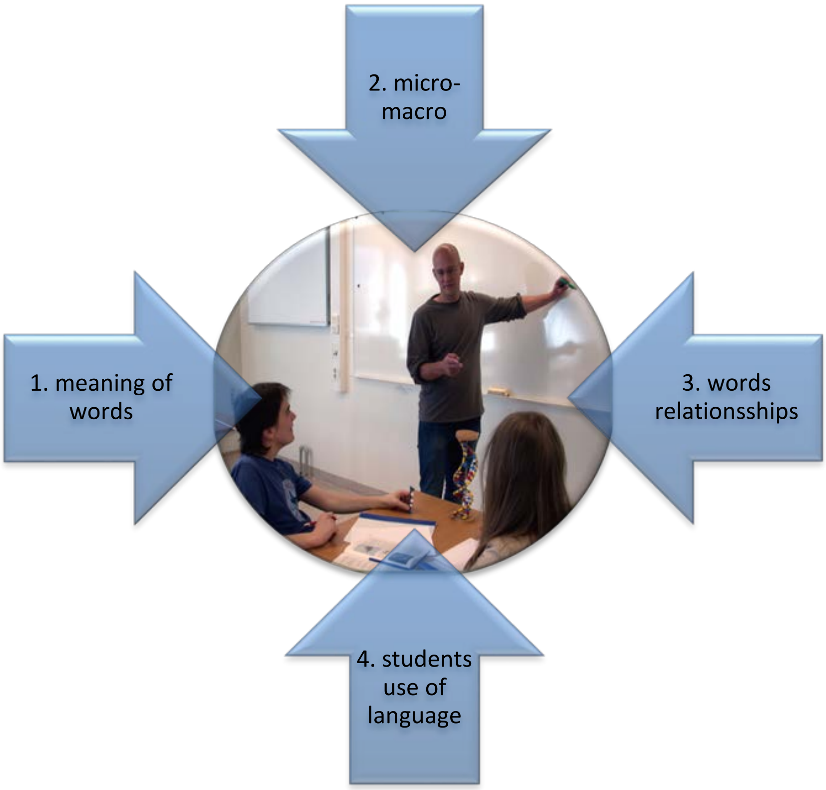

Figure 1. Four analytical 'lenses' were applied to the same corpus. The first article focused on how meanings of words were realized in the Mendelian context. The second examined the micro-macro-perspective, focusing particularly on the role of proteins. The third examined the semantic relations between words, while the final article analyzed the students' use of central words.

The first article focused on teachers' concept use while teaching Mendelian genetics. As such, this context was identified and selected by reading. All occasions on which the teachers used the words gene, allele, or anlag in this context were counted and qualitatively analyzed in terms of the total number of times each word was uttered, their relationships to adjacent words, how they were used, and what meaning they were given in context by identifying their positions in the thematic patterns. This made it possible to see how teachers defined the concepts and used them in context. All occasions on which gene and trait were interrelated in some way were further analyzed through the lens of thematic patterns to determine which meanings were realized concerning the gene-trait-relationship.

The second article dealt with the use of the word protein when communicating genetics. All occasions on which a teacher mentioned the word protein or talked about something categorized as a protein (e.g. and enzyme) were identified. These occasions were then compiled to describe the frequency with which proteins were discussed during the lesson sequence, the timing and distribution of their discussion, and to obtain general descriptions of the activities and content that the class was performing or working through when they were mentioned. To determine how the teachers talked about proteins, the roles ascribed to proteins, and the extent to which they were presented as links between genes and traits, the semantic relations between the word protein and the surrounding words were evaluated for each incidence of the word's use. This work provided the basis for a thematic pattern analysis that identified the main messages put forward by the different teachers concerning proteins and their possible roles as links between the micro and macro levels in genetics.

In the third article, which focused on gene, DNA and chromosome, all instances in which each teacher used these words were identified and counted. Further, all instances where the teacher interrelated these words were identified, counted, and qualitatively analyzed using semantic relation analysis to characterize the thematic pattern in which the teachers interrelated the words. In addition, the development of the thematic pattern over the teaching sequence was analyzed. The results for one teacher were described in detail as a case study, while those for the other three teachers were summarized. These analyses provided an overall picture of how the central concepts and their relationships were presented to the students over the full genetics teaching sequence.

The fourth article dealt with dialogue and its potential to support students in their efforts to learn the language of genetics. All instances where the teachers and students used the words gene, DNA, and chromosome in dialogue were identified. The frequency of the students' word use was compared to that for the teachers in order to determine how frequently the students used the words in classroom dialogues. In addition, the occasions on which the students used each word were categorized according to the nature of the activity in which they were used (teacher-centered or student-centered) and the dominant type of communication pattern. This was done using the framework for analyzing discursive interactions developed by Mortimer and Scott (2003). The utterances were also categorized from different theoretical communication perspectives relating to both form and content: question/answers, length, function, alignment with scientific consensus, and content focus. These analyses made it possible to characterize the communications in which the students used the genetics words.

The four studies of the thesis represents four analytical "lenses", as depicted in Figure 1, that together aim at from different perspectives attend to the overall aim to investigate linguistic aspects of teaching genetics, to contribute to the understanding of why genetics is so difficult to teach and learn.

Ethical considerations

The study was conducted according to the ethical guidelines of the Swedish Research Council (Vetenskapsrådet, 2011). All participants were informed both verbally and in writing about the study and that its focus was on classroom communication. Both teachers and students were told that the study might reveal both positive and negative issues relating to the teaching, and that the overall aim of the study was to find aspects of the teaching that could be improved in the future. Teachers, students, and the students' parents signed a consent form that provided information about the study, including information about their ability to withdraw their participation at will.

Although the participants were told that the study would examine classroom communication about the central genetic concepts, they were not given details about how this would be done. Moreover, the teachers were not informed about the exact words being analyzed because that may have affected their word use patterns. Since I wanted to study teaching under the most natural conditions possible given my presence at the back of the classroom recording the lessons, I decided that it was ethically acceptable to not tell the teachers which words I would be focusing on.

As it turned out, my studies revealed several problematic issues relating to the teaching of genetics. I therefore want to point out that the issues identified in the studies are merely symptomatic of a larger problem whose roots lie in the history of genetics, teaching materials, and the lack of focus on linguistic aspects in teacher education. I consider the participating teachers to have been very brave to have let me enter their classrooms and record every word they said over so many lessons. Being a teacher myself, I know that many things happen in every lesson, decisions must be made in seconds, and you never know what's going to happen next or what questions you will get as you deal with a group of teenagers who can suddenly transition without warning from being totally uninterested to completely fascinated (well, it happens occasionally) with the subject. Nevertheless, it is important for teachers to be informed about the problematic issues revealed in these studies because it will hopefully allow them to improve their teaching and make the subject more accessible and enjoyable for students. Moreover, it is also important to consider the ethical impact on students, their opportunities to learn and understand the subject, and the support they receive in their struggle to learn.

Trustworthiness

The two first articles in this thesis use the concepts of validity and reliability. However, these concepts were developed in the context of quantitative research and were originally related to statistical methods. In 1985, Lincoln and Guba presented guidelines more adopted to what they called naturalistic inquiry (or the post-positivistic paradigm). This framework has been widely used in qualitative research, but there is an ongoing debate about whether it is better to use the traditional terminology (validity, reliability and generalizability) or the terminology adapted for naturalistic or qualitative research (Noble & Smith, 2015). In this text, I chose to use the terminology from Lincoln and Guba

(1985) because I have come to believe it is more useful for explaining the methodological decisions made in support of the four articles. The general term used by Lincoln and Guba when discussing issues of validity and reliability is *trustworthiness*. Four issues must be considered to ensure trustworthiness: *credibility, transferability, dependability* and *confirmability*. Here, I discuss each of these issues in relation to the studies included in this thesis.

Credibility is comparable to internal validity, and is about “how to demonstrate truth value” (Lincoln & Guba, 1985, p. 296). There are different techniques for establishing credibility for results, of which we have applied *prolonged engagement, persistent observation, peer debriefing* and *members checks*. These are here outlined:

- *Prolonged engagement*. It is valuable to remain in the context where the data is collected for an extended period because doing so provides more opportunities to get to know the context, to really understand what is going on, and to thereby make reasonable interpretations of the data. Having worked as a teacher for 10 years in a similar school to those included in the study, I found it relatively easy to blend in during the observation period. I have taught genetics in grade nine several times, and I have also used many of the same teaching materials as the teachers in the study. I therefore found it easy to relate to and understand the context from the start. However, the long data collection period, which stretched over several weeks, naturally gave me the opportunity to become more familiar with these specific contexts, classrooms, and participants. In such cases, there is always a risk of “going native” (Lincoln & Guba, 1985, p. 304), or becoming so adopted to the studied culture as to affect one’s professionalism or objectivity. In my case, being a teacher meant I was already a “native” in some sense. Further, going from being a teacher to trying to develop as a researcher can be challenging (Labaree, 2003). However, bearing this challenge in mind and discussing the issue with others during the research process made me aware of these different roles, increasing the likelihood of retaining a suitably detached researcher’s perspective.

Another aspect of prolonged engagement is that some time may be needed to establish trust with the study's participants. The teachers in this study seemed to be a bit stressed about the recording devices at the beginning of the data collection period, but this effect decreased significantly after a few lessons. According to Robson (2002), there is a risk of *Hawthorne effect*, which means that individuals under observation will unintentionally change their behavior because they know they are observed, an effect that can decrease with prolonged engagement. Of course, being recorded while teaching with the knowledge that everything you say will be analyzed must be quite stressful and possibly make you want to perform better than you otherwise might. However, since the teachers were unaware of the exact focus of the study (which had not actually been firmly decided when the recordings were made), the likelihood of a severe Hawthorne effect is greatly reduced. My presence in the classroom and the recording of the lessons probably affected the students as well. However, it was the teacher and their teaching that were the main focus of the study and the recordings. To minimize the inconvenience to the students, I only videotaped the lectures using camera directed towards the front of the classroom where the teacher was standing during the lectures.

- *Persistent observation*. According to Lincoln and Guba (1985), persistent observation is important for the ability to identify and focus on relevant factors and to enhance depth of the study. They specifically highlight the risk of ending an observation too soon, before relevant themes have emerged. In this study, the complete genetics teaching sequence was observed, so the subject of interest was covered as comprehensively as possible. Having audio recordings of every observed lesson and video recordings of every lecture delivered by a teacher during those lessons made it possible to return to the raw data many times and repeatedly go back to the classroom situations, finding new aspects and themes of interest, which were carved out over a period of several years.

- *Peer debriefing*. Another way to increase the credibility of a study is to let a critical peer participate and ask questions about its content, focus, method, ethics, or any other potentially relevant factor. The aim is to get the researcher to think through the different steps and choices of their study, to reveal biases, to be perfectly clear about the standpoints and choices made, and to discuss possible new directions or revisions. These sessions can provide new input and ideas on how to take new steps in the research process. During my work on this thesis, I have presented my studies at different stages of the research process at several "check-point-seminars", where colleagues read my material before the session and then discussed issues arising from different angels during the seminars. These seminars have been valuable sources of input, from suggestions about small aspects of the analysis to more general issues about selecting the studies' directions.

- *Member checks*. Checking the results against the participants' views is an important way of enhancing credibility according to Lincoln and Guba. Therefore, the studies' results were presented to and discussed with one of the participating teachers, who found them consistent with his/her perception of the teaching situations and how he/she taught the subject.

Transferability is a concept replacing external validity in the naturalistic approach. Naturalistic studies such as those presented here will never be able to claim that their results are generalizable because of their context dependence. Therefore, transferability is best ensured by describing the methods and analytical process as deeply and transparently as possible so that others can judge for themselves whether the results are transferable to their context of interest. Transferability depends on the degree of similarities between the contexts, which is impossible for the researcher in the study obtaining the results to decide, as pointed out by Lincoln and Guba:

> It is, in summary, *not* the naturalist's task to provide an *index* of transferability, it *is* his or her responsibility to provide the *data base* that makes transferability judgements possible on the part of potential appliers.
>
> (Lincoln & Guba, 1985, p. 316)

The intention of this work was to ensure that the descriptions of the data analysis procedures and results were as detailed and thorough as possible (within reasonable limits) so as to enable others to judge whether the findings are acceptably transferable. Reassuringly, when presenting my work at conferences around the world and when talking to teachers with experience of teaching genetics, I have often been told that they recognize themselves in the material.

Dependability and confirmability are about showing that the study's results are consistent and grounded in the data, and would be interpreted similarly by another researcher, i.e. that the conclusions are not biased by the researchers' perceptions or opinions. To ensure this, one can seek an external audit. In the first article, a linguistics researcher experienced in SFL was engaged to scrutinize the data analysis process. We had sessions in which we discussed the complete research process, and this linguistic expert also read the whole manuscript and provided valuable input concerning the analysis of the data. In the second article, we used an alternative method in which an external researcher analyzed our data in parallel. In the third and fourth articles, no external researchers were involved analyzing the data, but the adequacy of the analysis was discussed with two independent researchers within science education research working from a language perspective.

Results

Main results of study I

The first article in this thesis focused on the context of Mendelian genetics, how teachers use the words gene, allele and anlag, and how they relate the word gene to trait.

The analysis revealed complex word use patterns that created different meanings for the words and their relationships. The Swedish (originally German) word anlag was sometimes explicitly defined as a synonym of gene, and was often used in a manner consistent with this synonymy. This was apparent because of the way the teachers related gene and anlag to other words and alternated between using the two words, for example by first saying “the dominant gene” and then shortly afterwards saying “the dominant anlag”. However, the word anlag was also used as a synonym for trait in some cases, as in the sentence *a gene controls the anlag*. This made the word’s meaning unclear.

The relationship between gene (or anlag) and trait was also complicated. The instances in which teachers semantically related genes to traits were divided into four categories. The first category included cases in which genes were described as controlling traits. In these cases, the gene was represented as an active entity that causes a trait, such as the genes determining eye color. The second category included cases in which genes were identified by traits. That is, the teachers used different traits to discriminate between different genes (i.e. alleles, although the word allele was never used). The third category included instances in which traits were ascribed to genes – for example, when a teacher used expressions such as “blue genes” or “brown genes”. The fourth category included occasions when teachers described traits as though they existed on the micro level, for example blue color on the chromosomes.

Main results of study II

The second study investigated teachers’ inclusion of proteins when teaching genetics, the roles ascribed to proteins, and the extent to which they were presented as intermediate links between organizational levels (i.e. between genes and traits).

The results showed that different teachers placed different emphases on the roles of proteins. All of the teachers noted that proteins are built constantly in the body, but some did not discuss the different functions that proteins perform in our bodies. Typically, only a few examples of proteins were given and the technical taxonomy of proteins was sometimes unclear (for example, it was not always clearly stated that enzymes are a class of proteins rather than separate entities at the same taxonomic level).

Two of the teachers used proteins as links between genes and traits, while two did not. Three of the four teachers explicitly described genes as instructions for protein synthesis. None of the teachers explicitly talked about genes as exclusively coding for proteins.

Main results of study III

The third study focused on how teachers used the words gene, DNA and chromosome in relation to each other. The word anlag was also included because it is commonly used in the Swedish context.

The results showed that the teachers used the words frequently during the teaching sequence, but only rarely established semantic relations between the words. For example, one teacher used the words DNA 196 times and chromosome 296 times, but related the two on only 8 occasions during the teaching sequence. In addition, an analysis of the semantic relations showed that the words were related in highly variable and often inconsistent ways. Typically, when relations were expressed, they linked only two of the words, separated by time and context. In addition, the expressed semantic relations were sometimes mutually inconsistent, resulting in confused meanings such as “On DNA we have genes” or “genes are built of DNA”.

The words were most commonly used without being related at all; while they were used together, they were rarely explicitly connected. Overall, these results indicate that students are not given effective support in understanding how these words are related, at least based on the way the teachers present the relations between them during classroom talk.

Main results of study IV

The fourth article concerned the students’ use of the genetic words gene, DNA and chromosome. The analysis revealed that the students used the words substantially less frequently than the teachers. The studied classrooms had different characteristics, but in all of them the students seemed free to talk and ask questions and were more or less encouraged to so during the lessons. However, when students did use the genetics words, it was in short sentences and at a basic level, mostly in short answers to teachers’ questions or in questions to the teacher intended to clarify the basic content of the lessons. Students used the words most commonly in teaching sessions dominated by the triadic communication pattern in which the teacher asks a question, the student answers, and the teacher responds with an evaluation. When students did use the words in a more advanced way, it was often in questions related to human genetics.

The overall conclusion is that students were given few opportunities to learn the language of genetics through dialogue with their teacher, indicating a need to develop strategies to support students in learning of the language of genetics in secondary biology education.

Discussion

The overall aim of this thesis was to investigate linguistic aspects of teaching genetics, to explore how teachers present genetics content, to determine what opportunities students have to learn the specific language of genetics, and to help explain why genetics is such a challenging topic to teach and learn. A corpus from four classrooms were analyzed from four different perspectives to get information about the teaching of genetics as it is undertaken in natural settings. The results showed that the language use in the classrooms was problematic in several respects. Specifically, the four analyses showed that 1) teachers used the words inconsistently, with varying meanings, 2) there were no clear connections between the micro and macro levels, 3) the words were inconsistently interrelated, and finally, 4) there was a lack of systematic teaching to help students appropriate the language of genetics.

Different meanings

The results presented in the first article show that the words gene and anlag are used with different meanings, that the definitions and uses of the concepts are sometimes inconsistent, and that the connection between gene and trait diverges from that of the gene as an active entity that causes the trait to the gene simply being the trait. Since previous research has shown that students have problems with the relationship between gene and trait (e.g. Lewis & Kattman, 2004; Marbach-Ad, 2001; Venville et al., 2005), this is problematic; the teaching practices observed in this work could actually *increase* the incidences of such mishaps.

However, this is not a problem limited to the participating teachers' way of presenting the subject matter; it is inherent to the context. Genetics has a long history as a scientific field. This is reflected in its inclusion on the school curriculum, which includes genetic topics ranging from Mendelian genetics to gene technology. Genetics terminology has a similarly long history and developments in this area have sometimes resulted in words with context dependent meanings as well as sliding definitions. This makes the language of genetics especially challenging to learn. Mendelian genetics is built on an old model of the gene-trait relation. At the same time, school biology textbooks were shown to incorporate elements of new molecular genetics knowledge into the older models that are incoherent because they lack important elements from different theoretical frameworks (Gericke & Hagberg, 2007, 2010a, 2010b). My classroom studies showed that teachers teach using these inconsistent hybrid models as well, which could cause learning difficulties.

Awareness is a crucial first step for making changes in the teaching of the content knowledge. Teachers might be aware of the differences between Mendelian and molecular genetics. However, an explicit focus on how language use can sometimes give rise to problematic and conflicting messages could deepen the understanding of this process and thus inform pedagogical discussions on identifying learning difficulties.

The second article clearly shows that the teachers did discuss proteins and their roles during the genetics course. However, they ascribed different roles to the proteins and some talked about coding for proteins as a parallel function, i.e. they described genes as coding for both traits and proteins - a learning problem identified among students by Duncan and Reiser (2007). Therefore, this aspect of the teachers' teaching does not seem to support the big ideas advocated by Duncan and colleagues (2009). However, one of the teachers used an explanation model that is more consistent with the big ideas by describing genes as coding for proteins and that proteins in their turn are contributing to traits. That might be an explanation that is functional at this educational level.

The literature about big ideas places a great emphasis on including the role of proteins in the teaching and being explicit about proteins being intermediate links between the genes and the traits. For example, in Boerwinkel et al. (2017, p. 1090):

> Part of the organism's DNA molecules contains genes. Genes are instructions for the cell to make proteins. These instructions are present in a genetic code that is almost universal in all life

and

> Proteins have a central role in the structure and function of all living organisms and form the main mechanisms that connect genes and traits

This is a very different model of the gene-trait relationship than that of Mendelian genetics because Mendelian genetics is concerned with other aspects of genetics, i.e. patterns of inheritance. However, as noted, these issues commonly become mixed in the classroom. So, if the first step for teachers is to be fully aware that different models were developed within different historical scientific frameworks and have bearing in different contexts, as well as how they are used and sometimes mixed, the second step is to figure out how to deal with how we talk about these different models when teaching. Ways of combining Mendelian genetics with mechanistic explanations have been suggested (Guilfoile, 1997). Another way of dealing with the issue is to use different models but be explicit about the fact that they are just models, with different explanatory ranges and that concepts can have different meanings in different contexts.

Flodin (2017) discuss how concepts with different functions in different disciplines could influence teaching, and argue that we should not focus on concepts as having one single stringent definition; instead, we should accept that a word's meaning can vary depend on the context. Flodin argues that this must be addressed within teaching, rather than presenting a static definition. That is, we might not need to present just one definition of gene, but to be explicit with the students that gene means different things in different contexts.

Whatever a teacher chooses to do, they must be aware of how small changes in the language use contribute to different meanings being realized in their talk.

Unclear thematic patterns

That small lexicogrammatical variations changed the meanings of the key words was made apparent by the third article, which focused on how teachers semantically related the words gene, DNA and chromosome. Relatively few semantic relations were made, but when the words were interrelated, it was done with considerable variation in the nature of those relations. As also shown in the other articles, small variations in the teachers' utterances created significant changes in realized meanings, giving rise to an inconsistent portrayal of the relationships between the words. According to the learning progression of Duncan et al. (2009), a big idea is about the hierarchical organization of the genetic information, where students should know that

> Genes are nucleotide sequences within the DNA molecule. DNA molecules make up chromosomes that make up our genome.
>
> (Duncan et al. 2009, p. 660)

It is known from literature that students find it difficult to keep track of the different relationships between these concepts (Lewis & Kattmann 2004). The teachers' inconsistent use of language meant that their talk did not provide strong support for students trying to grasp the connections between these concepts.

However, it should be noted that being entirely consistent in spoken language is very difficult. When we speak, we use different expressions and variations in how we talk about things. Sometimes we deliberately make simplifications or use everyday language because we want to make things easier; sometimes it is just a slip of the tongue; and sometimes it is to spare time or effort. For example, it might be perceived as tedious to always use an expression like "The gene variant that contributes to the white color". If we just want to tell students which allele we are talking about, it is much easier to say "the white gene". It has also been shown that too much emphasis on using accurate and precise language in the science classroom can have a suppressive effect on students' language use (Moje, 1995).

There is no clear-cut guidance on how to talk in every situation, but it is obvious that there are problems related to langue use that needs improvements. Based on the analysis in which I used Lemke's framework of thematic patterns (1990), I concluded that the inconsistencies revealed in the teachers' language use are likely to cause learning difficulties for students, who struggle to clearly see the network of words and how concepts interrelate. I think that it would be fruitful also for teachers to be informed about how variations in language use create inconsistencies in the conceptual meaning of words, and thematic patterns can be useful also for teachers as a teaching tool to make this variation explicit for students. One way to do this is by using concept maps to illustrate the thematic patterns. The use of concept maps has been reported fruitful both in research and teaching (Haskel-Ittah & Yarden, 2017; Novak, 2010), and in my view, this could also be a way to expose linguistic learning difficulties in genetics education.

Students' language use

The fourth article focused on the students' use of the central words gene, DNA and chromosome, and revealed a sparse use of these words by the students during genetic lessons. When students used the words, it was typically in single sentence answers to a teacher's question or questions to the teacher. In neither case was there any evidence of well-developed scientific language use.

The triadic pattern dominates many classrooms and has a strong tradition in education. However, several researchers have argued for more dialogic teaching (Alexander, 2008; Dysthe, 1996; Nystrand, 1997; Wells, 1999). According to Alexander's framework, dialogic teaching is characterized by being collective, reciprocal, supportive, cumulative and purposeful (Alexander, 2008). Thus, in a dialogic classroom, it is important to have a safe atmosphere where both students and teacher pay attention to each other's utterances and feel free to express their thoughts. As mentioned earlier, I found the atmosphere in all four studied classes to be very permissive; the students all seemed free to talk and ask questions. There was a fairly relaxed relationship between the teachers and students, and my impression was that the classrooms were a safe learning environment. However, the classroom talk did not seem to be structured according to any particular pedagogical strategy designed to help students learn the specific language of genetics as was recommended by Alexander (2008) and others. The teachers, however, appeared to want to engage the students in the dialogue, but they did not seem to have the tools, or the knowledge, to work in a way that would accomplish such an aim.

Alexander (2008) argue that it is just as important to focus on what the students say in the classroom as what the teachers says. When teachers ask questions, the students' answers should not be seen as endpoints but as something to consider closely. That is, it is not sufficient to respond with some routine judgment whether the answer was right or wrong; instead, continue the reasoning by building upon what the student said, or asking the student to elaborate on why they gave the answer they did. However, these kinds of dialogues were very scarce in the genetic classrooms I visited. The *didactical contract* (Brousseau & Warfield, 1999) could be an explanation of this, as discussed in paper 4, and of course, if a student gives the "right answer", the teacher might not see the point in asking further questions. Also, engaging in a longer dialogue with one student might convey the impression that others are excluded, so teachers often choose to ask different students to keep the whole class active. However, this practice resulted in a fragmented classroom dialogue because each student posed their own questions, going off on a tangent, and did not contribute to a deeper exploration of the genetic concepts.

Nystrand (1997) talks about two features relevant to this discussion: authentic questions and uptake. In addition, Dysthe (1996) emphasizes the importance of considering students' utterances, for example by asking authentic questions or by including the students' answers in further questions, taking the discussions in a direction that takes the students' ideas as starting points and considers them at a deeper level. Even though it is important to consider students ideas, Dysthe notes that the aim is not to have totally free and open discussions in every moment of teaching or for discussions to be allowed to go in any direction whatsoever as the students please. Teaching needs direction, meaning that there must be specific content to be learned. Therefore, implementing a teaching strategy based on a dialogic approach requires a structure. If teachers are to develop the skills needed to maintain a structure as well as use dialogue as a pedagogic tool, more focus should be put on students and their language development in a specific subject.

Implications

The four studies included in this thesis have helped identify some teaching problems that were not previously highlighted in genetics education research. Specifically, they showed that in some cases, the use of genetics language in the classroom can introduce difficulties into the learning process. The four studies all show, from different perspectives, that teaching genetics is a linguistic challenge. I believe this is a valuable contribution to the field of science education, but this knowledge will have to be developed into teaching strategies that help students to learn in a better way. My study can be a first step on this path towards better education on genetics.

Further studies will be needed to identify fruitful strategies for using the language of genetics in the classroom. One way forward may be to continue with design research, which has proven to be a powerful tool for developing educational designs and making theoretical contributions for solving educational problems (Easterday, Rees Lewis, & Gerber, 2016).

What should be taught in genetics education for all?

As discussed in the background section, considerable effort has been invested into striking a consensus about what constitutes the minimum level of genetics knowledge required to be a well-informed citizen (Boerwinkel et al., 2017; Duncan et al., 2009). In the absence of a universal consensus, the learning progressions discussed in this work can be useful guides for teaching practice and the selection of subject matter.

One issue that has been particularly controversial in science education research is whether Mendelian genetics should still be included in the curriculum. This was an important issue in my work because it has many implications for language use. It has been argued that too much focus is placed on Mendelian genetics and that this should be changed in favor of a more up-to-date curriculum with a greater emphasis on molecular genetics and its implications for society (Dougherty, Pleasants, Solow, Wong, & Zhang, 2011). My study revealed clear problems with the teaching of Mendelian genetics due to linguistic difficulties arising from the mixing of old and newer meanings of concepts such as gene and anlag. One must therefore ask whether Mendelian genetics has enough advantages to keep its place in contemporary science teaching.

Smith and Gericke (2015) argued in favor of keeping Mendelian genetics on the genetics curriculum. They argued that Mendelian genetics are an important part of our common history and culture, that Mendel was important in the development of genetics, and that to be considered educated, one must have at least a basic understanding of Mendel and his ideas. They see several pedagogical benefits of including Mendel in the teaching of genetics and identify several ways in which this can be done.

Smith and Gericke (2015) also argue for the pedagogical benefits of beginning with simple cases to establish a basis for understanding more complex issues. They suggest that Mendelian genetics can be used as a way of introducing genetics content, which can then be elaborated upon in a sequence of increasing complexity, gradually introducing other models that illustrate, problematize, and address the limitations of Mendelian inheritance. In contrast, Dougherty (2009) argued that starting with Mendelian genetics might make it more difficult to introduce a more adequate and complex model, and could cause students to see all traits in the light of Mendel's single gene-trait relationships. Moreover, Boerwinkel et al. (2017) conclude that Mendelian genetics can be misleading because it is based on a model of the gene-trait relationship that stands out as an exception rather than being representative of the rule. Acceptance of "one allele, one trait" can give rise to misleading claims in the media as exemplified by the phase "the gene for...”. Instead, they emphasize the importance of clearly communicating that the development of traits typically depends on many genes that all interact with different environmental factors.

In my studies I have shown that using varying language is linked to Mendelian and molecular genetics respectively, and from a Swedish perspective the word anlag is a very problematic word. I think it is important not to mix the terms in teaching the respective domain. For, example, the term anlag could be consistently used in Mendelian genetics, while the terms gene and protein could be used consistently in teaching molecular genetics. In this way the teacher could create two different and consistent thematic patters in the two contexts, which might facilitate students’ understanding.

Redfield (2012) described a university course on introductory genetics that was restructured to improve student learning outcomes, leading to a reflection about the need for a much more extensive and general revision of genetics teaching to better reflect modern genetics. The original course was structured along the lines of traditional genetics courses, with a sequence that mirrored the field’s historical genesis – starting with the principles of transmission genetics based on Mendelian genetics, while molecular genetics were dealt with later on in the course. According to Redfield, the students did not learn genetics at any deeper level. The course was therefore restructured, and now begins with a discussion of gene function before going on to discuss inheritance issues. However, this restructuring did not actually address the core of the problem according because it still fails to directly address aspects of genetics that bear on societally relevant issues such as questions about personal genomics and GMO. To better prepare students to deal with these societal issues, Redfield suggests a major break with tradition, for example by starting with personal genomics. Redfield argues for the importance of focusing on genetic variation and the structure and function of genes and chromosomes, and always including molecular explanations, avoiding the “black box” that is an unavoidable feature of Mendelian genetics. She also argues for excluding parts of the genetics curricula that are not compatible with knowledge needed in the modern society, such as Mendel’s laws and Punnett squares.

Even though both the teachers and at least some of the students in my study seemed to enjoy working with Mendelian genetics such as Punnet squares, I think it is more important to prioritize other areas given what is happening in today's society. For example, if arguments such as those put forward by Plomin and von Stumm (2018) become more prevalent in the near future, i.e. that we should IQ-test children to give them a customized education, we will need citizens with competences other than using a Punnet square to predict how many peas will be wrinkled. What we need as citizens is a basic knowledge about what genes are, how they function in relation to chromosomes and proteins, what DNA is, and what information a sample of their DNA contains.

The curriculum gave the Swedish teachers a lot of freedom to develop their teaching in accordance with their own interests and inclinations, as previously discussed. However, as several studies have shown, teachers have a strong tendency to rely on the textbooks when selecting content (Nelson, 2012). The practical consequence of this is that there are many similarities in teaching practices across different classrooms. This was also apparent in my study, since the teachers all had a similar focus on content selected from the textbooks. Sitting in the classroom and listening to the four teachers, I recognized the content and the sequencing from my own teaching experience in genetics as well as from biology textbooks I have come across in the area. The rather weak guidance from the curriculum could inadvertently encourage teachers to adopt traditional genetics teaching sequences and activities based on the structure of existing textbooks that emphasize Mendelian genetics first and foremost.

The function of proteins as intermediate links between genes and traits has been highlighted as an essential element in understanding how genes affect us, and as a concept that could help teachers and students to get away from the simplistic view of one gene one trait (Duncan & Reiser, 2007). Three of the four teachers in my study included a description of protein synthesis in their genetics teaching. However, the pedagogical benefit of doing this is somewhat unclear because the teachers did not clearly establish the gene-protein and protein-trait connections during these rather detailed lectures. Instead, the teachers sometimes talked about proteins as alternative products, implying that genes encode both traits and proteins.

In a recent study by Haskel-Ittah and Yarden (2017), they noted that students held this dual view of genes as being either connected to traits or to proteins. By introducing a teaching unit including a computerized learning environment with visual representations, Haskel-Ittah and Yarden were able to improve students' ability to insert proteins as a link between genes and traits. It was apparent that mechanistic understanding was a crucial factor in grasping the link and the understanding of *how* proteins affect traits. It would be of interest to investigate these mechanistic explanations from a linguistic perspective in the future to see if and in what ways these explanations contribute to students' understanding.

A longer debate about the inclusion of protein synthesis may be warranted, but my results also show that the use of proteins when explaining how genes affect traits needs to be considered further to fully exploit its pedagogical potential.

Teaching with a linguistic focus in science classrooms

As argued throughout this thesis, language plays a crucial role in education. Language is not to be seen as something we use to transfer knowledge; language is at the very core of learning and development (Bakhtin, 1981; Vygotsky, 1975). While this thesis focuses on genetics education, the wider issue of how language is used in science education is in my opinion relevant to science education more generally and possible to all school subjects.

There is a growing tendency to place more emphasis on linguistic aspects within teaching in the Swedish educational system. The curricula implemented in 2011 call for a greater focus on language than the preceding curricula, and highlight the importance of addressing linguistic issues. A commentary report (Skolverket, 2012) on the curriculum offers several recommendations for supporting students' development of language skills within specific subjects such as biology. For example, it is suggested that teachers could (author's own translation):

- Establish a linguistic perspective on teaching by consciously working with language and content in parallel when planning and implementing teaching activities.
- Use discussions and all teaching activities to give children and pupils opportunities to acquire more subject-specific language skills and insights that can be communicated in different ways in different contexts.
- Give children and pupils examples of subject-specific conversations showing what words, concepts and expressions are commonly used in the subject area, and provide examples of linguistic expression forms that are rarely used within the field.
- Consider what linguistic challenges the teaching presents the children and the pupils, and make sure to support them so that they can overcome these challenges.

(Skolverket, 2012, p. 5)

These recommendations are consistent with studies that have emphasized the role of language in science education (e.g. Lemke, 1990: Mortimer & Scott, 2003). Such approaches may be harder to implement for science teachers because such skills were not included in their own education.

In recent years, increasing amounts of guidance have been made available by the Swedish National Agency for education, in the form of in-service professional development based on educational modules, with texts, films and guides to be used by practicing teachers to develop their competences and as discussion material in teacher teams[4]. It is gratifying that the importance of linguistic competence is increasingly being recognized. However, science teacher training has no tradition of teaching about linguistic factors, so more effort will be needed to develop courses and strategies to prepare teachers and allow them to acquire linguistic competence as part of their pedagogical content knowledge.

[4] https://www.skolverket.se/kompetens-och-fortbildning

In my present role as a teacher educator, I meet many pre- and in-service students. When talking about genetics, I have noticed that many are concerned with the issue of students' practical *activities* in the classroom. Student teachers often ask for recommendations for suitable lab work rather than how to communicate and discuss subjects with their pupils. The view that practical work is important and pedagogically productive is embedded in these questions. However, as Wellington and Osborne (2001) argue, and as my study shows, this is not necessarily true. I would therefore prefer questions such as "how should we *talk* about genetics during lessons to be clear enough to not confuse the students?" or "how can I get the students to talk more during lessons?", or "how can I support the students in learning the language of genetics?". My hope is that this thesis will encourage more questions of this sort in the future.

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LINGUISTIC CHALLENGES IN SCIENCE EDUCATION

This thesis centers on linguistic aspects of genetics education. The aim is to contribute to the understanding of how teachers present genetics content in the classroom and what opportunities students have to learn to use the specific language of genetics. It may also provide insights into why genetics is such a challenging topic to teach and learn. The study is based on observations and recordings of genetics lessons in the final year of compulsory education. A corpus of 45 genetics lessons was analyzed with different analytical lenses to reveal how teachers and student use core concepts. Findings show that the teachers used genetics concepts with varying meanings and interrelated words in many different ways, which results in an ambivalent and inconsistent communication of genetics content in the classroom. The students use central genetics concepts to a much lesser degree than do the teachers and mainly in short sentences which indicates that the students are not given the opportunities to develop the language of genetics. The results show several aspects of classroom talk that might contribute to the learning difficulties that previously have been reported in the genetic education literature. These are important to consider in future efforts to improve genetics teaching.

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