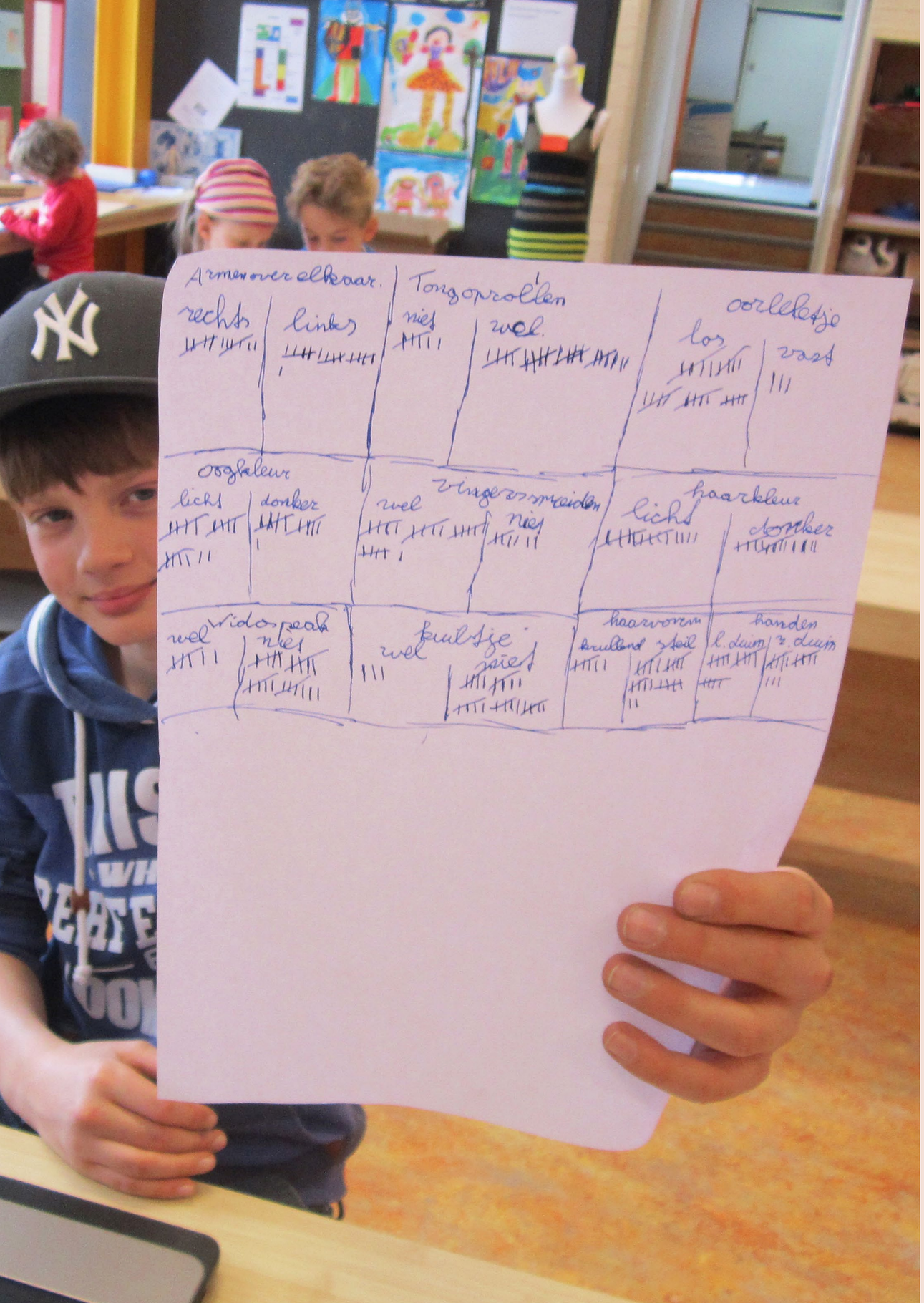


Chapter 3. DNA

This chapter describes the research theme 'DNA' in two sections. Section 3.1 'Sick due to new errors in your DNA' delves into the research from the Department of Human Genetics of the Radboudumc. Since DNA is not an everyday school subject in elementary school, it is wise to first acquire the basic knowledge about DNA. For this, subsection 3.1.1 is included titled 'DNA and heredity'.

In section 3.2 you will find a description of how the research is translated to students of the fifth and sixth grade. In this section, the activities that took place in the classroom have been described. Input was received from three schools. Subsection 3.2.1 describes how the students of the Montessorischool Nijmegen dealt with the project of the replicative behaviour of DNA and the possible mistakes that can arise. Subsection 3.2.2 addresses a similar project on the elementary school 't Holthuus. The students of 't Holthuus have broadly covered the topic of DNA and have been introduced to the phases of inquiry-based learning. Subsection 3.2.2 further describes how the students conducted their own research regarding the different sub-topics of DNA. Last, in subsection 3.2.3 the teachers from elementary school De Lanteerne describe the activities the students performed during the exploration phase and the research projects that were conducted in class.

Occasionally during this chapter, references are made to video material. These specific fragments of the DNA project are only available in Dutch. However, films with an explanation regarding each phase of inquiry-based learning are available in English and can be found on our website, www.wkru.nl/english.

Original publication in Dutch:
Peeters, M., Meijer, W., & Verhoeff, R. (red.) (2013). *Wetenschappelijke doorbraken de klas in! DNA, Gedrag en Infecties.* Nijmegen: Wetenschapsknooppunt Radboud Universiteit.

3.1 Research on DNA at the Radboudumc

‘Sick due to new errors in your DNA’

Joris Veltman (Associate Professor Genetics) and Han Brunner (Professor Human Genetics and Head of the department), Lisenka Vissers (Senior Researcher), Joep de Ligt (PhD student) and Diederik de Bruijn (Postdoctoral Researcher). All work at the Human Genetics department at the Radboudumc

Watch the film: 201. Lecture ‘Sick due to new errors in your DNA’ read by Joris Veltman at the Winter School, 1 February 2012. [only available in Dutch]

Intellectual disabilities and errors in the DNA: Where is the problem?

Many things in life arrive unexpectedly. This holds true in genetics where hereditary afflictions sporadically develop in a family without a clear reason. The word ‘genetics’ is derived from the Ancient Greek word genesis (γενετικός) which means ‘origin’. The basic principles of genetics describe how organisms, such as humans, transmit characteristics to their offspring through gametes (sperm and egg cells). Besides normal properties such as eye colour and hair colour, hereditary diseases can also be transmitted from generation to generation.
These characteristics are embedded in the genetic material which is housed in the nucleus of all cells: the DNA. A piece of DNA that codes for a specific characteristic is referred to as a gene. A single DNA abnormality in such a gene can induce a genetic or hereditary disorder. Examples of genetic disorders that can be caused by a change (mutation) in a single gene are Huntington’s disease, cystic fibrosis and breast cancer.

An error (mutation) in just one gene can thus be responsible for the development of a respective disorder. Errors in the DNA can arise during cell replication when all 6 billion building blocks of our DNA must be copied. During this process, errors can occur when occasionally an incorrect building block is read and copied. When such spontaneous replication errors occur during the formation of sperm or egg cells, these errors are transmitted to the offspring and can be further passed on from generation to generation. These DNA errors do not always have to be already present in the DNA of the parents. They can also generate during the replication of DNA in sperm and egg cells. In science this is referred to as de novo mutation. A newly generated mutation is a possible explanation for the development of hereditary afflictions among children of parents who do not suffer from this condition. A good example of this is Down syndrome which develops as a result of an extra copy of chromosome 21 (see knowledge frame DNA and heredity for an explanation of the term chromosome) in the DNA of the child, a very special form of a DNA error. We already knew that new DNA errors were the cause of several rare syndromes, such as DiGeorge syndrome, Angelman syndrome and Miller-Dieker syndrome, whereby intellectual disability plays an important role. The question here though is whether these errors also play an important role in the most common forms of intellectual disability which have not been diagnosed as a known syndrome.

Research question. *Do new errors in the DNA play a role in the development of intellectual disability?*

As researchers in Nijmegen we thought that new DNA errors could be an important cause for intellectual disabilities that often occur in the population in families whereby the parents had a normal IQ. We thought that a DNA error would elaborate this common affliction, because our brains are so intricately put together that many, possibly 1000, genes have to work in perfect collaboration in order to develop a normal intellect. A new error in one of these genes could already be enough to induce an intellectual disability. The probability for this to occur is rather large considering that many DNA errors occur with each cell replication.

Our hypothesis, that new DNA errors are an important cause of intellectual disability, would imply that someone with such a disorder is not only the first one in the family, but also the only one. This is because people with severe intellectual disability usually do not bear children. It is a real coincidence which often leaves the parents of children with an intellectual disability with many questions. Many parents often wander around for years with the question why their child has a specific disorder, what the exact diagnosis is, the prognosis, the life expectancy and the recurrence risk for the future. Our lack of knowledge about the causes of intellectual disabilities leads to less adequate explanations for parents and less insight in possible treatments. Once a genetic cause has been identified, many questions can then be answered.

Professor Han Brunner

Han Brunner studied medicine in Groningen and then specialized in Clinical Genetics in Nijmegen. Han has weekly consultancy hours for questions regarding heredity. Occasionally special cases arise which leads to scientific research. In the recent years, he has conducted research on the genetic causes of all kinds of diseases and problems such as behavioural problems, skeletal abnormalities, congenital defects and brain development. Since 1998 he has been the head of the Genetics department at the Radboudumc.

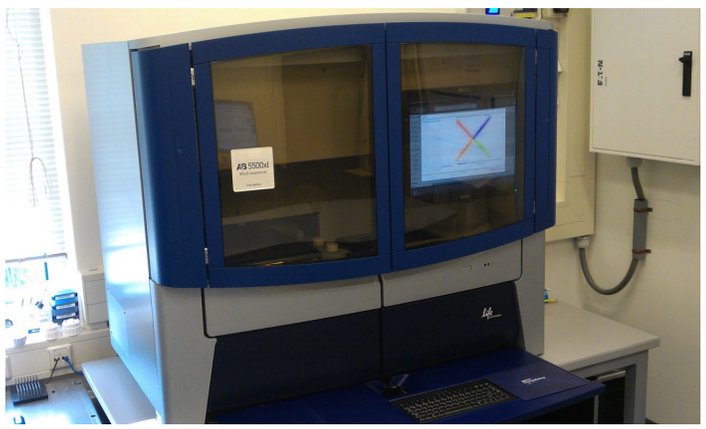
Associate Professor Joris Veltman

Joris Veltman is a genetics researcher employed as an associate professor at the Department of Human Genetics at the Radboudumc. Prior to his arrival in Nijmegen, he studied Molecular Sciences in Wageningen, was promoted on the basis of his research in genetics of head and neck cancer in Maastricht and worked as a postdoc with new DNA techniques at the University of California in San Francisco. He is fascinated by the enormous force with which new DNA methods enable us to better and more rapidly understand what is happening to many people with hereditary diseases. He is also convinced that we are only at the beginning of the genetic revolution in the hospital; in about twenty years your medicine usage will be better tailored to your unique genetic profile.85

Finding new DNA error within our collection of 24,000 genes was until recently practically impossible. Traditionally, medical genetics focused primarily on locating DNA errors in large families in which many members were affected. Through detailed family research, the affected family members were screened for a common genetic denominator. Doing so permitted for the selection of possible genes, out of the 24,000 genes, that bore a mutation. However, in the case of patients with intellectual disabilities, the lack of large families makes this practice for selection impossible. As a result, you would have to screen all 24,000 genes in patients with intellectual disabilities. That was a nice idea, but until recently it was not possible to screen more than a few simultaneously. Not only would it take years before the screening for a patient was completed, but it would also be incredibly expensive. Furthermore, it would be questionable whether you would even find the mutation. Fortunately a new technique became available in 2009 which allowed for the systematic testing of 'new DNA errors' hypothesis in patients with intellectual disabilities; one test that can screen all 24,000 genes of a patient with an intellectual disability for mutations.

All genes in one test: On the search for new DNA errors

In the past years much research has been conducted in Nijmegen into the genetic causes of intellectual disabilities that affect only one child within a family. We focus on research into new DNA errors that occur prior to fertilization, during the production of sperm and egg cells. We, therefore, have to use a technique that was capable of scanning all 24,000 genes simultaneously to find a specific mutation. In addition, besides scanning the affected child, the parents also have to be scanned in order to distinguish between the large amount of hereditary variation in the DNA and the new DNA errors (mutations) that could be responsible for the intellectual disability. Only when the DNA information of the parents is available, is it possible to identify new DNA mutations in the child. This only became possible in 2009 once we acquired the apparatus capable of analysing the entire genome simultaneously. This new technology, referred to as 'genome sequencing', provides the information about all mutations in the entire genome of a person. Prior to this, series of separate gene tests had to be performed, but now in the present day, one test is sufficient.

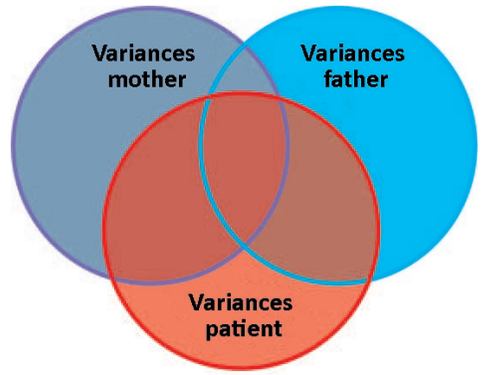


Genome sequencer. This machine scans the entire genome for variations accurately, quickly and at an affordable cost.

We first learned in the laboratory how well genome sequencing techniques could be applied and how the massive amounts of data produced per person are to be interpreted in a good way. For this purpose, the doctors, who clinically examine the children and parents, work in close collaboration with biologists in the laboratory and with bioinformaticians (computer experts) who conduct the analyses on the retrieved data. The doctor draws blood from the parents and child and from this, the DNA is isolated. The DNA is subsequently processed in the laboratory until only the genes remain. The exact DNA order of all these genes is read by the 'genome sequencer'. The 'genome sequencer' produces data files based on the read DNA and these files are then assembled by bioinformaticians. Through the computer we can ultimately decide whether new mutations have arisen in the DNA of the child in comparison to that of the parents.

And do you actually discover spontaneous mutations? Results of our first studies

In a small pilot study in 2010, the genes of 10 children with intellectual disabilities and their healthy parents were mapped in this way. We discovered 9 new mutations in total in 7 of the 10 children. However, mutations are not necessarily the cause of intellectual disability. Even in healthy children, new mutations can arise which is an inherent possibility during the process of DNA replication. It was thus important to look at the locations in the DNA where these mutations occurred. Could it be that they had detrimental effects because they were located in genes involved in brain development? We could look this up because for most genes, it is approximately known in which organs they play a role. And indeed, the DNA of 3 of the 10 children included new mutations in genes which are known to be involved in intellectual disabilities. Aside from that, we also found in 4 patients new mutations in genes that also play an important role in brain development, but which were not known to be associated with intellectual disability. This small study illustrated the significance of new mutations in the development of intellectual disabilities. In addition, it was also the first study whereby all the genes of 10 child-father-mother trios were compared. Since then, we have repeated this research on a larger scale, now with 100 child-parent trios. Once more, it was shown that new mutations are an important cause for intellectual disability in a large portion of these children. Supported by these results, we offer this form of 'genome sequencing' from 2012 onwards as a diagnostic tool to families with a child suffering from an intellectual disability.



Overlay in the variances in the genome of the father, the mother and the child.

What can we do with these results?

The results offer good news for parents with an intellectually disabled child who wish to determine the cause and know how large the probability is for a repeated case in the eventuality of having another child. In more than half of the cases, we were not capable of providing an answer, but with this new approach, 30 to 40 percent of the still unknown causes can be clarified. A giant leap for progress! Additionally we know that the chance for a repeat incident is hardly greater than for the average population. For many parents this is a reassuring message which plays an important role in the decision of attempting for an additional child. Also, the improved diagnosis can have significant results for the care of these patients. If it is known that an intellectual disability is caused by a genetic defect, an excessive and potentially burdening, medical examination can be avoided. A clear genetic diagnosis may also help parents find fellow sufferers and offer them the opportunity to join patient organizations. These patient organizations can help by providing information regarding life expectancy and development prognosis. Unfortunately, it is not within our capabilities yet to offer customized treatments for many patients. Although the genetic understanding of the origins of the disease offers new clues for research into treatment options, it is also clear that intellectual disability is a very complex disorder that will remain difficult to cure. For genetic research this does imply a small revolution. Until now, intellectual disabilities were always believed to be the result of changes in multiple genes. The assumption was that it could involve thousands of genes within the population. However, now we see that it is often only one gene with a mutation that results in a specific disability. By studying all the genes of the parents and the patient, locating the mutated gene can be achieved quickly, because there is only one factor, one error that is the cause of it all. This provides an entirely new perspective on disease, diagnostics, therapy and prevention.

What now? Do new DNA errors play a role in other diseases?

The research also showed that new mutations do not occur very often. That is fortunate, because otherwise we would have plenty of diseases and problem that we would prefer to prevent. Nevertheless new errors in the DNA arise and regularly cause diseases. It is estimated that in every newborn an average roughly 100 new DNA mutations can be found of which only one really affects a gene. Almost everyone has a new mutation in their genes and that does not necessarily have to lead to a disease or problem. Only a small portion of these types of mutations damages a gene that is important for the functioning of the brain. While little is known about the origins of these new DNA errors, it seems that they are more common during the development of sperm than egg cells. It also seems that the age of the father has influence on the number of new mutations per sperm cell. Both these observations are in line with the fact that sperm cells have to be continuously restocked (which requires continuous DNA replication) and that as men age, the process becomes more susceptible to errors. Furthermore, we know very little about the role of new mutations in other diseases. Recently, comparable research into new mutations was conducted with children with autism and schizophrenia. Here too, new mutations seem to play a role, but for now, it seems as if these are less significant than in severe forms of intellectual disability.

Geneticists from Nijmegen present a new paradigm for research[1]

Spontaneous mutations important cause for intellectual disability

Date message: 15 November 2010

Many intellectual handicaps are caused by a spontaneous mutation in the sperm or egg cell of the parents. With that in mind, researchers from Nijmegen are not only solving a paradox, but are causing a minor revolution in the world of genetics. They describe their research in the article 'A de novo paradigm for mental retardation' in the science journal Nature Genetics.

Two percent of the Dutch population has an intellectual disability. Diverse causes for intellectual handicaps have been found, but together they don't even explain half of the reported cases. What is the 'missing link'? What is the unknown cause of most intellectual handicaps?
Under the leadership of Joris Veltman and Han Brunner, researchers from the Radboudumc show in an article in Nature Genetics that new (de novo) mutations explain a large portion of handicaps. These intellectual handicaps are thus not passed down from generation to generation, but arise from spontaneous genetic changes in the sperm or egg cell of the parents. The child receives an error in a gene which is intact in both parents.

Genetic difference between parents and child

The researchers mapped all 20,000 genes of ten children with an intellectual handicap. The same thing was conducted for their respective parents. By comparing the results with each other, it is possible to see whether and where changes have occurred between the genes of the parents and the genes of the child.
In nine of the ten children, the researchers found a difference in a different gene each time. In three children the gene was not involved in the disability, but in the remaining six children, they found two genes that are for certain to be involved and four genes which are suspected to be involved in intellectual handicaps. Geneticist Joris Veltman: "The intellectual handicap in six of the ten children arises as a result of a new mutation, a de novo mutation. That is more than half of the, so far, unexplained intellectual handicaps!"

Paradox solved!

In the field of genetics, intellectual handicaps form an intriguing paradox. People with an intellectual handicap rarely or never have children; they don't pass their handicap on to the next generation. With that said, the percentage of intellectually handicapped people in the population remains at roughly two percent. How is this possible? Where do the intellectual handicaps then come from? A satisfying answer was not available. Veltman and Brunner now offer a surprising solution for this paradox. Many intellectual handicaps arise by coincidence; through new mutations in the hereditary material of children. Possibly 1000 of our 20,000 genes play an important role in the development of our brain and brain functions. Mutations in these genes could lead to intellectual handicap.

More confidence

Parents that have an intellectually handicapped child want to know the cause of it and the chance of a repeat incident. Clinical geneticist Han Brunner: 'In more than half of the cases, we were not capable of giving an answer, because we did not know the cause. With this approach, roughly 60% of the still unknown causes can be clarified. This is an enormous leap forward. On top of that, we know that an intellectual handicap that develops from a new mutation has roughly the same probability for a repeat incident as the average population. For many parents, this is a reassuring message that can influence the decision for a next child.

Small revolution

During the replication and transmission of the parent's genes to the child, one new mutation occurs on average. Since roughly 1000 of the 20,000 genes (1 in 20) play a role in intellectual disabilities, the probability of acquiring an intellectual handicap as a result of a new mutation is fairly large. This also applies to other conditions, such as schizophrenia and autism, in which many genes are involved. These mutations can also play an important role here.
For genetic research, this implies a small revolution, a paradigm shift. Veltman: "Until now, intellectual disabilities were studied with the idea that their occurrence was related to multiple genes that collectively caused the disorder. This is referred to as complex genetics. In the entire population, intellectual handicaps do indeed involve thousands of genes. However, now it turns out that per individual, only one gene underlies the disorder. The newly mutated gene can be located quickly by screening the genomes of the parents and patient, because there is only one factor, one change that underlies it. This provides an entirely new perspective to approaching diseases, diagnostics, therapy and prevention."

Next Generation Sequencing

The researchers were not capable of performing this researcher in the past, because the necessary apparatus was not available at the time. Brunner: "Earlier this year, the Department of Human Genetics purchased the most modern sequencer available. This device now reads all 20,000 genes in one shot instead of one gene at a time. This enormous acceleration has brought upon a revolution in the fields of genetics and is referred to as 'Next Generation Sequencing'. Screening of personal genomes is now practically viable in terms of finance and time. This research is a good example of this.

Reference

(1) Radboud Universiteit, Spontane mutaties belangrijke oorzaak van verstandelijke handicap, http://www.ru.nl/%40790494/spontane-mutaties/ (21-11-2012).

3.1.1 DNA and heredity

Returning to the basics...

DNA is nearly everywhere: in television series in police investigations, in a newspaper article about genetic modification of plants. But what is it exactly? In this section, we will briefly explain the basics.

Every living being (organism) contains DNA. All animals, ranging from the smallest of insects to the large whales, and even plants, possess this genetic material. Encrypted in the DNA lies the hereditary information of the organism. Putting it into perspective, you could consider it as a type of 'recipe' that determines how an organism is constituted. DNA determines why a particular person has green or blue eyes and why a cat might have brown-white spotted or black fur.

For simplicity sake, we will continue with our discussion of DNA with the focus on humans.

Where is the DNA housed exactly?

A human is composed of many parts: arms, legs, head, hands, finger et cetera. To get to the DNA, we need to zoom in on the body to arrive at the organs. These organs are made up of different tissues, which, in turn, are made up of cells. Cells are the smallest units of our body. Inside the cell is a small compartment, known as the nucleus, and herein lies the DNA. In every cell of your body, a complete copy of all your DNA, called the genome, is housed within the nucleus. Each cell nucleus thus contains all the genetic information which is necessary to develop, maintain and propagate an individual.

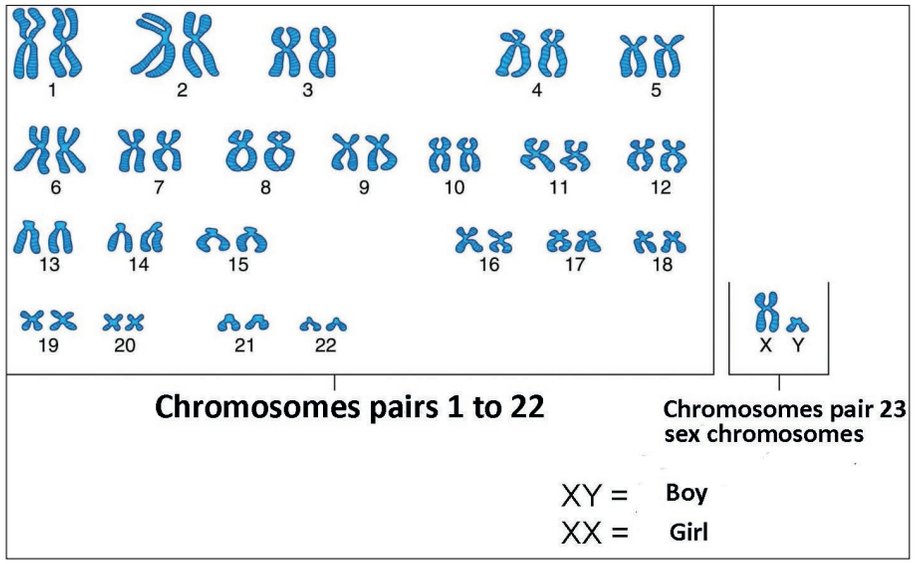


Illustration of the chromosomes of a human. In a cell, the chromosomes are not as tidily organized as in the image and are only rolled up this way when a cell divides.

Chromosomes

In every nucleus of each cell is thus an entire copy of your genome. The genome is subdivided into 46 chromosomes. This is a structure in which the DNA is packed. Every chromosome consists of DNA-chain of millions of building blocks (ATCG). Each chromosome comes as a pair and therefore, there are 23 pairs in total. A chromosome pair consists of a chromosome obtained from the father and a chromosome obtained from the mother. That is the reason why you have two copies of each chromosome. An exception to this rule is the 23rd chromosome pair in males. The 23rd chromosome pair are known as the sex chromosomes. In males, this pair consists of an X and a Y chromosome, while females possess two X chromosomes.

What is the structure of DNA?

DNA is an abbreviation for deoxyribonucleic acid. A DNA molecule consists of two long strands that are intertwined and fit each other exactly. This shape is referred to as a double helix.

A DNA strand is composed of four building blocks (referred to as nucleotides) which are attached in sequence to a scaffold. The four building blocks or bases are adenine (A), thymine (T), cytosine (C) and guanine (G). The two DNA strands are akin to a zipper in the way they are connected, whereby A is always paired with T which lies opposite of it, and C with G. Essentially, a human consists of 46 DNA strands in total that are folded into the shape of chromosomes.

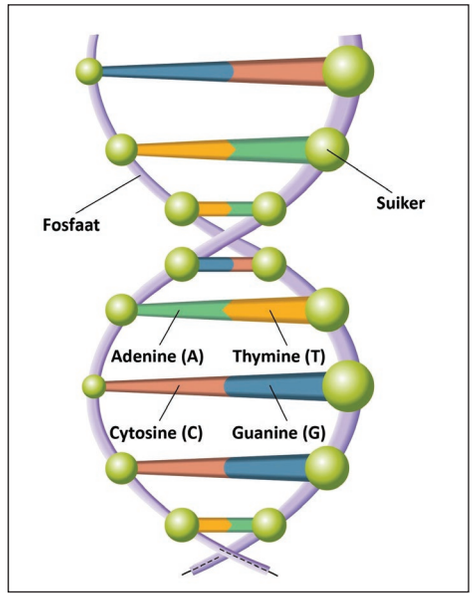
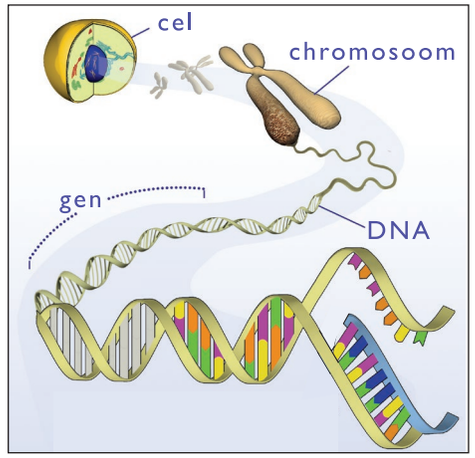


Illustration of the structure of DNA.

Genes

Everyone knows the familiar expression: "Its all in the genes". But what exactly are genes? Segments of DNA in the chromosomes contain the code for the building blocks of the cells and hence our body. These segments that contain a specific code are called genes. How does the code of DNA work exactly? The sequence of the bases of DNA (ATCG) constitute the code which bears the blueprint for creating the building materials (proteins). Segments of DNA that form one code for one particular protein are referred to as genes. Each gene thus contains the information to produce one of the many building materials of which are bodies are made up of. Proteins are essential for every cell. They ensure the sturdiness of a cell, determine whether a cell becomes a nerve cell, muscle cell, hair cell or if it receives a different function. Through these proteins, the genes determine what will ultimately be our hereditary characteristics such as the colour of our hair or our eyes.



How do you inherit DNA from your parents?

A father and a mother both contain 23 chromosome pairs in their cell nuclei. In a hypothetical situation where both parents would transmit 23 chromosome pairs, the offspring would receive 2 x 46 = 92 chromosomes. This would not work which is why prior to reproduction something special occurs. During the formation of gametes (sperm and egg cells), certain checks during the process ensure that not the entire genome of the father or mother is copied, but that only half of the chromosome pairs (23 chromosomes) are deposited in the nucleus of the gamete. In the gamete there will therefore only be one chromosome of each chromosome pair.

To conceive a child, the egg cell from the mother and the sperm of the father must fuse together. Because the egg cell and sperm contain each 23 chromosomes, upon fusion the child will have 23 chromosome pairs (46 chromosomes). During the formation of the gametes, the chromosome pairs must be split up into their separate chromosomes. This process occurs differently each time which results in the combination of chromosomes in each gamete to be different. In this way, parents actually transmit a different combination of chromosomes each time which explains why children of the same parents can inherit different characteristics. After all, they end up receiving a unique combination of chromosomes.

After the sperm and egg of the parents have fused in the mother's uterus, the cell will divide. Each time the cell divides, the entire genome is replicated. In this way, each cell will contain the same information.

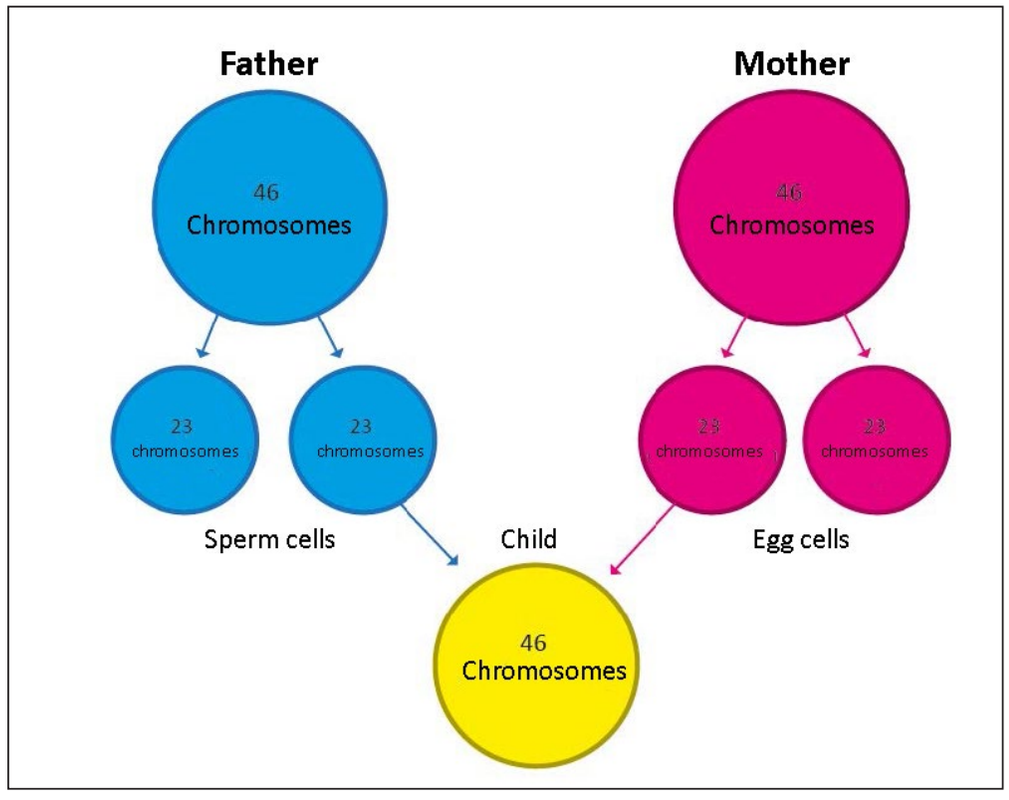


Illustration about the transmission of chromosomes from parents to child

DNA errors and diseases

Every cell in our body is the result of replication of the original cell which is derived from the fusion of the parental gametes. At birth, the cell and its DNA have been numerously and repeatedly copied considering that a baby consists of millions and millions of cells. It is not difficult to imagine that a DNA error can occur. Such an error is referred to as a mutation. Usually they errors are quickly repaired by the cell itself. Also, not every error or mutation necessarily results in a problem. Without changes or variability in the DNA, there would be no diversity among humans and animals.

However sometimes an error can have detrimental consequences, for example, if it involves a gene that codes for the information necessary to develop brain cells. Han Brunner and Joris Veltman showed in their research that just one mutation (incorrect base placement, for example an A instead of a C) in a gene can lead to disease.

Reading the right genes per cell type or organ is an extremely complex process which we only partially understand. For the correct functioning of brain cells, it is important that 'brain genes' do not contain any severe errors (mutations).

3.2 Project 'Unique due to new errors in your DNA' in the classroom!

In this section, three projects will be addressed whereby the research from Han Brunner and Joris Veltman has been translated into research activities for in the classroom. The research titled 'Sick due to new errors in your DNA' has been changed to the project title 'Unique due to new errors in your DNA'. This title emphasises the idea of uniqueness more and calls for a more positive association than the word 'sick'. This section is divided in three parts.

First, subsection 2.2.1 describes how the students of the Montessorischool Nijmegen dealt with the project of the replicative behaviour of DNA and the possible mistakes that can arise. Although the children did not perform their own research regarding DNA, this project might inspire teachers who wish to perform a more defined and short-term project about DNA.

Subsection 2.2.2 describes the comprehensive project conducted at the elementary school 't Holthuus. In this project, the children learned about DNA and the errors that can occur. Subsequently, the children designed and conducted the research themselves.

As last, subsection 2.2.3 addresses a similar project conducted at the elementary school De Lanteerne. The teachers of De Lanteerne describe the additional activities they performed and which research the children conducted regarding the theme of DNA.

3.2.1 Project 'Working with replication errors of DNA' on the elementary school Montessori Nijmegen

Angelique Driessen (pre-service teacher at the HAN)

Overview DNA project in grade 7/8 of elementary school Montessori Nijmegen

As a student in the final stage of my study, I received a proposal from the pre-service education Nijmegen to participate in a project from the Science Education Hub within my minor. Wow! To me, this was something completely new which seemed really interesting! For my internship, I worked with grade 5 and 6 at the Montessori elementary school Nijmegen. Although the principle of inquiry-based and design-based learning aligned nicely with Montessori's philosophy (help me to do it myself) there was little experience with this pedagogy. During my internship, I received the space and freedom to carry out this project, which was very interesting and challenging for both myself and the children! When I started reading more about the subject, I saw many opportunities to develop lessons using these experiences for my internship. I set different goals for my own personal development and for the development of the children with whom I worked during my internship.

Goals

- The children get acquainted with 'science'.
- The children develop an inquisitive attitude.
- The children learn the skills of inquiry-based learning.
- The children get acquainted with 'DNA'.
- The children are challenged to think more deeply about various (scientific) topics.

Core objectives of the Dutch curriculum

Core objectives of the Dutch curriculum that were addressed during this project:

Oral language education

1. The students learn to acquire information from spoken language. They also learn to structurally present that information, either orally or in writing.
8. The students learn to structure information and opinions when writing a letter, report, a form or a paper They should pay attention to sentence structure, correct spelling, a legible handwriting, layout, and possibly visual elements and colour.
9. The students develop a sense of enjoyment in reading and writing stories, poems and informative texts intended for them.

Mathematical understanding and application

26. The students learn to broadly understand the structure and connection of numbers, integers, decimal numbers, fractions, percentages and ratios, and to use these in practical situations.

Orientation on the world and yourself

41. The students learn about the build of plants, animals and humans, and about the form and function of their parts.
42. The students learn to conduct research about materials and physical phenomenon such as light, sound, electricity, force, magnetism and temperature.

Project layout and time investment

To make an abstract concept like DNA understandable for children on elementary school, I divided the lessons on the different phases of inquiry-based learning over three parts.

Phase 1 and 2. Introduction on DNA. We start with an investigation on heredity. Through group discussions and explanations using a PowerPoint presentation, the children learn about the topic DNA. The following components are covered:

- Introduction game and worksheet;
- Theory on DNA by means of a PowerPoint presentation;
- Making your own DNA;
- Replicating DNA.

Phases 3 to 6. As a result of replication errors, variations in the DNA arise which can lead to new talents, different characteristics and diseases. Through research, the children optimise the replication process. To do this, they use their handcrafted DNA strands.

Phase 7. The children go on an excursion to the Department of Genetics of the Radboudumc. The children then write a report or story on the theme of DNA or science. When writing, all the steps of the writing process are followed.

Phase 1. Introduction theme 'DNA'

Everyone is unique

Introduction game 'Everyone is unique'

After the break, the children cheerfully return to the classroom. "You can all go back outside again! Everyone, go stand at the centre of the football field." Confusion and amazement everywhere! "Ha nice, going outside again, but why?" I am standing on a chair on the side-line of the football field (so that I have a better overview). "All girls go stand at the left goal." Everyone is having fun and the two groups aggregate to form small clumps. The children are still unaware of what is going on, but are eagerly awaiting the following assignment. "Everyone who is right-handed, take 5 steps backwards."

The goal of this game is to provide several assignments until no groups remain; everyone will stand alone and will therefore be unique. That is the basis with which we will proceed: 'Everyone is unique'. The children find it exciting and monitor each other closely. After the third assignment (can you roll your tongue?), we already isolated two 'unique children'. I announce aloud: "Hey, here are two children alone". We proceed and the children begin to understand what the activity is about. As we come down to the last pair, the assignments get more exciting. Eventually they too will be separated, because they twist their hands differently. Ultimately it required nine questions in order to make a group of 31 students unique.

The children received questions until everyone stood in a separate area. To do this, it required nine questions, but of course, this differs per group. I kept the pace of the game by asking the questions in reasonably quick successions. In between I took a moment to observe what was happening to the group (the groups diminished in size and there were already 10 children entirely alone!).
Doing so ensured that the children remained involved with the game. At the end, I asked the group: "Who is not standing alone? Nobody? I asked nine questions and nobody seems to have the same combination of characteristics! I think that is extraordinary! We will discuss this further in class."

Group discussions about introduction game 'Everyone is unique'
Back in the classroom, the children were still rolling their tongue, and the different ear lobes and eye colours were being examined. During a brief group discussion, we directed the discussion to the subjects of heredity and DNA. We discussed this briefly and then proceeded to begin working on the worksheet 'Who do you resemble the most?'.

Assignment. 'Everyone is unique'

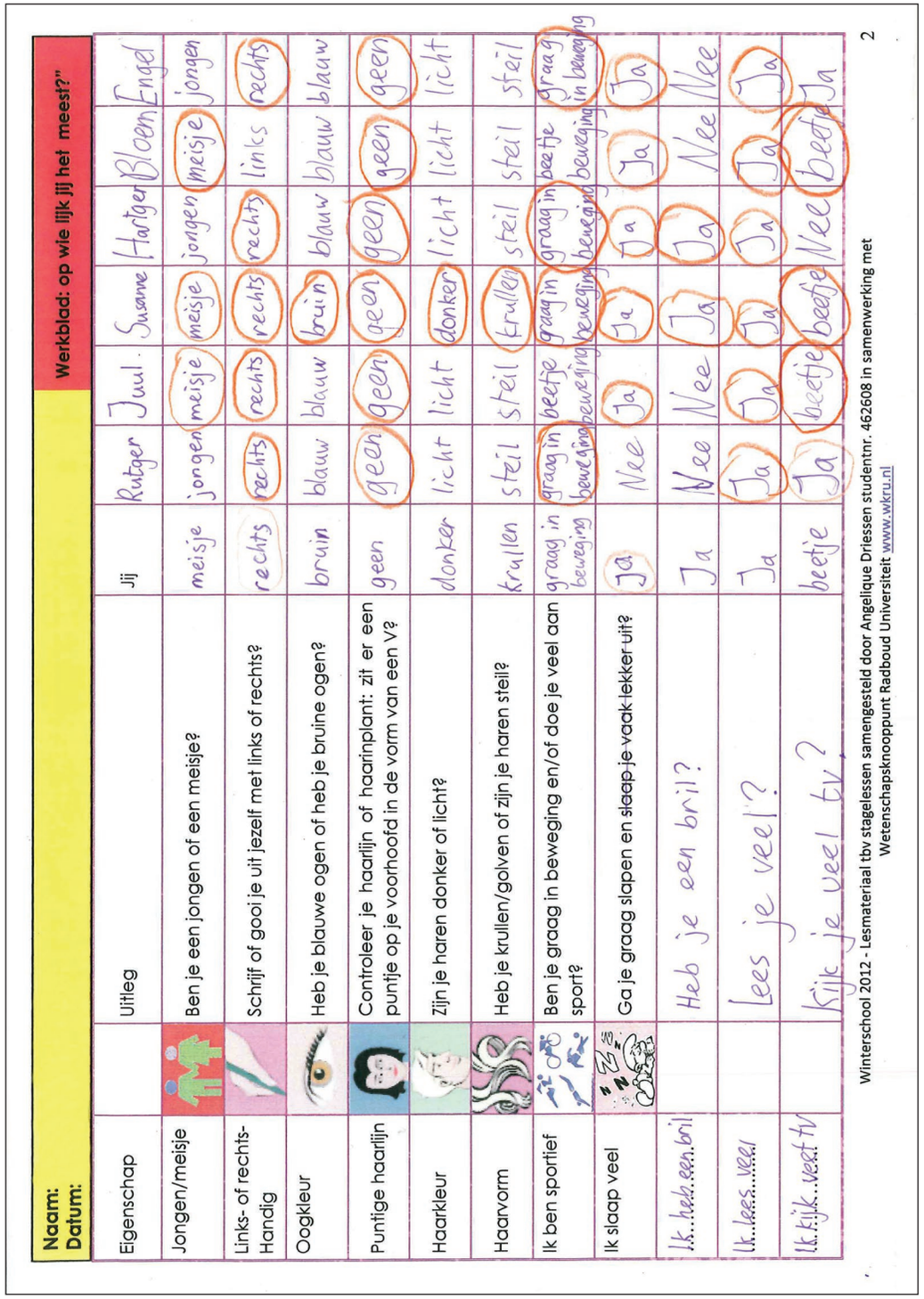
Overview of the questions:

1. Are you a boy or a girl?
2. Are you left- or right-handed?
3. Can you roll your tongue?
4. Do you have blue or brown eyes?
5. Do you have dark or light hair?
6. Do you have curls or straight hair (naturally)?
7. Are your ear lobes attached to your head or partially loose?
8. Do you have a dimple in your chin?
9. Embrace your hands. Which thumb is on top?
10. Can you make a V with your fingers (demonstrate)?
11. Cross your arms. Which arm is folded over the other?
12. Does your hairline converge to a point on your forehead in the shape of a V?

Worksheet 'Who do you resemble the most?'
The introduction game was a good source of inspiration to start thinking about heredity. In order to complete the worksheet 'Who do you resemble the most?', the children had to think about their own characteristics and that of their family. By filling in the worksheet, the children will come to learn that some characteristics are hereditary. After the group discussion, I wanted to give the children space to think further about it themselves. That is why I added blank sentences below in the worksheet. Here the children could add the characteristics they thought were interesting. The own interpretation of the children was a good occasion to briefly further discuss after class which characteristics are hereditary and which are not. While filling in the worksheet, several questions were asked such as "Can I mention our cat, because it always lives with us?" and "Can I add my grandfather, even though he has passed away?". The characteristics that you would like to research were creatively filled in by the children:

- Are you original?
- Are you nice and awesome?
- Do you have soft cheeks?
- Do you finish your plate?

Everyone showed their completed worksheet with amazement. "I resemble everyone equally much! I never realized that" and "Fortunately I resemble my favourite sister" and with much amazement "I resemble my aunt very much, how is that possible?".



Naam:
Datum:

Werkblad: op wie lijk jij het meest?"

		Jij	Rutger	Juul	Susanne	Hartger	Bloem	Engel
Eigenschap	Uitleg							
Jongen/meisje	Ben je een jongen of een meisje?	meisje	jongen	meisje	meisje	jongen	meisje	jongen
Links- of rechts-Handig	Schrijf of gooi je uit jezelf met links of rechts?	rechts	rechts	rechts	rechts	rechts	links	rechts
Oogkleur	Heb je blauwe ogen of heb je bruine ogen?	bruin	blauw	blauw	bruin	blauw	blauw	blauw
Puntige haarlijn	Controleer je haarlijn of haarinplant: zit er een puntje op je voorhoofd in de vorm van een V?	geen	geen	geen	geen	geen	geen	geen
Haarkleur	Zijn je haren donker of licht?	donker	licht	licht	donker	licht	licht	licht
Haarvorm	Heb je krullen/golven of zijn je haren steil?	krullen	steil	steil	krullen	steil	steil	steil
Ik ben sportief	Ben je graag in beweging en/of doe je veel aan sport?	graag in beweging	beetje graag in beweging	beetje graag in beweging	graag in beweging	graag in beweging	beetje graag in beweging	graag in beweging
Ik slaap veel	Ga je graag slapen en slaap je vaak lekker uit?	Ja	Nee	Ja	Ja	Ja	Ja	Ja
Ik..heb..een..bril	Heb je een bril?		Nee	Ja	Ja	Ja	Nee	Nee
Ik..lees..veel	Lees je veel?		Ja	Ja	Ja	Ja	Ja	Ja
Ik..kijk..veel..tv	Kijk je veel tv?		Ja	beetje	beetje	Nee	beetje	Ja

Winterschool 2012 - Lesmateriaal tbv stagelessen samengesteld door Angelique Driessen studentnr. 462608 in samenwerking met Wetenschapsknooppunt Radboud Universiteit www.wkru.nl

2

Explanation for the worksheet 'Who do you resemble the most?'

Do you resemble your friend or your family?
If you look around you or if you played the game 'How unique are you?', then you will realize how different you are compared to your friends when paying attention to just a few characteristics: you are unique! Even then, sometimes we say: 'I have that from my mother or from my grandfather'. You probably resemble your family more than you do your friends.

Strange family?
Below is a list with several characteristics which we will investigate whether they frequently occur in your family.

- Are you a boy or a girl?
- Do you write or throw with your left or right hand?
- Do you have blue or brown eyes?
- Check your hairline: does your hairline form a point on your forehead that resembles a V?
- Is your hair colour dark or light?
- Do you have curls/waves or is your hair straight?
- Are you active and/or do you conduct sports?
- Do you like to sleep and do you often sleep in?
- Do you have glasses?
- Do you read a lot?
- Do you watch a lot of television?

Once filled in, you will see who of your family you resemble the most. In the first table, you find an explanation of what is meant by the characteristics. Fill in the bottom rows some characteristics you also want to investigate. For example: I love to read / I am always happy / I always resolve arguments quickly.

Execution
At the top of the columns you write the names of your father, mother, brothers, sisters, grandparents or even those of your uncles, aunts or cousins. Then complete the table for you and your family. Doing this will provide you with a whole list of who has what characteristics. Circle the characteristics of others that correspond with those of yours. The one with the most circles resembles you the most.

Who do you resemble the most? _____

Phase 2. Exploring

Phase 2 is divided into three components:

- The explanation about DNA;
- The children construct their own (symbolic) DNA strand;
- The replication of their own DNA.

Explanation about DNA

The first slide of the PowerPoint presentation is already on the digiboard when the children return to the classroom. "Oh cool, we are going to continue with DNA!" is what I hear the children shout. It barely requires any effort to get the children's attention when I want to begin with the lesson.

The presentation is very basic. "I am going to explain DNA. You might hear words you do not understand. Write those words down on a piece of paper and we will discuss them at the end of the lesson again. If you have a question during the presentation, you are allowed to ask it. I will try to answer it, but if I do not know the answer, then we will write the question down. In a few weeks, we are going on an excursion to the scientists that conduct studies on DNA and we can ask them our questions."

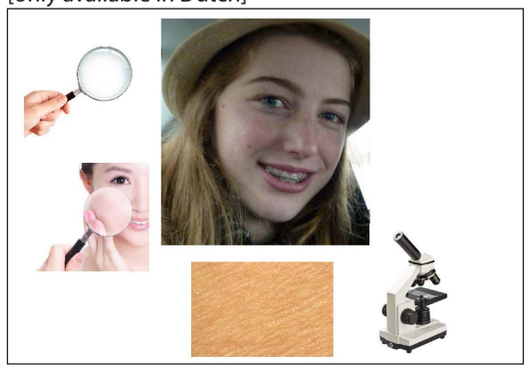
There were many questions during the presentation, which is why it lasted longer than planned. After half an hour, the presentation was finished. It was very interesting! A topic that really occupied the children was: "How do twins arise?" and "How do Siamese twins come to be?" The large numbers (for example: all the DNA in our body has a total length equal to 400 times the distance to the sun and back, and that our body consists of three trillion cells) also spoke to their imagination and remained the centre point of the discussion. In the second film, I again emphasised how small a cell is and how much smaller a chromosome is. After the film, I was asked 'whether we also have these kind of stones in our bodies."

The PowerPoint presentation as presented by Angelique and where later in the chapter is referred to by other teachers is presented in this chapter. Per slide you will find a text which you can use when giving the presentation to your class.

The PowerPoint presentation about DNA can be downloaded from the website www.wkru.nl/english.

Explanation for the PowerPoint presentation about DNA

Slides 1 and 2: We begin with a short film about DNA from the Dutch schooltv 'Everyone is different'[1] [only available in Dutch]

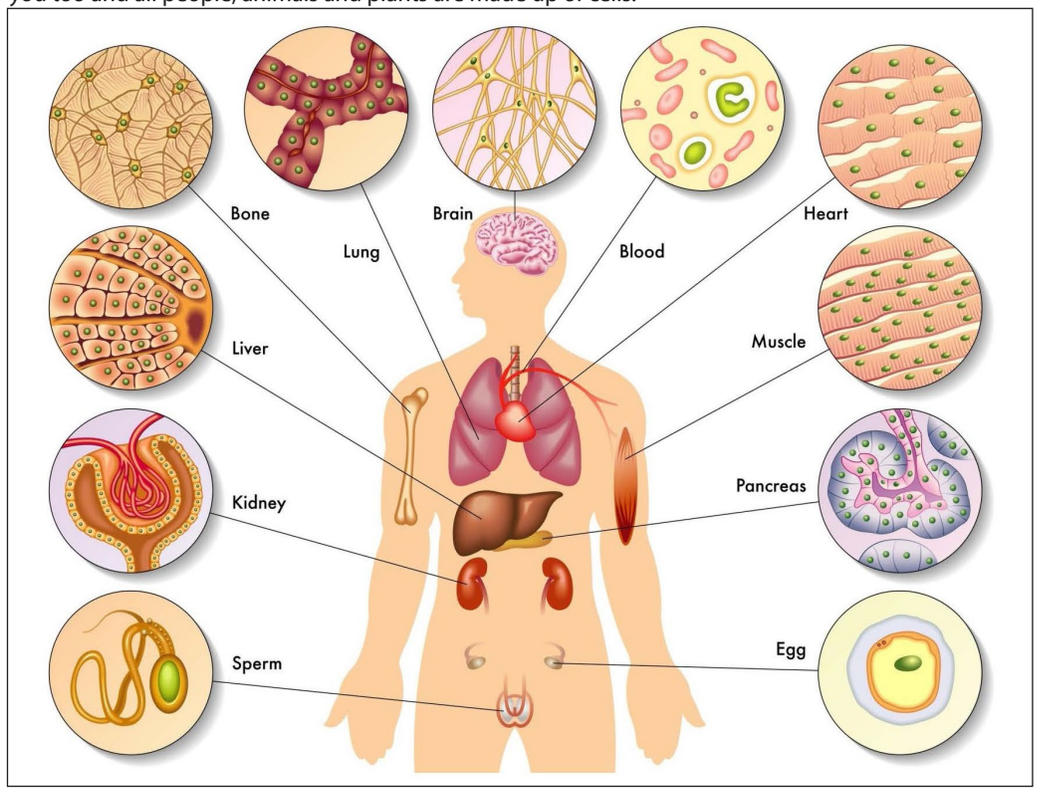


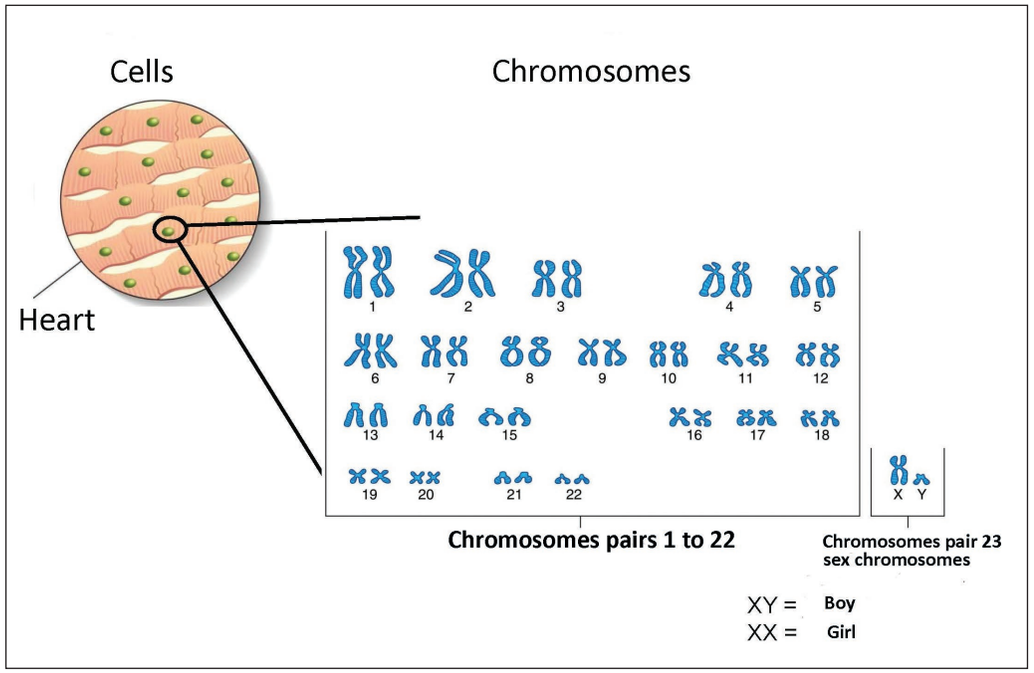
Slide 3:

Here you see Evi. Evi is made up of muscles, bones, skin, blood vessels, brains, kidneys and many other components. If we used a very strong magnifying glass (CLICK) you would see that Evi is composed of many small components: cells. They are very small, even smaller than grains of sand. Even this microscope is not strong enough to view these cells. Nowadays, computers are used to visualise cells.

Slide 4:

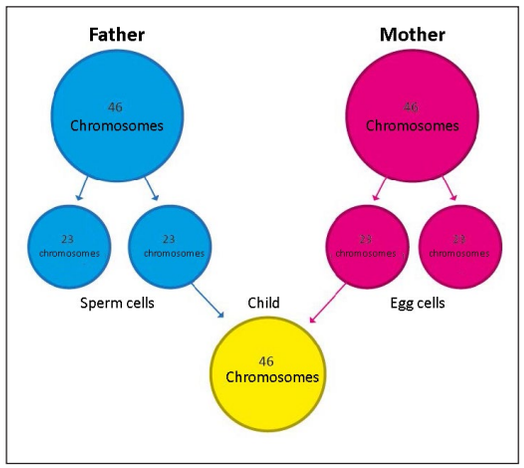
The muscles, the liver and the heart of Evi and her whole body are all composed of cells. Not only Evi, but you too and all people, animals and plants are made up of cells.





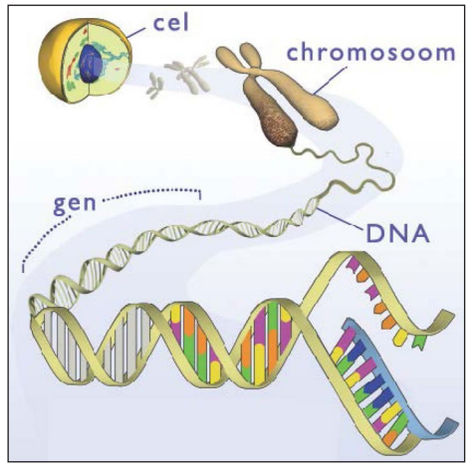
Slide 5:

Here you see a few cells from Evi. In the middle is a kind of kernel: the core (or cell nucleus). And in the nucleus are chromosomes. I will show a picture of that in a moment. The DNA is packaged in these chromosomes and that DNA specifies which characteristics you have. We discussed this in the previous lesson. You researched who you resemble the most of your family. Your characteristics – or the way you are and how you look – are derived from your parents. On the following slide, I will illustrate how that works.



Slide 6:

In every cell there are chromosomes. Each chromosome is present in pairs, one from your father and one from your mother. Therefore, there are 23 chromosome pairs in total. All cells in your body contain the exact same chromosomes. Only in the sperm and egg cell are chromosomes not found in pairs, but as single chromosomes. When the sperm and egg cell come together, then together they have 23 chromosome pairs. In order to grow, the chromosomes are replicated. After they have replicated, they are divided because the cell which they are in splits in two. That is why every cell in the body has the exact same chromosomes.



Slide 7:

To explain how replication works, I will first illustrate what DNA looks like. This is an image of a cell. In the cell, you see the cell nucleus and within the cell nucleus are the chromosomes (23 pairs). A chromosome roughly looks like this. And in the chromosomes lies the DNA like a sort of coiled rope. Imagine how small this actually is, especially when you consider that a cell is even smaller than a grain of sand! The DNA looks like a thin, coiled thread. And that thread can be divided. That is what you see here magnified. Important to pay attention to are the colours on this image. On the following animation, you can see this better.

Slide 8: Animation of DNA replication

(Open the link) Pay attention to the colours. Do you notice anything? (Give the children time to observe).

Each colour has a letter and each colour always associates with the same colour. Yellow associates with blue and green associates with red.

A segment of DNA, with different colours together, is what we call a gene. And for every gene there is a characteristic. So this segment specifies, for example, your blue eyes and this segment specifies your curly hair.

In this image, you can see how DNA replicates itself: the colours that associate with each other separate and new colours are attached. This goes on for some time until the entire chromosome has copied itself and then you have two chromosomes. Are these chromosomes then exactly the same? YES. In your entire body, the same chromosomes are found, except that everywhere a different piece is used. The cell 'reads' the information in the gene and only reads what it really needs. A cell in the eye, for example, reads the information for eye colour, but not for curly or straight hair. That is how researchers can determine your DNA from your hair follicle, or from your skin, or your mucus. The DNA is the same in all cells. Cells must always work very hard to replicate themselves, first because you are just a small egg (a single cell) and need to grow, but afterwards cells have to continuously replicate because your hair needs to grow and because you get new muscles and because all cells must be continuously renewed.

Slide 9: Short film about DNA replication

(Open the link) I will now show you an English film2 that illustrates how DNA replicates itself. Keep in mind that this has been magnified!

Slide 10:
Finally, a few interesting facts.

Facts:

- How many cells does the human body consist of? 30.000.000.000.000 = 30 trillion

- How many chromosomes are in a cell nucleus? 2 x 23

- How long is one strand of DNA? 2 meters

- How long is all the DNA of one human? 400 x to the sun and back!

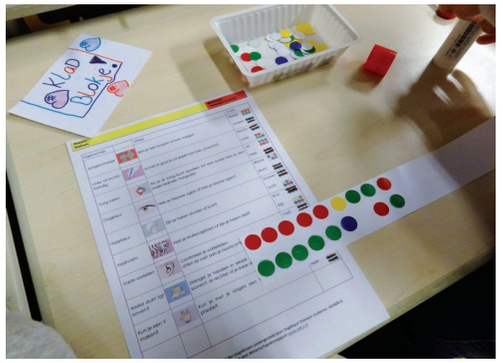
- How long on average does it take for one cell to divide? 24 hours

- Out of how many pieces is DNA composed? 6 billion = 6.000.000.000

Connect to math, such as working with big numbers. Let the children themselves consider how the numbers with all their zeroes are pronounced.

Making your own DNA

Through a lot of brainstorming, I designed a lesson to explain the abstract concept of DNA as concretely as possible. The children will make their own DNA. The characteristics from the first lesson (from the worksheet 'Who do you resemble the most') will form the basis for this. For each characteristic, I have assigned a colour code. The colours used here included red, yellow, green and blue. In science, these colours are also used to schematise the DNA.



Making your own DNA!

Assignment. Making your own DNA

"You are going to make your own DNA! You will all receive a strip of paper, plenty of circles to paste, glue and the worksheet 'everyone is unique'. Last week we discussed several characteristics. You have experienced that everyone is unique; nobody from this class is identical to you! On this worksheet, I have all the characteristics listed and a colour code. You could compare the colour code with a gene from the DNA. These codes are not real however; I made them up, but if we stick to the code, then we can compare our DNA within our class. You will receive such a sheet from me in a moment. You will begin with crossing out the colour code of the characteristic that does not belong to you. Then you will paste the circles on this strip. They have to be pasted precisely in this order and they should also be neatly pasted under each other. When everyone is finished, we can check whether there are some identical strips. Of course the answer will be NO, because everyone is unique. That is what we figured out and experienced during the first lesson after all.

Example DNA strip:

.....etc

The 'DNA-who-is-it-game'

After the strips were made and we had finished the group discussion, the children came up with an idea. They wanted to play a game with the DNA strips: the 'DNA-who-is-it-game'. I would pick one strip of DNA. The children would stand on their chairs and from the colour code I would read the characteristics that were on the DNA. I would repeat this with the other strips until only one child remained since everyone is unique and no strip is the same. The children had invented this game themselves; proof that they understood that everyone is unique. We have played this game often in the classroom in following lessons. I had to always start with the last question, because the first question is rather predictable 'Are you a boy or a girl?' and the children were less amused by that!

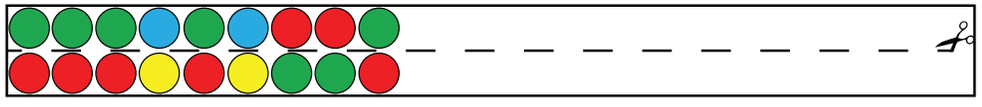
DNA replication

The basis for these lessons is the scientific research 'Sick due to new errors in your DNA'. This study demonstrated that during DNA replication errors can occur. These errors may lead to new characteristics, talents, diseases and such. By letting the children copy their DNA strip, they experience for themselves that errors can indeed occur during the replication process. Doing so will allow them to better understand the research. With this basis, the children can then think about changes (characteristics, talents, diseases and such) that they recognise in themselves or in others. In the group discussion, we will go into more detail.
From these preparatory lessons, the children will acquire inspiration for setting up their own research.
See phases 3 to 6 for this.

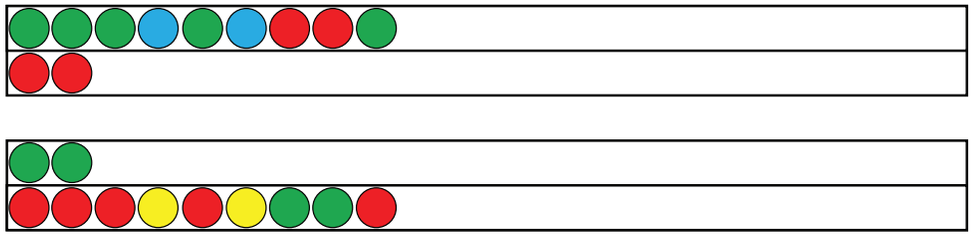
DNA replication

Assignment. Explanation DNA replication

Your own strip of DNA is cut length-wise through the middle. Doing so will result in two thin strips.



Paste each strip on a new broad strip and add the complementary colours.



The DNA project is the focal point of attention in the classroom. This is partly because the slides of the PowerPoint presentation are hanging in the hallway. Especially the last page depicting the large numbers remains the centre of discussions! Most children are very interested in working further on this project. Replicating their own DNA strip made them feel as if they were replicating themselves! I concluded this lesson as usual with an evaluative group discussion. I asked the following questions:

- What has happened? / What have we done (DNA has been replicated)?
- Did everything go well?
- What was difficult?
- Where can errors occur?

Afterward we jointly concluded: this happens in our body constantly! Everyone was very impressed!

Phases 3 to 6. Research into the replication process

The basis for these lessons is the scientific research 'Sick due to new errors in your DNA'. This implies that you can acquire characteristics that differ from your parents or acquire diseases as a result of spontaneous errors arising during the replication process. I wanted to let the children optimise the replication process of their own DNA. At the end of the lessons of phase 2, I noticed some resistance from the children when it came to pasting their DNA strips. Until now this was not a problem because the children were busy with their own DNA and the assignment of replication was still overseeable. For phases 3 and 4, I had the plan to establish an optimal replication process. The children had replicated their DNA once already and in doing so, experienced what problems could occur (not enough circles, poor adhesives, difficulty to maintain the correct order, etc.). It seemed like a good idea to optimise this process. However, I also understood the reluctance of some children: it involved a lot of pasting… Maybe it would have been better if I had originally used stickers. But I did not have those and then there would also be less errors in the replication process (because the adhesive would not be a variable anymore). I was able to get the children excited about working in groups to construct a plan for optimising the replication process. It was nice to see the different practices! Because I noticed that the interest was dwindling, primarily in regard to the paste work, I decided to no longer conduct the presentation and improvement exercises.

Research into the optimal replication process of the DNA strips

Phase 7. Deepening/broadening

Excursion to the Department Human Genetics

We have been on excursion with the class to the Department of Human Genetics of the Radboud Hospital. This was a great experience! Both the children and accompanying parents and teachers were very impressed. More about this excursion is described in sections 2.2.2 and 2.2.3. As an alternative to phases 3 to 6, I devoted more attention to phase 7. I let the children decide if they wanted to write a story or a report or even set up a small research. I also gave them the choice to decide whether they wanted to read or present their story, report or research to the class. The story, report or research had to be based on DNA or science. The children who wanted, could use a worksheet that I made to aid them in writing their story, report or research. In this worksheet, I worked out the different phases of the writing process.

There were some surprising stories and reports released. They were very fun to read and a real chore to evaluate, but very worthwhile! The presentations were also very pleasurable. The children enjoyed listening to each other's stories. There were definitely more children who, in hindsight, wanted to read to the class, but had not practiced. A must for next time is to let the students present to the class again!

"Great that we could look around in the lab." (Student)

Evaluation

Regarding myself, I enjoyed and learned a lot from the entire project. The collaboration with the project team and the enthusiasm of the children during the lessons will stay with me for a long time. I also witnessed how valuable this project was for the children. They learned about a completely new world (science) and the associated inquisitive and explorative thought process. The integration with oral language (for example in group discussions), writing (for example during the assignments) and calculations (working with large numbers) added value to the whole.

Because working in this manner was a first for me and since I had to conduct this project by myself during my internship, not all possibilities within this project were used to their full advantage. In a follow-up project, I would really like to devote more attention to setting up our own research. Following the evaluation session with the other project team members, I received new input which can be used for this.

"I enjoyed the DNA project so much that I will never forget it." (Student)

3.2.2 Project 'Unique due to new errors in your DNA' at 't Holthuus

Yvonne Koldenhof (teacher elementary school 't Holthuus)
Charèl Huisman (pre-service teacher at the HAN)

Science and technology at elementary school 't Holthuus

Inquiry-based learning and Reggio Emilia

For years now, 't Holthuus has abandoned its methods for biology, history and geography, and instead the teachers design projects themselves using the seven phases of inquiry-based learning as a structure and as a source of inspiration. During so-called 'work afternoons', we come together as a team and thoroughly prepare these projects using the 'ZAB model'. In Dutch, the 'Z' stands for 'zinvol' (meaningful), the 'B' for 'betekenisvol' (significant) and the 'A' for 'activiteiten' (activities). As teachers, we look at topics that we consider 'meaningful' to address in a project. In doing this, we use the core objectives of the Dutch SLO Tule3. In addition, we predict what the children find meaningful with regard to the topics. We usually align these two points and develop projects based on these. In this way, we ensure that the projects are not only meaningful, but also speak to the children's interest. Traditionally, we look for inspiration in the educational vision of Reggio Emilia. Namely, we want to work on the overall development of the child. A child wants to learn to read, write and count, but it also wants to truly understand the world! Why does it rain? How is that possible? Can I copy that? A child can and feels a lot. It can dance, paint, build, act and so on. A child can speak '100 languages'. At 't Holthuus we try taking these 'languages' of the children into account. We find inspiration to do so in the educational philosophy Reggio Emilia, which helps us to implement different ways of processing to meet the intellectual needs of the children.

Science and technology workshops

For several years now, we provide science and technology workshops in specifically designed workplaces in our school. In the workshops, the focus is on the technical and scientific aspects of the projects conducted at school. The workplaces have a basic interior where the children can find things to express themselves in different way, such as an easel, tools and chalk. The children can work here independently with various materials, such as Kapla and technical Lego. With these workshops, we also try to connect with the projects in the classroom. For example when a project on 'snails' is running in the classroom, the children can get started on this topic using additional assignments and materials found in the workshops. In short, it is an inspiring workplace that triggers the curiosity of the children.

Collaboration with the Science Education Hub

This is the second year that we are working in collaboration with the Science Education Hub. Last year we performed the project: 'Thoughts about the beginning4' by Professor Ellen van Wolde in grade 4. This project was so successful that we decided to renew the challenge in order to give scientific research a position in our projects. The strength of the Science Education Hub is that it brings together different parties which provides the projects with more depth. We are pleased that the Science Education Hub gave us the opportunity to get this support.

The project

The project was performed in grade 5-6 of elementary school 't Holthuus and included six lessons of 2 hours distributed over six weeks time.

Goals

- By the end of phase 2, the children can recognise the inherited characteristics within their own family.
- The children will learn to use a code for the transmission of information.
- The children understand the terms 'cell', 'chromosome' and 'DNA'.
- The children understand the concept of DNA and what is coded in the genetic code.

Core objectives of the Dutch educational system

Oral education

2. The students learn to express themselves in form and content when giving and requesting information, reporting, giving explanations, instructing and discussing.

Written education

4. The students learn to derive information from informative and instructive texts including schematics, tables and digital sources.

Numbers and operations

26. The students learn to broadly understand the structure and connection of numbers, integers, decimal numbers, fractions, percentages and ratios, and to use these in practical situations.

Artistic orientation

54. The students learn to use images, music, language, play and movement to express feelings and experience, and to communicate.

Orientation on yourself and the world

34. The students learn to take care of the physical and mental health of themselves and others.

37. The children learn to behave with respect towards generally accepted norms and values.

41. The students learn about the build of plants, animals and humans, and about the form and function of their parts.

Learning goals regarding the phases of inquiry-based learning and research activities:

- Doing research and developing research skills.
- Designing research questions.
- Acquiring information from spoken language and presenting the information in a mindmap.
- Processing data in graphs and tables, and drawing conclusions
- Asking questions to an expert.
- Making predictions and giving explanations.
- Recognising conditions for fair research and applying these.

Integration with other subjects

This project has not only made a link with the subject 'world orientation'. The subjects expression, social-emotional development (SED), philosophy, mathematics and language were also addressed. After all, some children processed their research results in tables and graphs. No assignment from a mathematics book can offer these two skills in a more meaningful and functional way than how these children worked with it. In terms of SED, terms such as 'being different' and 'judgement' were mentioned. Important themes to discuss during such a project because very personal stories and experiences are exposed such as diseases in the family or physical characteristics. During the presentation, the subject 'expression' was highlighted. The children were allowed to choose how they wanted to present their research. Ultimately the children chose for a song, a visual piece, a film, a play, photos, etc. All languages that children can communicate through, but are often forgotten! Language emerged in the processing of their research results and in the preparation of their research. For example, letters had to be sent to the supervisors of the children with the question if an interview was allowed to be conducted in the classroom. The children learned to formally construct a letter. In short, there was plenty of integration with other subjects!

DNA in grades 4 to 6!

When the other classes heard that we would conduct a project in grade 5-6 about 'Unique due to errors in the DNA', the teachers were immediately eager to also devote attention to the topic DNA. The months March and April were marked in sign of DNA for grade 4 to 6. Only grade 5-6 devoted specific attention to the research by Han Brunner and Joris Veltman.

Phase 1. Introduction theme 'DNA'

Children share experiences

It is Friday afternoon… Normally it is buzzing with energy in grade 5-6 and now even more so! They caught word that they are allowed to participate in a very exciting project: scientific research is the starting point.

Some children still remember the 'Ideas project' from last year and anticipate this project to be special. We start the project in a community room within the school. The children stand there as a group. I inform them that I will call out some characteristics and when the children recognize themselves, they can join the children with the same characteristic. Who can roll their tongue? When you cross your arms, which arm is above the other? Do you have light or dark hair? The group is quickly segmented into smaller groups. Sarah stands isolated quickly and more children follow her. Two girls manage to survive as a group after all the questions. How is that possible? And what does that say about their characteristics? What characteristics do they not have in common?

Game 'Everyone is unique!'

We head back to the classroom and discuss what this game says about us. The children notice that everyone is different and therefore unique! "You receive DNA from your parents, from your father and your mother, that gets mixed, therefore you are unique!" The girls find it strange that they share many of the same characteristics despite not having the same father or mother. Someone realises that it is extraordinary that Daan and Floris, whom are distant cousins, were so quickly split up from each other. And that is supposed to be family? Soon the conversation moves to one about the characteristics that can be inherited from your parents. The circle becomes rowdy and I notice that the children feel the need to share their experiences and questions about hereditary characteristics. "My grandfather and grandmother both have brown hair and received a son with red hair, how is that possible?" Someone suspects that one hair colour will be stronger than the other. "My parents do not have dyslexia, but I do, why is that?" A few children think that dyslexia skips a few generations and question whether her grandfather or grandmother had dyslexia? "My sister has a blue eye and a green eye, how is that possible?" All the children want to eagerly share their mysterious stories about unusual characteristics that run in their family with the rest of the circle. I expect that this topic will evoke questions at the dinner table.

Who do you resemble the most?

I assign the children homework. The children are allowed to do a mini research to evaluate which family member they resemble the most. They may use the worksheet: 'Who do you resemble the most' to achieve this. The children may also research whether they have a 'hereditary characteristic' that nobody in the family has. Do you resemble your father? Do you laugh like your grandmother? Do you have something

that nobody in your family does? This assignment stirs up the commotion in the group and the children are buzzing with revelations and questions. One special character after the other passes through the circle. The aim of this assignment is that the children discover that they might have characteristics that nobody else in the family has. With this, we can start thinking about how that is even possible.

Lastly, I mention the direction of this project. This is important for the children, because you focus them on the research that they have to ultimately perform themselves. Essentially, in the coming phases, they will filter the information and can work more goal-orientated during the exploration phase. During this project we are going to discuss 'errors' in DNA. Everyone makes mistakes, even nature! In this project we will research whether and how this happens, and think about how this can lead to diseases. The children are allowed to set up research themselves and at the end of the project, our knowledge will be tested in a real DNA lab!

DNA question strand

I, hereby, introduce the DNA question strand. This is a variant of the 'do and do not know sign'. On one strand the children can keep track of what they already know about DNA and on the other strand they can post questions they want to answer. At the end of the project, we will take these with us for the scientists to answer! 'Are bad characteristics the result of errors in your DNA?', 'Is ADHD involved with DNA?', 'My father used to have blond hair and now brown hair, why is that?', 'Does your DNA change?', 'How does DNA look like up-close?'. It is the intention that we update this question strand every lesson. For which questions did we receive an answer and what questions are added?

The DNA question strand

Phase 2. Exploring DNA

Wall pedigree!

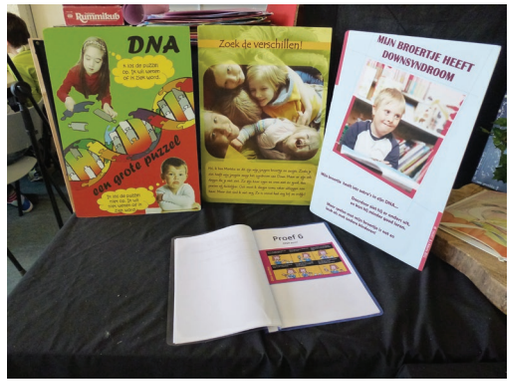
Pictures of fathers and mothers of the children in grade 5-6 quickly flood the room. Some children have pictures of their parents when they were the same age. And then it comes down to guessing. Whose mother do you think this is? Whose grandmother is this? Some children look exactly like their mother or father at the same age. Mike, the supervisor of grade 5-6, hangs all the photos on the wall creating a large wall pedigree. During the week, I am constantly asked by the children about the project: "Yvonne, look at this picture of my mother, she had crazy hair right!", "Whose father do you think this is?". It is clearly visible that the children find pleasure in sharing their family photos. I realise that it is a focal point of attention within the group. On Friday afternoon, all the children have their homework assignments from last week on hand. I come to the realisation that the children have discussed their assignments a lot at home. All characteristics were checked at home and grandmothers were even called with the question which thumb sits on top of the other when grandpa has his handed clutched together. And then the conclusions of their characteristics-research. Anne comments that she is always told that she resembles her father a lot. But through the assignment, she found out that she actually shares more characteristics with her mother instead. Charlotte was surprised by the discovery that her brother shares the same characteristics as her.

PowerPoint presentation about DNA

Using a PowerPoint presentation, the terms DNA, chromosomes and cell nucleus are explored (see description of this PowerPoint in section 2.2.1). I display a picture of a cell nucleus and ask the students what would be in there. "Those things that look like an X, chromosomes!" Someone adds: Cells can also split up. They first become larger and then split in two. Bad cells cause diseases and the good cells fight the bad cells". "DNA consists of all those lines". The children share their understanding about the different terms. I am amazed at the knowledge of some children regarding this complex issue. With a ball of wool, I symbolise the structure of a DNA strand. Why would the DNA be made in this way? The children see the importance of all genetic information being structurally stored so that information can be easily 'read'.

Working in the workshop

Meanwhile the science and technology workplace in the hallway has been turned into a DNA workplace. Here a variety of assignments and materials are prepared so that in the coming week, the children can independently explore the concept of DNA in different 'languages'. The children can construct DNA strands using Lego building blocks, solve DNA puzzles, browse the internet, conduct experiments involving fingerprints, copy bead boards (to mimic the replication of cells) and so on. (These and other exploratory activities are described in detail by the teachers of De Lanteerne in section 2.2.3). Of course there are also informative books for children who learn best this way. The most favourite and fun task was surely the creative assignment in the workshop: "How would the child from teacher Mike and his girlfriend Deborah look like?" which is a good example of an activity that is both meaningful and significant for this grade.



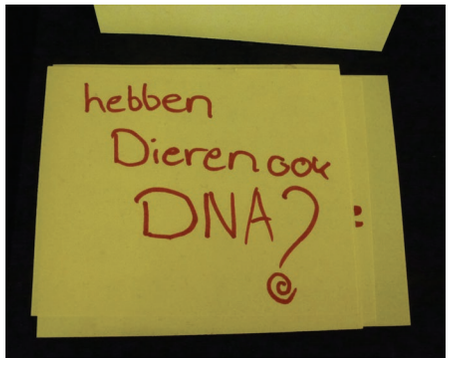
Project corner in the classroom

Assignment. Making your own DNA

The children also made their own DNA strip using coloured stickers. For more of an explanation about the assignment 'Making your own DNA', see section 2.2.1 phase 2 Exploring.

DNA question strand

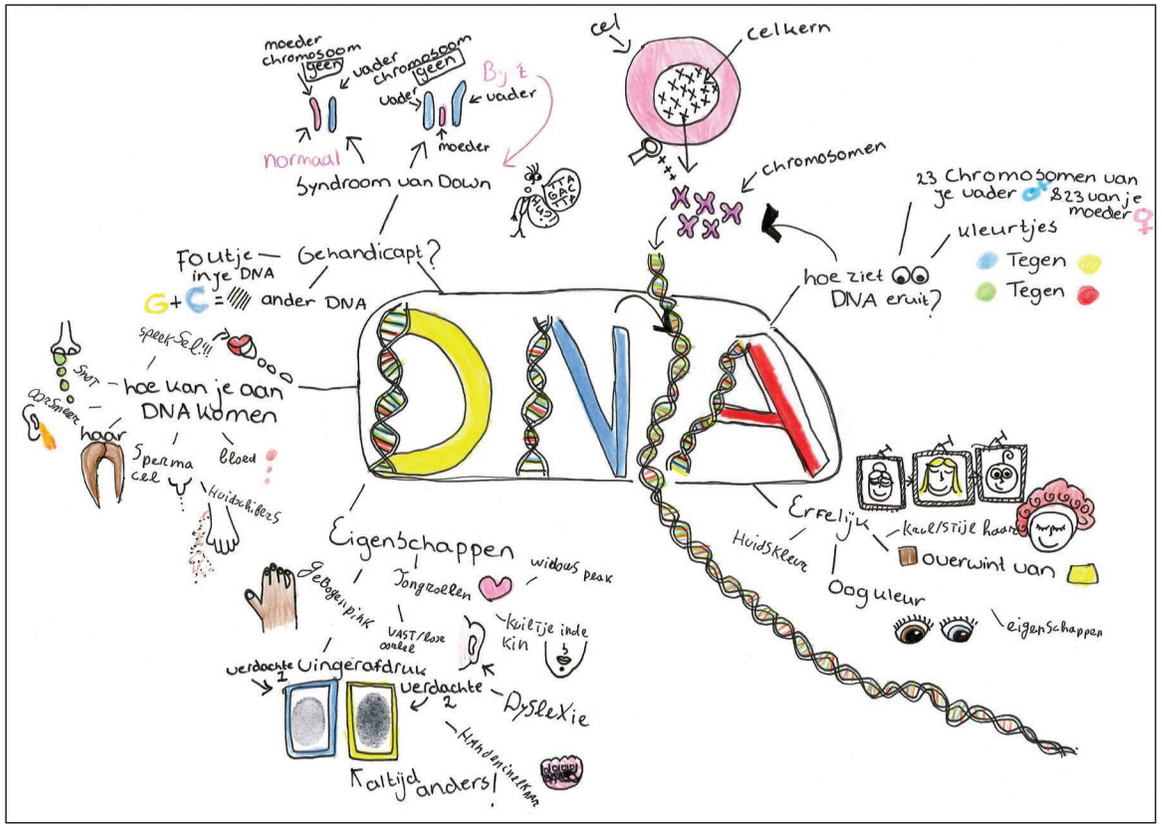
When I refer to the DNA question strand, we can, to our delight, provide answers to some of the questions that were suggested in the previous lesson! Thanks to the PowerPoint presentation and the workplace assignments, the children can now elaborate and depict how DNA looks like up-close. They also found out that DNA continuously replicates which results in each cell being identical! Hence it does not change! Except when errors occur during the replication process.

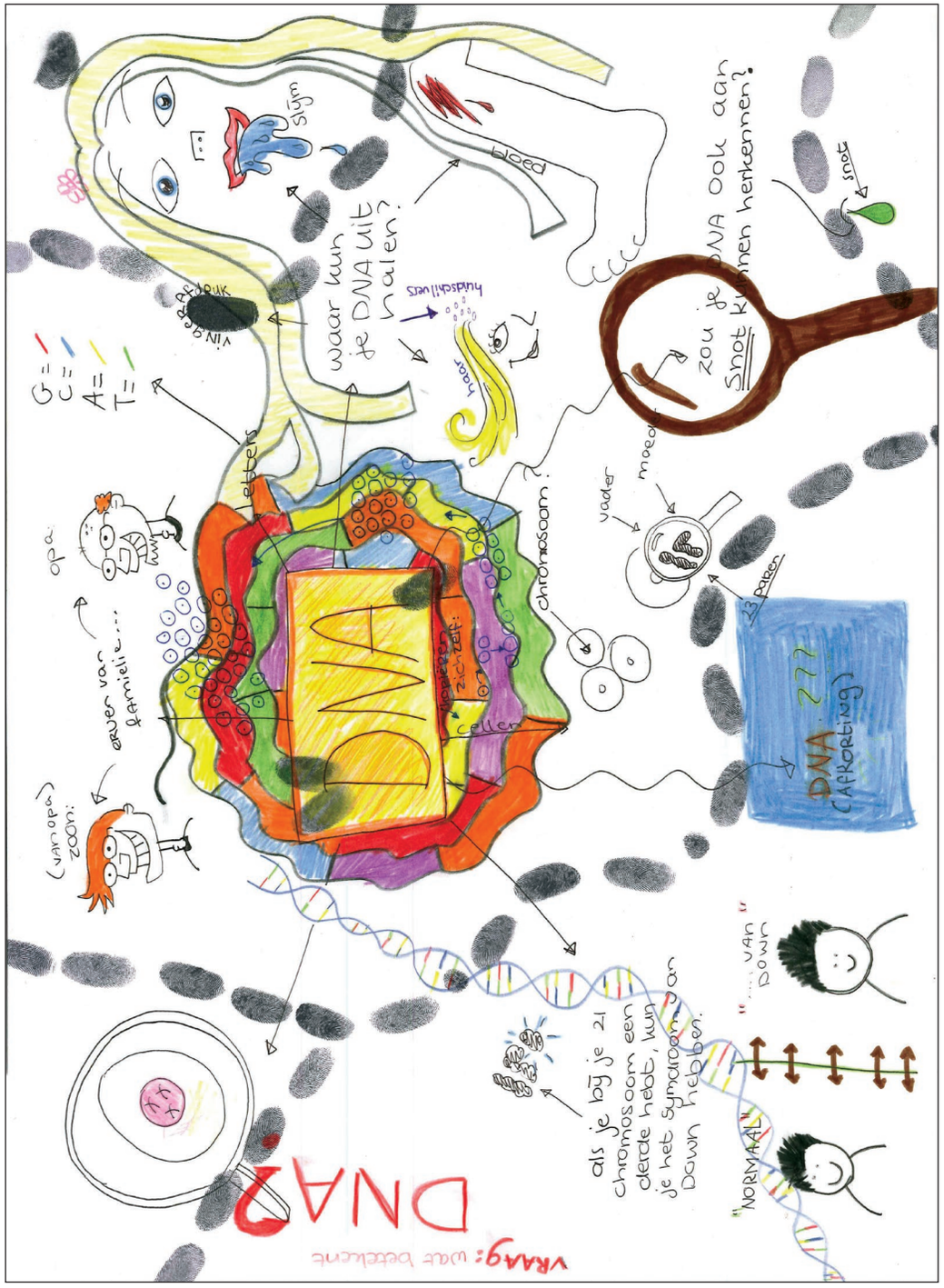


What we still want to know. . .

Making a mind map

The children have acquired a lot of information. Time to structure the information and to illustrate it in a mind map! The children form pairs for this. Every pair conducts research together and creates mind maps. The children are aware that they are creating the mind maps to ultimately derive a research question.





Phase 3. How can you design an experiment about 'DNA' yourself?

Research map

After just having received two fairly theoretical lessons, we decided it would do the children good to let them get started. The children all receive a research logbook in which they step-for-step detail the design and execution of their research. Each step is described in detail. Research starts with a research question, but what criteria must a question fulfil in order to be considered researchable?

Thinking of researchable questions

We know from experience at elementary school 't Holthuus that children consider it difficult to devise a good 'researchable' question. The children require skills for this that need to be developed from kindergarten onwards. But how do you give these skills a place in your education? What skills do you let the children make their own? This is a search process that we as a school still find ourselves in! In the project team, we decided to set clear 'requirements' for the research questions:

- The answer to the question has to be unknown to them;
- The answer has to be out there;
- A question must not be too 'narrow' or 'closed';
- The question must be answered through measurements, experiments or technical or creative solutions;
- The research must be executable in the allotted time and with the available resources.

In the research map, the allotted time per step is defined. The children receive a period of two weeks to create and execute a plan. There will also be a 'test run' which involves the children presenting their research to another group which, in turn, might help them modify or improve their research.

Working together with the research map.

What should you pay attention to when setting up research?

The children have their beautiful mind maps about DNA in front of them. All the information that they have acquired over the past weeks is illustrated with beautiful drawings, a cheerful whole. The children can choose from three different themes for their research:

- Errors during replication;
- Research into differences in characteristics (within your family, school, your class, etc.);
- Design a craft project in which much information can be stored. This must have the characteristics of a DNA strand: flexible and long.

We added the craft project for several reasons. It addresses the strengths of visually-oriented children. It also allows them to depict their understanding of the theory via a creative outlet. Lastly we also try to implement design learning along with inquisitive learning within our World Orientation curriculum at 't Holthuus.

The children quickly made a choice for a specific theme. The step to create their own research question from here is a tad more difficult. I, therefore, emphasised the theory in their research report about the 'types of research questions'. These types of research fit pre-eminently with the DNA project. We cannot 'really' perform DNA research in our workplace and therefore have to be creative in coming up with questions.

By letting the children choose one of these types of research, we can narrow down the questions. For each question, I provided an example and discussed it with the children.

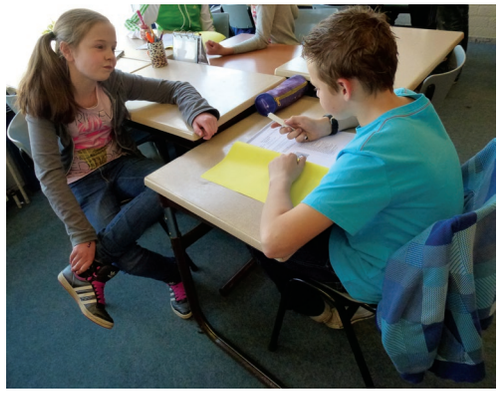
Table 1. Types of research

Type of research	Example research question
Comparative research Differences and similarities What differences...? What similarities...?	Which characteristics do I have that nobody in the family has?
Effects research Honest comparisons What happens if...?	What happens with a cake if there is an error in the recipe? Is every mistake equally bad or can the cake taste better as a result?
Causal research Goal-based searching How can you...?	How can you properly transmit a DNA code without making replication errors? (Whisper games, pasting strips).
Craft research	We will search for a sturdy 'carrier' which can store a lot of information.
Measurement research	How many children with dyslexia attend our school?

Formulating a research question as precisely as possible

The theory about the different types of research questions provides the children with more grip and the first questions follow shortly. Many groups come with very meaningful questions. I emphasise whether the questions are also significant for them. In the coming two weeks, I want to see groups that are full of enthusiasm and dedication towards their research! Do they see the challenge in it or do they only have a question that is 'meaningful'?

Lieke and Mees come up with a good example of a meaningful and significant research question. They heard that a boy with Down syndrome is on a school near them. They wish to interview the parents of the boy to figure out whether this disease is caused by an error in the DNA or if it is hereditary. I see their eyes sparkling and I notice their motivation to get started with this question in the coming weeks!



Discussion about the research question

The differences between 'searchable questions' (for example using Google) and 'research questions' (where you are required to perform an experiment) are still being explained and gradually the children each stumble upon a nice research question. On a Friday morning, I invite each pair to share their research question with me and to eventually work on a more precise formulation.

Some of the research questions that arose:

- How many children in our class have a hereditary disease in the family?
- What characteristics are most common in our class? How does the 'profile' of the average student from our class look like?
- How does a cell(nucleus) look like under a microscope? How does my saliva look like?
- Does Bram have the syndrome of Down as a result of an error in his DNA? Interview with Els, she is 49 years of age and has a son with the syndrome of Down.
- How do we create a storage system where we store the DNA of our class in?
- What percentage of children wants to see if they will get a disease of which they can die from using their DNA?
- How will the child of teacher Mike and Deborah look like?
- What characteristics are most common in school? Have toddlers already developed the tongue roll?
- Research based on a television program: "What if?" What if… DNA would not exist? What if… everyone was handicapped? What if… there were only girls? What if… everyone had errors in their DNA?

Research preparation

It is time for the children to prepare their research and create a clear plan. To do so, they will use the following questions which they will answer in their research map.

- With who are we doing the research?
- What are we measuring exactly and how do we measure it?
- What in the research will remain the same and what will change?
- How much time do we need?
- Where and when do we conduct the research?
- Who does what during the research?
- How do we record the research results?
- How often do we have to repeat the research to be able to draw conclusions?
- Describe now step-by-step how the research is done. (Try to write it as brief as possible.)
- What will the research yield? (Write down what you think is going to happen or what the answer will be to the research question.)

Phases 4 and 5. Executing the research and concluding

The teacher takes a step back

And then 't Holthuus became a large DNA research lab… Everyone should know, grade 5-6 is conducting research! Children that are questioning the entire class for certain characteristics, children that are baking cakes, doing research using microscopes, phone calling relatives, video recordings, handcrafting in the workshop, conducting interviews with teachers… What an involvement and commitment! The teacher who had been occupied with the process over the past few weeks, can now take a step back and rely on the good preparation of the children. They were so well prepared! Mike, the teacher of grade 5-6, was in utter amazement. A boy, who is normally forgetful, properly did groceries for his 'cake experiment' and was completely ready to conduct his research, great! I find it extraordinary to see so many different skills being used during the research. The girls, who are interviewing the mother, learn to call and make an appointment for an interview with a woman completely unfamiliar to them. How do we thank this lady? On the day of the interview, they both came with a bunch of tulips for the lady who lovingly provided information about her son's disease. She was in awe by the independence and courtesy of these young ladies. And how do we converge all the information about hereditary characteristics of 250 students? In a table? As a percentage? How do we deal with question forms that are not returned by the children?

The raw research results.

DNA question strand during phases 4 and 5

While conducting their research, the children learn and come up with new questions. At the end of the lessons, there was space on the DNA question strand to add newly acquired knowledge and questions

Phase 6. Presenting

Many different forms of presentation

And then all the children have results and possible answers to their research questions… How do you process all this information? How do you convert this into a presentation? On 't Holthuus, we try to familiarise the children with as many different forms of processing as possible. The children are allowed to choose their own 'language' to present their research. In their research report, the children find a list of examples of different ways as a source of inspiration: video recording, an artwork, poem, rap, poster, report, PowerPoint, drawing, newspaper, etc. The requirement for the presentation was that the audience should receive information about the research process, the research question and the results of the research question. The day of the presentations was the 'highlight' of this project. The children had all chosen their own way to present their research. One group had made a PowerPoint, while others had turned their interview into a rap. Birth announcement cards, comics, graphics, photos, cakes… all were done. One group had illustrated their results of the most common characteristics in the classroom as a chalk drawing on the schoolyard. They presented this proudly using pictures. The involvement of the group during the presentations was great and the children were sincerely interested in the process and the results of the research of their classmates.

Phase 7. Deepening/broadening

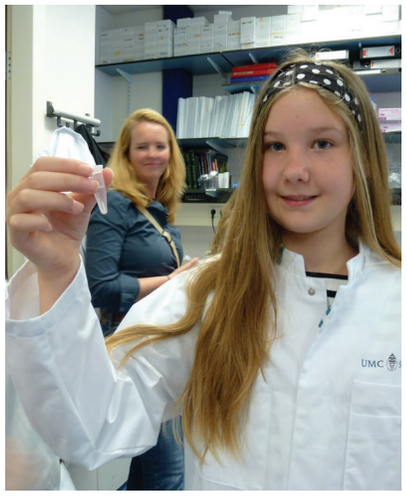
Visiting the DNA lab in Nijmegen

And then we were allowed to visit the Department of Genetics in Nijmegen. Usually it is rather difficult to find parents who wish to accompany us on an excursion, but this was not a problem at all for the visit to the DNA lab in Nijmegen. Better yet, parents were actually eager to join! With the questions of the children in my arsenal, we were welcomed into the Radboud hospital. It was impressive for some children to even walk in such a large hospital. We gathered in a room and were welcomed by the researchers. Joris Veltman showed his wonderful Radboud Science Award and gave a short presentation about his research. After we were divided into three groups and the researchers had three activities in store for us.

First we were given a tour of the department. This implied a route along gigantic machines, computers, robots, cold storage rooms and researchers that were working. During the tour, the children received explanations from Joep de Ligt about how errors in the DNA were located using the computer.

After the children were allowed to isolate their own DNA at the Tumor Genetics lab. But they all had to wear a white lab coat of course. The children were given a drink and had to rinse their mouths and spit the content into a cup. It did not taste good, so fortunately the children receive a marshmallow to mask the taste. With a pipette, a liquid was added to their saliva and a 'worm-like' thread developed in the liquid. They had isolated their own DNA from their saliva! They pipetted this DNA into a small container to take home. They were completely amazed by this activity and were really involved!

The large robot in the DNA lab that isolates DNA from blood



Look, I can see my own DNA!

Then we watched films and received an explanation about Erwin van Wyk's research. Among other things, this showed us how zebrafish are used in scientific research.

At the end of the excursion, the children were permitted to ask questions to the winners of the Radboud Science Award 2011: Han Brunner and Joris Veltman. Han and Joris also gave an explanation about their research.

Evaluations, reflections and lesson suggestions from elementary school 't Holthuus

Evaluations by the children

After the project, the children completed a questionnaire about the DNA project. Here are some evaluations from the questionnaire:

"I thought I did not resemble my family much, but that was wrong!"
"Calling my family went well, because everyone had time for our research."
"I enjoyed telling my grandparents about it!"
"During the group work, we divided the tasks well."
"I enjoy thinking of a research question as a group, because with more minds come more ideas."
"Next time I would make the plan more extensive."
"I enjoyed thinking of a research question and researching it, because we had a lot of freedom."
"I learned that you can conduct research in many ways."
"I learned that working together can also be fun without your friends."
"I learned that doing research takes a long time."
"I learned that DNA is in hair and shedded skin cells, among others!"
"I learned how chromosomes look like!"
"It was difficult to put movies on a cd."
"I thought there were ten hereditary diseases in the families of the class, but there were a lot more."
"Next time I will plan better so that I finish everything on time."

Evaluation and reflection by the teacher and pre-service teacher

The strength of this project
The strength of this project was that the children looked very specifically at the 'hereditary' bond between themselves and their family. I noticed that the children were proud of their family and they released many stories about characteristics, and not only 'external' characteristics. Beautiful character traits were mentioned, or occupations, life stories, talents, etc. The children were aware that they are who they are as a result of all the genetic information from both the father and mother, grandparents, great grandparents and so-on! They are like the generations before them!

Recommendations for teachers
Teachers who want to run this project should not misjudge the theoretical knowledge about DNA. It is important that you read in advance and understand the material. The subject DNA is a complicated topic, especially if children come with questions and experiences. What teachers should not do is endlessly linger in the theory. Try to come up with nice exercises to share the knowledge with the children. Children want to get busy and not just listen!

Talents of children
The children must bear some responsibility for their research. Supplies and materials had to be in order, because otherwise they could not advance. They had to look ahead and plan. You also noticed in the groups that children with a strong talent for organizing took the lead. They arranged the telephone number, emailed institutions, made an appointment with the class and so-on.

DNA project caused a stir
It amazed me how the children all gave their own interpretation to the research. They all chose a meaningful question and presentation form that suited them. There was a boy who really wanted to work with microscopes: 'How does saliva look like up close? Can you see the cell nucleus with a microscope?'. It surprised me how much the DNA project addressed: all the pictures of the children and their families, all proud stories! Also, the first group discussion surprised me immensely. The theme 'hereditary traits' liberated the children in the sense that they all had an experience or a question about it. They all wanted to share something before moving on to the next phase of the process.

Learning outcome regarding research and science
The children have learned how to develop a research question, how to construct a solid plan in preparation for the research and that research takes a lot of time! In the DNA lab, they saw that many people work in such labs. There are a lot of people needed to do research. One handles everything in the computer, the other maintains the robots, and another examines everything under the microscope or examines small organisms. I believe this has left a great impression on them!

Learning outcome about concepts concerning DNA
Before and after the implementation of the project, we showed the children several pictures that concerned DNA such as a 'DNA helix', Down syndrome, fingerprints and Turner syndrome. Here we asked the students how these pictures are related to DNA. At the end of the project, the children were capable of relating the pictures to certain concepts that they learned during the different activities such as the concept of 'chromosomes'. You also noticed that students involved their own experiences in the explanation of the project. This allowed us to observe that the students had properly learned the concept. We found it very valuable to work with concepts within a given theme, because this way we were able to map the learning outcomes and got a good picture of what the children already knew prior to the project. We were also able to assess what the children learned about the concepts after class.

"Down syndrome. You can recognise it by the thickness of the eyes and the eyelids, it is involved with DNA, errors in the DNA." (Reaction of a child when observing a child with Down syndrome).

3.2.3 Project 'Unique due to new errors in your DNA' at De Lanteerne

Jan Konings (teacher elementary school De Lanteerne)
Kristel Arntz (teacher elementary school De Lanteerne)
Ilse van den Brand (pre-service teacher at the HAN)

Science and Technology on elementary school De Lanteerne

Elementary school De Lanteerne is a Jenaplan school. One of the basic principles of the Jenaplan education is that world orientation occupies a central role within the school based on experiencing, discovering and exploring. Inquiry-based learning starts with the curiosity of the children. Stimulating the children, creating a match with the children's experiences and promoting the curiosity of the children are, therefore, important aims of our education. But it is also a prerequisite for achieving other goals:

- To increase domain knowledge and to build a flexible conceptual framework;
- To gain insight into how knowledge is created;
- To develop research skills;
- To promote an inquisitive attitude.

With it, we hope that the children become more capable of using their curiosity as a starting point for new research. This also implies that teachers have to be better equipped to guide and encourage them. Developing knowledge and competencies of teachers within the field of science and technology is, therefore, an important goal.

Collaboration with the Science Education Hub and the 'Learning Square'

Collaboration with the Science Education Hub fits with these goals. One of the spearheads of the Science Education Hub is to promote the inquisitive attitude of children and teachers, and to familiarise them with the pedagogy of inquiry-based learning. In the meeting with scientists, young researchers, pre-service teachers and teachers, children experience what the world of science and technology has to offer them. This school year, we launched the so called 'Learning Square'. With this, we aim to create an environment where children can learn from this amazement and where an appeal is made on their natural ability to acquire knowledge. On the 'Learning Square', the children develop knowledge, abilities and skills that they need to orient themselves in the world. Their own learning and research questions form the starting point to this. The project that we started with the Science Education Hub is in line with the goals that we envision with the 'Learning Square', namely that children learn to ask questions and to provide them with the necessary tools to put those questions into research.

Core objectives of the Dutch curriculum

The same core objectives of the Dutch curriculum as those of elementary school 't Holthuus are addressed in this project (see paragraph 2.2.2).

Other goals

Knowledge and skill-related goals

- Increase knowledge about DNA and heredity.
- Skill-related goals (research skills, among others).
- Observing and experimenting/researching.
- Search skills and internet skills.
- Presenting and communicating.
- Desire to understand (thinking and reasoning about, formulating own statements).
- Desire to be innovative (searching for creative solutions and explanations).
- Desire to achieve something (working persistently and goal-oriented, thinking in terms of sequence and cause-and-effect relations, working carefully and respectfully with materials).
- Desire to be critical (measuring fairly, repetition of measurements).
- Collaboration skills
- Desire to share (information exchange, open to opinions of others).
- Attitude goals.
- Development of a positive attitude towards science.

Time investment

The project was implemented in two classes of grade 4-6. In addition to the teachers, a pre-service teacher was actively involved. At De Lanteerne, we divided the different phases of inquiry-based learning over several weeks. There are seven phases to distinguish and in total we devoted six weeks to working on this project. Every Monday afternoon was allocated towards the project. In addition, the children worked on the project during the week during hours allotted to independent working. This was hardly the case for the first two weeks though, because at the time they did not have enough assignments that they could fulfil independently. In the following weeks, these periods were occupied by the project.

Phase 1. Introduction 'DNA'

The activities in this phase are largely drawn from the workshop that we organised for the Winterschool of the Science Education Hub (a professionalisation day about Science & Technology). Through games, the children discover that everyone is unique (see section 2.2.1). After some theory about DNA and heredity is addressed, the students build and replicate their own DNA. The children were enthusiastic and told us afterwards that it "was not as difficult as they thought it would be". Several interesting questions came up (not necessarily to research, but still interesting…) such as: "If you eat meat, are you eating the animal's DNA?" or "What happens to your DNA when you die?".

The DNA strips

Phase 2. Exploring

DNA-circuit

To explore the topic, we designed a number of activities to be carried out by the children in circuit form. This way, they explore the theme of 'Heredity and DNA' from six different perspectives. The children then 'mess around' in a controlled fashion through the use of different work exercises. There are six different assignments:

- Did you know?
- It runs in the family
- Who am I?
- Watch and listen
- Building DNA
- Replicating

Did you know…?

On the tables there are a variety of books about DNA, heredity, cloning, family, diseases and so-on. There is also a list of questions about all sorts of facts about these topics. By first finding the right book and then making use of the index, the children find the answers to various questions. They record these together under a scheme. If they do this well, the following can be read from top to bottom: "The apple does not fall far from the tree." The purpose of this activity is to improve the children's capability in searching for information and become acquainted with many facts about DNA and heredity.

That sheep is named Dolly!

It runs in the family

The children were instructed to make a 'baby candy animal' according to the blueprint of the mother and father candy animals. For this, they picked up a strip 'father' with the characteristics of the father and a strip 'mother' with her characteristics. The blueprint with the characteristics was invented by ourselves:

- The tail could be long or short.
- The eyes could be on the side or the front.
- The head could be angled or twisted.
- The body could be long or short.
- The legs could have different colours.

"I learned that the father and mother have different DNA." (Student)

Tabel 2. Components and possible characteristics of the candy animal

	Characteristic	
Torso	Long 	Short 
Head	Angled 	Twisted 
Feet	Green 	Other colours 
Eyes	Front 	Side 
Tail	Long and thin 	Short and wide 

The children had to base their baby candy animals on the characteristics of both parents. If the father and mother both have a long tail (a long sour mat), then the child will naturally have this as well. But what if the father has a long torso (3 marshmallows on a skewer) and the mother a short torso (only 2 marshmallows)? Then both cannot be, so one or the other has to be chosen. Through this assignment, the children become aware of the fact that characteristics are derived from both parents. In addition, they learn that some characteristics win (are dominant). Of course the children based their choice on 'as much candy as possible'. So if you had to choose between a long or a short tail, then this would not be a difficult decision and the long tail seemed dominant!

How do you like my animal?

Below is an example:

Table 3. Characteristics from father, mother and the baby candy animal

	Tail	Eyes	Head	Torso	Feet
Father	Short	Front	Twisted	Short	Coloured
Mother	Short	Side	Twisted	Long	Green
Child/candy animal	Short	Front	Twisted	Long	Coloured

Who am I?

Using a 'do-book', the children playfully explore their inherited characteristics and make a handcrafted DNA puzzle6. Through this assignment, the children become aware of their and their families hereditary characteristics.

"I made a candy animal, he has something from his mother and something from his father." (Student)

Working with the do-book.

'Watch and listen'

On the internet is much information to be found about DNA and heredity. Following an assignment made by us, the children came into contact with different informative sites. The students saw a film of Klokhuis in which it became apparent that DNA plays an important role in tracking criminals. The children were also introduced to Bogi which explains about heredity. Through these assignments and the accompanying questions, the children acquired knowledge about various aspects of heredity and DNA in different ways.

DNA assignment sheet

- Watch the film from schooltv [Only available in Dutch]
  Can you answer the following questions:
  1. Why is DNA like a fingerprint?
  2. Name a few characteristics that are stored in your DNA

  DNA is therefore also important for solving a crime.

- Watch the fragment from Klokhuis7, pay attention! Until 4:30 minutes. [Only available in Dutch]
  1. Why can a piece of gum help track a criminal?
  2. What does the forensic detective look for?

- Continue the episode from Klokhuis7, from 7:45 minutes until 8:40 minutes. [Only available in Dutch]
  1. Can you now explain how the forensic detective tracks a criminal?

- Time left?! Meet Bogi8 [Only available in Dutch]
  Bogi is a website containing information about heredity. Children can obtain this information by playing a game, listening to a rap and reading texts.

"I learned that it was quite difficult and not one DNA is the same." (Student)

Building DNA

With the magnetic sticks and marbles from Magnetix, the children attempt to build a DNA double-helix. There is an example illustrated on paper and they have to figure out themselves how to recreate it with the provided material. To do this, they make use of their knowledge acquired from the first lesson to establish the correct colour combinations. Some children succeed in creating the helix with its beautifully twisted structure. Through this assignment, the children acquire insight into the composition and physical attributes of DNA.

"And now turn."

"The reconstruction of DNA was rather difficult, it kept falling over." (Student)

Time to replicate

In this activity, a link is made with the replication of DNA, which continuously occurs in all living organisms. The intention is that the children on the bead boards replicate the given examples as quickly as possible. They experience how (time) pressure can influence the replication process, especially as the examples becomes more complex. Student: "Wow! Why do we not do this more often?" Teacher: "Maybe because it is kindergarten work?" Student: "And? That is why it is fun!"

Student 1: "I did not made any mistakes."
Student 2: "But you did not complete it."
Student 1: "Yes, but I did not make any mistakes."

Phase 3. Designing research

What do we still want to know?

A crucial stage in the activity cycle involves designing and formulating the research question. We look back on the first two weeks and identify what knowledge and questions about DNA and heredity we acquired. Everyone writes that down on cards which we stick to two posters; one for the things we already know and the other for the things we still want to know. Generating facts and questions about what is and is not already known about DNA and heredity was enthusiastically resumed by the children the following day and resulted in two full posters in no time.

Characteristics of a good research question

The second poster is the starting point for a group discussion on good research questions, whereby the children use their experience with questions for the 'Learning Square'. They mentioned the following characteristics for a good question:

- You should not yet know the answer;
- You need to want to know or learn something;
- It must be entirely clear what you exactly want;
- With it, you can move forward, you can work with it;
- It is an open question.

"Can you change DNA?" (Student)

Research domains

After we had established what a good research question is, we hung coloured sheets with the answers above the board. The research domains were explored in order to inspire the students towards devising appropriate research questions. These domains included:

- Heredity;
- Coding (where do you use codes, why, when and what is the best);
- Replicating (when does it work best, how do errors occur, is that detrimental);
- Ethical concerns (do you want to know everything about what is in your DNA, should researchers and doctors be allowed to change hereditary characteristics);
- And coming up with an ideal information carrier and identifying the criteria it must fulfil. Information in DNA determines who you are and thus is very important. How would you store everything that is highly important to you so that it is easy to take it with you and keep it protected from loss, theft or damage? (See also the crafting assignment in section 2.2.2).

I explain to the children that there are different types of questions and with that knowledge we look at the poster. We assess which questions are research questions and how they differ from other types of questions.

Types of research questions

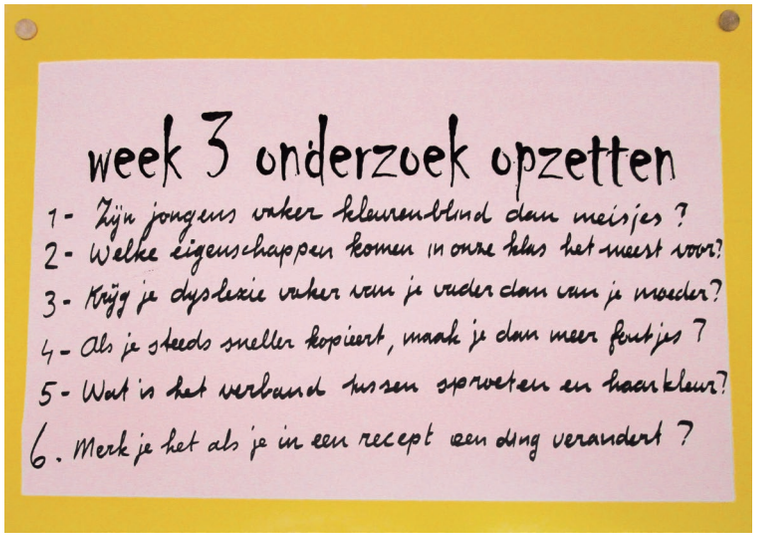
To properly show the children that there are different types of research questions, we address the different types with a few examples. We also identify the possible research areas that work with these questions. We then show a film about the project 'Fear' (see book 1, project Fear, film 4) [Only available in Dutch]. The film illustrated how the children, which participated in the previous year, received explanations about how to design a research question. It was for many children an eye-opener to see their peers struggle with the same things. And it was especially very inspiring to see the fun and the original studies that resulted from it.

From question to research question

In each group, the children think of a question. In doing so, they use the 'What do we want to know' poster as a starting point. The challenge here was to convert those questions to researchable questions. In the group discussion, the children were able to quickly categorize the different types of questions. That resulted in researchable topics with varying results from which each group chose one. For example, a question about whether dyslexia is hereditary was made researchable by changing it into 'Is dyslexia more common in boys or girls?'. The question of how many mistakes can be made before you notice something, ultimately resulted in the question of whether you notice it if you change a recipe component for apple turnovers. The pre-service teacher and I walked around to support them.

At the end of the lesson, all six groups presented their question during the group discussion. One group could not decide, but with specific questions we were able to help them further. They wanted to know more about the probability of a certain eye colour. In each group, we looked together if they indeed came up with a good research question. Is it executable at school? Is it a question which you can get to work on? For some questions, there was still some uncertainty. For this, we requested feedback from the Science Education Hub.

If the children do not come to a research question, then ask specific questions such as:
Which characteristics of yourself would you like to explore?
Which facts from the poster are interesting?
What did you do during the 'mess around' lesson that you would like to continue with?



The research questions. And now to work!

Adjusting questions

A group had come up with the question of whether you could change DNA and wanted to incorporate Brussels sprouts in hamburgers. 'If the children, who do not like Brussels sprouts, enjoy the hamburger, then we changed their DNA.' This was, as we presumed, not a question that could be researched at school. This group changed their plans of Brussels sprouts to apple turnovers and wanted to research if small mistakes in the recipe affected the taste.

Division of roles

Each group is responsible for a clear division of roles and tasks which derived from the cooperative work forms: president, secretary, head experimenter and controller. The research question is then translated into a research plan. For this, each group receives a worksheet that serves as a step-by-step plan to organise the various aspects of the research after which the logistics operation is initiated. The research plan was first addressed with the entire class. In the following lessons, the necessary materials are collected, rooms reserved, questionnaires prepared… etc.

Phase 4. Executing research

Below are a few descriptions of the research carried out by the students

'Are boys more often colour blind than girls?'

This group used laptops to perform tests with a research group. The probability of colour blindness is then displayed using various pie charts.

'What characteristics are on average the most common in our class and in the class of the Zebras?

This group took the results from the 'everyone is unique' game from the first lesson which they converted into percentages and processed these into a graph. Then they ran the same questions in a different class and also converted the results into percentages. The result was two overviews of the average most common characteristics in both classes. With these data, two large figures were drawn to represent the average child of 'the Rockcrystal' and the average child of 'the Zebras'. Funny enough, these figures were equipped with four arms each. One pair of arms was necessary to demonstrate which hand is above the other when the arms are crossed and the other pair was to show which thumb is above the other when the hands are intertwined.

What colour hair is most common in our class?

'Are boys more often dyslexic than girls?'
This group developed a questionnaire which was distributed to all dyslexic children in school. They had to fill the questionnaire at home, because a few questions pertained to the fathers, mothers, grandparents, etc. This was to establish whether you inherit dyslexia more often from your father's side or your mother's side.

'What is the relation between freckles and hair colour?'
Children with freckles from all classes were summoned. Subdividing the students based on hair colour was quite difficult, because how do you define hair colour (dark, quite dark, very dark)?


Sem provides a little peek into the results.

Phase 5. Concluding

'Are boys or girls better in replicating under pressure and without pressure?'

This group was inspired by the supplementary exercise from the introduction lesson. They found this to be a fun assignment and were curious whether girls or boys were better at this when performing the exercise in an environment characterised by a lot of distractions. The original research question was: 'Are boys or girls better in replicating under pressure?'. After discussing it, we came upon the idea that it would also be interesting to observe replication without pressure. Hence why the research question was ultimately adjusted to: 'Are boys or girls better in replicating under pressure and without pressure? (In this research, replicating should actually be called completing).

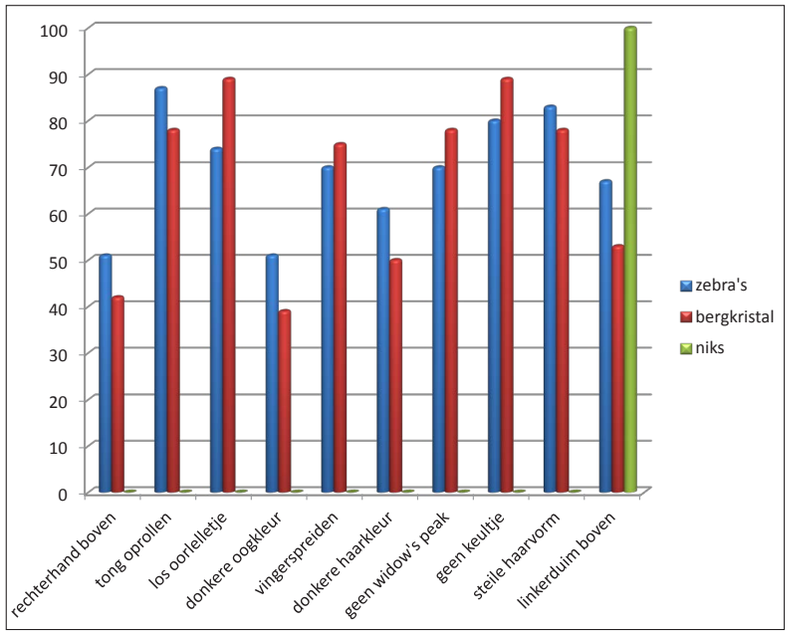
This group of young researchers made strips with four colours on the computer. The children received the instruction to mark a green stripe next to a red stripe and a blue stripe next to a yellow stripe using a marker. They requested 2 boys and 2 girls from each grade 6 class to participate. These subjects received 50 seconds to complete the assignment. After a break, the same assignment was repeated, but this time, the researchers ensured for the necessary distraction. The distraction was elicited through talking, playing music from a cell phone, falling books and a running faucet. The subjects were not informed that these distractions were part of the experiment.
The amount of correct and wrong stripes were recorded. The researchers ultimately concluded that boys perform better without distractions, but that girls perform better 'under pressure', so environmental distractions.

'Do you notice it when there is a mistake in the recipe?'
The children decided to research whether it is bad if a minor mistake is made in a recipe. They did this by making mini apple turnovers, each slightly differing from the other. There were 'standard apple turnovers' made according to a fixed recipe and also apple turnovers with a mistake in a different step of the recipe: different apples, different dough, no sugar, no cinnamon, etc. All apple turnovers were provided with flags, so that the researchers could distinguish them.'Heeft rekentalent met je DNA te maken?'

Then the children from the tasting panel were allowed to enter the 'tasting room' one-by-one where they tasted two apple turnovers, a normal and a flawed one. They then had to indicate whether the second apple turnover tasted identical to the first or if they noticed something different. In the latter case, they had to mention how it tasted different.

Does she taste it or does she not taste it?

What was striking was that most of the children tasted no difference or that they believed to have tasted something which was not incorporated in the apple turnover. For example, one apple turnover without sugar was said to taste sweeter. At the final evaluation, the search for explanations about these observations yielded interesting results. The children came to the conclusion that the apple turnovers always differed from each other, because there was never an identical amount of pieces of apple or identical amount of dough. In other words: the need to keep certain factors constant and only manipulating one variable was experienced through this.



Bar graph illustrating the percentages of characteristics that were present in the two classes

'Is mathematics talent related to your DNA?'
This group was very curious about the genetic influence on intelligence. They soon found out that this was a very broad topic and the group of young researchers decided to focus more on the field of mathematics. However, they stumbled against a(n) (ethical) dilemma. The research would then involve those people weaker in mathematics, which would not be considerate towards them. A discussion about this eventually lead to the choice: 'Kieners' as subjects (Kieners are mathematicians that are challenged by enriching calculation programs). In every class in grade 6, Kieners received a form for their parents. The parents could then submit their average score for mathematics in grade 6.

This group eventually had a little trouble with drawing a conclusion. What they forgot to do prior to the research was to determine a threshold value: when is and isn't there a relation between genetics and mathematics? Their conclusion provoked an interesting discussion within the group. Because if the mother has an average of 7, is this considered an inherited talent or not? And where is the threshold? The data showed that the fathers of the 'Kieners' had on average a higher report grade in grade 6 than the mothers.

Table 4. From the research logbook

	'Is mathematics talent related to your DNA?'
16-04	How are we going to do it: with a survey and letters. Audience: grade 6 (Kieners)
17-04	We filled in the sheet and are a step further.
20-04	We distributed the letters through the teachers and Monday we will do the other letters. After that, we can research. We have not been able to distribute everything.
23-04	Today we are going to give the letters to the parents. Hopefully they fill it in and hand it in, so that we can start researching. Hopefully the teachers approve of us testing a sample.
23-04	We have now distributed the two letters, however there was one mistake in the letter. But we resolved that. Wednesday/Tuesday it is returned and we can start our research.
26-04	I have been working on DNA at the 'Learning Square'. I calculated the average of the grades of the fathers and mothers.
08-05	Today we are going to put the information in PowerPoint. Then we are going to determine who is going to say what. After that, we will rehearse our piece and present it later this afternoon. Our hypothesis is that we expect the mathematics talent of Kieners has to do with the mathematics talent of grade 7 of their parents.
14-05	This project was about DNA. Your body is made up of cells and in those cells is DNA. On Friday (11-05) we went to the Radboud Hospital. We had three groups. One group was shown a PowerPoint by the researcher. The other group was given a tour through the laboratory. And the others conducted a small DNA research. Every 20 minutes we switched. The DNA research that we were allowed to do: first we had to rinse our mouths with salt water and then spit it into a small container. Then we had to gently shake it, so that the DNA would come together and then we added alcohol and shook it again and.. YOU HAVE YOUR DNA!

Phase 6. Presenting

During the presentations, five groups made use of a PowerPoint presentation to present the research results and one group made a poster for it. Two groups performed a theatrical piece and one group had drawn two large figures which represented the average student.

Phase 7. Deepening/broadening

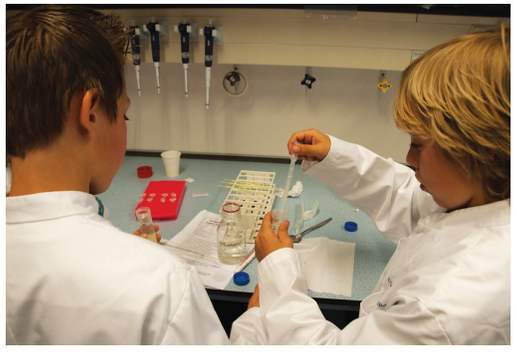
Also the children of elementary school De Lanteerne visited the DNA lab at the Radboud Hospital. Some reports from the children follow below:

On 11 May 2012 we went to the Radboud Hospital to learn more about DNA. We watched a movie about blind and deaf fish, and then received a tour of the department of DNA. Inside there were robot machines that replicated and read the DNA, that occurred real quickly. In the lab we examined our own DNA. You had to rinse your mouth with salt water, which was unpleasant and when you were done with rinsing, you spat it into a container. A detergent was then added to the container and the white threads were extracted, that was your DNA.

Seeing if your DNA becomes visible

11 may 2012

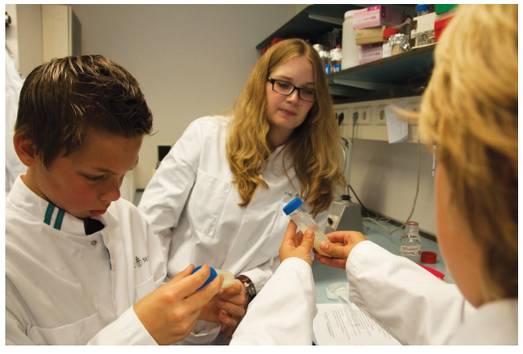
We went to the Radboud Hospital and we went there by bike. When we arrived, we were received by Mr. Diederik. He lead us to a room where we could deposit our bags and coats. Then he informed us a bit. We were split into three groups and I went to the lab with Clemens. There you had to swallow salt water and rinse your mouth, then spit it out and add soap to it, and mix it well. After you had to add alcohol, so that the DNA clumped together and that went into a small container. Later you could take it with you. Then we went with Mr. Diederik for a tour of the building. We passed devices where they isolate DNA and there it was slightly cooler. Then there was a PowerPoint about fish, it was a nice day!



Isolating DNA

Radboud Hospital

We went with the class to the Radboud Hospital. We went by bike. First we received a tour. There were a lot of machines with gripping arms which were reading DNA. Then we went to the laboratory, there we had to isolate our own DNA. We first received very salty water in our mouths to loosen our cells. Then we added alcohol, so that the DNA would stick together. The DNA we could take with us in a container. Afterwards a man showed us a PowerPoint about zebrafish that were deaf and not deaf. And about dogs that were blind, but which received medicine so they could see again. At the end we were allowed to ask questions about DNA.



Isolating DNA together with a researcher

See my DNA

Evaluations and reflections from elementary school De Lanteerne

Evaluations by the children
Here below are several reactions by the children from the written evaluation.

What did you think of working in a group to come up with and research a research question? What went really well and what did not go so well?

- "I thought it was great! You learned a lot from each other."
- "I liked it, because you were allowed to ask your own question."
- "Coming up with a question went well, because we voted for it."
- "I thought it was fun and difficult to come up with a research question."

What would you do differently next time?

- "Work faster."
- "Recruit more children, because you then know more."
- "I would not change anything."
- "Think of a better question."

What did you learn about DNA during this project?

- "That DNA continuously replicates."
- "That an error in the DNA is not necessarily bad."
- "You can track thieves with DNA."
- "That if you uncoiled the DNA, you could go to and back from the sun 400 times."
- "That DNA is the blueprint of the body."

What did you learn about working together?

- "That it is better to discuss."
- "That it would not have been a success if I worked on my own."
- "That you need to adjust yourself sometimes."
- "That you need to divide the roles properly."

What did you learn about doing research?

- "That you need to stick to your plan."
- "That everything needs to be precise."
- "That it has to be fair."
- "Prepare well."
- "That you need to write everything down."
- "That not everything always works out well during research."

Name three other things you have learned during this project:

- "That on average the fathers of Kieners are better."
- "That mistakes are not always bad."
- "You have to give everyone something to do."
- "Recessive and dominant."
- "Yellow with blue and red with green."
- "And that the police uses DNA."
- "How they can see whether fish are deaf or blind."
- "That you receive half from your mother and half from your father."
- "That everyone has different DNA."
- "If you have errors, it can lead to cancer."
- "Your whole body is composed of DNA."
- "If you eat meat, you eat DNA."

What else do you want to say about this project?

- "That it was fun and educational."
- "That I will never go to the bathroom while they divide the roles."

Evaluations by pre-service teachers and teachers

Pay sufficient attention to formulating the research question

In hindsight, it is important to pay a lot of attention to the phase 'formulating research questions'. It is difficult for children to keep their questions concrete and 'small'. But also for teachers it is a challenge to provide each group with sufficient guidance without steering too much. Some groups started very large, such as 'Why do Chinese and Japanese people have squinty eyes?' or 'How did people come to existence?'.

Both research questions and knowledge were gained

The children have, for the first time, learned a lot in two areas; on one hand about DNA and DNA replication, on the other hand they have mastered many research skills. Somewhere halfway through the project, I was sitting at my desk and I overheard children that were working independently say: "no, that is not our target audience" or "we need to write this down properly and ensure that everything stays the same, otherwise our research results will not be good". Even children from grades 5 and 6 had similar remarks! That surely indicates that they have learned a lot!

Research and science has become more concrete

I think science, research and the university has become a little more concrete for the children after this project. They now have a better idea of what it entails. In addition, I can probably imagine (although I did not ask them!) that some children think that all professors and researchers are 'busy with DNA'… I would like to devote some attention to this during my classes. For children, doing research has become clearer to them.

Other authors

- Jos Marell (pre-service teacher instructor at the HAN)
- Winnie Meijer (project assistant WKRU)
- Marieke Peeters (project leader WKRU)

DNA