The meaning students attribute to genome metaphors

Name: Melanie van Berkum
Student number: 3383644
Number of ECTS: 30
Supervisor: Dirk Jan Boerwinkel
Second assessor: Liesbeth de Bakker

Institute: Freudenthal Institute for Science and Mathematics Education
University Utrecht, Faculteit Bètawetenschappen,
Departement Biologie

Possible journal to submit to: Journal of Biological Education

Abstract

There are several reasons why people should undergo genetic tests. To make informed decisions, people should have a basic knowledge in genetics, what is taught at high school. Genetics is often hard to understand, and for that reason metaphors are used to explain the genome. The blueprint and the recipe metaphors are often used and also both determined as excessively deterministic. Metaphors are also pluripotent and used different in different contexts. For that reason, in this research we studied how students use genome metaphors, and how they use these metaphors in different contexts. In total, twelve students of four different schools were interviewed.

This research showed that there is a great difference in the use of metaphors between students: only 21 percent of the comparisons that are made between genome and blueprint consist of one unique comparison by several students, without another comparison. Besides that, there were many incorrect comparisons: the input component (genome, blueprint and recipe) was compared with the translated component (organism, building, meal). Comparisons were also made between parts of the genome and the metaphor, which contained different characteristics. When students were asked to the view they had about the genome and the metaphor, it seemed that students did not always combine genome characteristics with characteristics of the metaphor. This shows that when students have a deterministic meaning of the metaphor, they do not immediately have a deterministic view of the genome.

When students were asked to the involvement of the genome and environment on their life and in different contexts, and how much the metaphors fitted with the different contexts, it appeared that the greater the influence of the environment, the less the metaphors fits. This shows that the meaning that students attribute to genome metaphors depends on the context in which it is used.

This research shows that the use of metaphors does not always lead to better understanding of the genome. However, metaphors can be used in science education, for example to test the preconceptions of students about the genome.

Index

Introduction

There are several causes for an increase in situations in which people undergo genetic tests. One of them is that genetic testing becomes faster, cheaper and more relevant for a host of diseases. Another reason is that genetic tests can also be used in society, for example in using genetic information for insurance, forensics or sports, in order to measure risk factors. The population should learn to use information from genetic research to make informed decisions about pre-symptomatic genetic testing. However, this genetic information is often hard to understand (Boerwinkel, Knippels & Waarlo, 2011). To make well informed choices, the population should have a basic knowledge about genetic processes and in particular be aware of what genetic information predicts (Condit & Condit, 2001). Understanding genetic processes and have an opinion about genetics related topics are both critical parts of scientific literacy, what is taught at high school (Duncan & Reiser, 2007). For that reason, students should be taught well in this branch of biology: genetics.

Genetics, the study of heredity, is one of the several biological sub disciplines that is hard to understand (Konopka, 2002). Genetics encompasses several organizational levels, while most students do not see the connection between these different levels (Knippels, 2002). In addition, the genome is invisible which makes the understanding of genetic processes abstract and therefore difficult (Duncan & Reiser, 2007).

Since it is impossible to see the genome and its processes, one way to improve understanding of genetics and make the genome more visible is the use of metaphors (Condit & Condit, 2001). Metaphors have the ability to clarify concepts by connecting facts and interpretations and are important to prevent misconceptions and misinterpretations (Konopka, 2002). In daily use they are often applied: a well-known metaphor is 'time is money' (Lakoff & Johnson, 2008). Use of metaphors also has risks: metaphors are complex, pluripotent and can lead to several meanings among users (Condit & Condit, 2001).

Already in the eighties and nineties of the last century the metaphors 'blueprint' and 'recipe', which are used to explain genome functions, were investigated. Even though these metaphors are different and are used often in the media and by scientists, they both were considered to be excessively deterministic (Condit et al., 2002). The blueprint metaphor does not encompass all features of the genome and is for that reason not as complete as it should be (Pigliucci & Boudry, 2011). The recipe metaphor is less static, but is for the same reasons as the blueprint not applicable (Condit & Condit, 2001). They both do not take epigenetic processes into account, which is an important aspect because of its ability to influence gene expression. Therefore the blueprint and recipe metaphors might be too old-fashioned to explain the genome (Cohen, Bates & Efroni, 2009).

Condit et al. (2002) concluded that the meaning of metaphors differed in different contexts. Each metaphor also appeared to have different associations, depending on the user (Condit et al., 2002). Study of Heijkoop (2013) showed that a majority of 11th grade students with a biology course preferred the blueprint metaphor over the recipe metaphor, because the students believe that the blueprint and the genome are both a design that has to be executed, a deterministic characteristic.

Self-invented metaphors were also mainly deterministic in character. Besides that, students can simultaneously use several different metaphors, allowing students to have different interpretations, and thus it is not sure whether these students really have a deterministic view of the genome (Lammers, 2010). This is in line with the findings that can be pluripotent and the context in which it is used (Condit et al., 2002).

These properties (pluripotency and different meaning of metaphors in different contexts) are not studied yet and this is the knowledge gap. It is important to study these properties in understanding the meaning that students address to genome metaphors in order to comprehend the genome. For that reason, this research will focus on the understandings that students have of the genome metaphors. It will be investigated how students use the metaphors, how much the meaning between students differs and how much the interpretation depends on the context.
With this information, teachers will know better how to use genome metaphors in their lessons. This can lead to correct use of metaphors (in media and in education) and can thus prevent wrong predictive genetic typing and incorrect risk measurement (Condit & Condit, 2001). A more general contribution of this research is that the use of metaphors by students will be better understood, especially which aspects have an effect on the meaning of metaphors, and how the meaning can differ in different contexts and between different users.

Research aims and research question

The aim of this research is to improve the knowledge about the meaning that students attribute to the metaphors in different contexts and how they use metaphors in reasoning about the genome. Results of this research can be used in teacher training and development of educational materials, with recommendations about the productive use of these metaphors in classroom.

The main research question is:
Which meaning do students attribute to genome metaphors?

The meaning that students attribute to genome metaphors can be investigated by studying how students relate the genome with the metaphor. Therefore, students are asked how they relate genome characteristics with characteristics of the metaphor.

This main question will be answered by the use of the following sub questions:
1. *How do students match genome characteristics with characteristics of the metaphor?*
2. *To what extent does the meaning that students attribute to a metaphor depend on the context in which the genome is discussed?*

Theoretical background

Metaphors in general

Aristotle is the founder of rhetorical theory, of which the metaphor is an important part and is still fundamental for language (Condit et al., 2002). Metaphors are innovative, problem-solving and can clarify concepts and relationships (Knudsen, 2005). They can avoid misconceptions and misinterpretations, and are therefore essential for the communication of concepts (Konopka, 2002). Finally, metaphors can organize the meaning cognitively and emotionally, by emphasizing relationships, while weakening others (Condit & Condit, 2001).

Cameron (1999) gave a definition for the metaphor:

> A stretch of language in its discourse context is said to be a linguistic metaphor if it contains a reference to a Topic domain by a Source term (or terms) and there is potentially an incongruity between the domain of the Source term and the Topic domain. (p. 118).

Recording to this, a metaphor consists of three parts (Ceccarelli, 2004; Knudsen, 2005).

1. The target: the subject we would like to explain (also called the target domain)
2. The source: the metaphor (also called the source domain)
3. The relationships between the target and the source.

An example is the metaphor 'love is war' (Lakoff & Johnson, 2008). The word that should be explained is the target, in this case 'love'. The word with which this should be compared, the source domain, is 'war'. The user of the metaphor combines the presuppositions of the source (war), with the target (love), en within the context of the target, the target will be understood (Lakoff & Johnson, 2008). In the future, the terms 'source' and 'target' will be used to make a distinction between the metaphor and the concept that should be explained respectively. The target and source are not related, but do share relations or characteristics. (Knudsen, 2005). It should be avoided that the target and source are too much the same: then the target cannot be explained properly because it is not sure whether the metaphor really is a metaphor or not. However, the target and source should not be too different: then the source is not related with the target and cannot explain the target (Knudsen, 2005; Martins & Ogborn, 2007).

Metaphors are not developed with a scoop. Sometimes it takes more than 25 years to construct a metaphor. A metaphor is designed hypothetically and by using it, relevant comparisons can be made. Sometimes new insights can come up, while in other cases additional metaphors are generated, which is together a long process of creating the perfect metaphor. This will lead to one root-metaphor, with surrounding related metaphors. These related metaphors can be used to explain or scaffold the root-metaphor. An example in biology is the root-metaphor code for genetic information. This metaphor is surrounded by scaffolding metaphors like 'digits', words', 'letters' (for the use of 'bases', 'amino acids' and 'protein') (Knudsen, 2005).

Users of a metaphor should be aware that the source is a metaphor, and that it is not exactly the same as the target domain (Knudsen, 2005). Sometimes multiple metaphors are used together, to improve the perception of the target by the use of the interaction between different metaphors.

This will improve the complexity of the metaphors (Ceccarelli, 2004). No metaphor gives the full meaning of a word and therefore metaphors can interact with each other (Condit & Condit, 2001). Condit and Condit (2001) state that every user of a metaphor has its own association and meaning, and also depends in which discourse or context the metaphor is used. Sometimes it is thought that metaphors only have one meaning, in contrast with scientists who believe that metaphors have different meanings, depending of the user (Condit et al., 2002). What is in common is that novel metaphors can be used in several ways, and for that reason developers of the metaphor should push the users of metaphors in the right direction so people get the intended meaning of the metaphor (Knudsen, 2005). It is not sure whether the metaphors which are used in this research, the blueprint and the recipe, are used in the right way and people get the intended meaning or not. For that reason, the meaning that students attribute to genome metaphor is studied.

Metaphors in science education

Metaphors are not only used in daily life, but also in science education. In science, many concepts are hard to understand because they are invisible or perceived by other senses. In science education, many concepts are based on models, derived from scientists, what is hard to imagine. Therefore, concepts have to be imagined, and one way to do this is by the use of metaphors (Niebert, Marsch & Treagust, 2012). Often, textbooks use metaphors to clarify a difficult concept:

> The body’s three lines of defense are somewhat analogous to the defenses of a besieged city: first the city walls, then ordinary soldiers, and finally intelligence officers who identify and track down specific dangerous infiltrators (Campbell & Reece, 2002, page 900)

Teachers have an important role in the construction of knowledge with the aid of metaphors. Concepts are constructed when students make comparisons between source and target, and teachers help to clarify the metaphor (Niebert et al., 2012).

There are some difficulties with metaphors in science. Wilbers and Duit (2006) point out that the process of making comparisons between source and target is dependent on prior experience. Students have other experiences than teachers, and therefore it is difficult for students to make comparisons, while this is for the teacher less difficult. When the source domain of students is different from the teachers, the target domain will also differ. Therefore, students have to actively built this knowledge. Another difficulty is that not all aspects of a source domain are in the target domain and vice versa (Niebert et al., 2012). For that reason, this property of metaphors is studied in this research to gain insight into how students compare genome (target) characteristics with characteristics of the metaphor (source).

Metaphors in genetics

Metaphors should be studied so that they can be further developed. This is especially the case because the explanation of the metaphor changes in time because of new findings and developments (Knudsen, 2005). One discipline in which there are often new developments and which is one of the toughest subject in biology, is genetics, which is challenging for learners to understand. Genetics is very complicated because it encompasses several organizational levels, these levels are ontological different and because the genome is invisible and inaccessible (Duncan & Reiser, 2007).

To gain the right understanding of the genome, students should have a basic knowledge about the molecular complexes and mechanisms. However, they also should know that these mechanisms are a moderator of the effects of the genes. Most students do not see how genetic effects are mediated. In other words: students do not understand that proteins are involved in genetics (Duncan & Reiser, 2007). Metaphors can be useful in biology, especially in genetics, because of its ability of forming relationships between different concepts (Condit & Condit, 2001). Therefore, it is necessary that metaphors are well developed when used in genetics, and that metaphors include all characteristics of the genome.

In 1944 the first metaphor in genetics is described: the genetic code, in order to understand the process of the synthesis of proteins. However, this root-metaphor was not perfect and too narrow and for that reason new, less conventional metaphors are developed (Knudsen, 2005). These metaphors such as computer disks, books, cassette tapes and maps, were found to be equal to the code metaphor and therefore had the same objections (Condit & Condit, 2001).

The blueprint and recipe metaphor

During the 1980s and 1990s a new metaphor evolved: the blueprint metaphor (Condit et al., 2002). This metaphor was considered to be excessively deterministic, because it indicates a too simple relationship between cause and effect. Because this metaphor seemed to be too deterministic, simple and static and thus inappropriate, a new metaphor was considered to be more appropriate: the recipe metaphor (Condit & Condit, 2001). Katz Rothman, author of the book Genetic maps and Human Imaginations: The Limits of Science in Understanding Who We Are (1998), stated that the recipe includes time, process, growth and variability, while the blueprint does not include that. Besides that, in a recipe there is no one-to-one relationship between the ingredients and the end-result (for example: a meal), just like genes and that end-result (for example: eye color), what is the case with blueprints.

Condit and Condit (2001) refute this by saying both metaphors are the same and that the blueprint is also variable. They say the recipe metaphor is rather used than the blueprint metaphor because people are more familiar with it, especially females. That is why preference of the blueprint and recipe metaphor depends on gender and familiarity. However, both metaphors seem to be too simple and do not suit with the genome.

A quantitative survey with undergraduate students is performed by Condit et al. (2002) to study the meanings that are activated by the use of the metaphors. A semantic scale was used to determine the attitude of students towards the blueprint and recipe metaphor. The blueprint was considered to be less variable, more fixed, more controlling, more uniform and more determined than the recipe. The recipe metaphor was considered to be smaller, more personal, more simple, more friendly, more familiar and more female. Both metaphors were more related to production than to growth (Condit et al., 2002).

Condit et al. (2002) found out that the recipe and the blueprint metaphor both provide several meanings in different people. To investigate the meaning in more detail, an interview study was performed, and both metaphors appeared to have a one-to-one correspondence between original ingredients and final results. This showed that the preference for a metaphor did not depend on the deterministic characteristics of a metaphor. The wide dispersion of opinion can be explained by various clusters of people that shared the same results, due to different contexts en social groups. The familiarity of the recipe metaphors turned out to be important that people preferred this recipe above the blueprint (Condit et al., 2002).

Carver, Waldahl and Breivik (2008) stated that different meanings, attributed to the concept gene, are used in different contexts and that the concept can be communicated in different ways. Based on their research they developed a framework to classify different gene frames (see Table 1). These frames are all different in the way that the concept 'gene' is communicated and gives a different meaning to the concept. Each frame results in a different interpretation of the gene (Carver et al., 2008).

Table 1
Gene frames, according to Carver et al. (2008)

Gene frame	**Subframe**	**Description of the gene**	**Key words and phrases**	**Metaphors**
Materialistic	-	A discrete physical unit	DNA, chromosome, identify, locate, isolate, deliver, transfer, specific, replace, inject, discover, code, protein, mutation	Alphabet, book, map, code
Deterministic	Classic	A definite causal agent	Gene for, cause, control, culprit, blame, disease-gene, responsible for, wired in genes, born with	Computer program, recipe/instruction manual
	Gene versus environment	Contrary to environmental factors	Genes or environment, not down to our genes, genetic, environmental	-
Relativistic	-	A predisposing factor	Risk, chance, factor, associated with, susceptible to, linked to, contribute, predispose, interfere, influence, play a part in, genes are involved	-
Evolutionary	Unit of selection	The central object of evolution	Being selected, make copies, replicate, reproduce, through generations, adapt, maladaptive	The selfish gene
	Historical	A marker for evolutionary stage	Evolve, evolutionary relatedness, conserve, diversity, development, DNA record, gene bank, marker, extinction, change	-
	Interactive	Interacting with the environment	Interact, complexity, dynamic, capacity, external influence, environment, depends on, in combination with, affected by, expression, triggered by, prevent, respond, turn on/off	Like a switch or tap
Symbolic	Rhetorical	An abstract representation of inheritance	It must be in the genes, good genes, gene pool, inherit, talent, ' I inherited a shopping gene'	-
	Metaphoric	A metaphor for information transfer	For example, Mazda got ' Ford genes'	-

The first frame is the frame that is the most present at biology textbooks and is often used in newspapers. The 'code' metaphor is an example. The deterministic frame is discussed by Cohen et al. (2009), and is an example where there is an one-to-one relation between gene and protein, as discussed below. The relativistic frame is often used in newspapers, for example when risks for breast cancer are discussed. In the evolutionary frame both the environment and complexity are involved, and therefore a complete image of the genome is present. The last frame, the symbolic frame is often unscientific and humoristic.

As said, the evolutionary frame is the most complete frame, and involves all the processes and influences of the genome. The genome is indefinite, developed by evolution, and DNA sequences are modified by several epigenetic processes. DNA is not just the precursor of RNA and proteins: RNA and proteins can also regulate DNA, just like the environment: this means that there is no one-to-one relationship between DNA and proteins. These features are not included in a deterministic metaphor, such as the computer program metaphor (Carver et al., 2008), but has to be included in genome metaphors. For that reason, in this research it will be studied whether these characteristics are present in the blueprint and recipe metaphor, also determined as deterministic metaphors, even though they are not present in the deterministic computer program metaphor. The following characteristics will be studied, and are based on Cohen et al. (2009):

- A DNA sequence is interrupted by introns (meaningless DNA) .
- A gene can produce different proteins.
- A protein can function in different ways in stages of development.
- The DNA is changed by evolution.
- The DNA can change by the environment.
- One can predict the response of the DNA to the changing environment.
- One can cure maladies by using the DNA.
- The DNA is not indefinite.

Important in these features is that the genome and metaphor have an input aspect containing the coding information (the genome, the blueprint/recipe) and an output aspect (the organism as translated information, the building/meal as translated information). In this research, we study whether students compare the input aspects with output aspects. It is also important with studying the characteristics, whether students mix up those input and output aspects or not.

Recipe and blueprint are both used often in public science communication. However, the interpretations of the scientists and general population of metaphors is different and it depends on the contexts (Condit et al., 2002). Heijkoop (2013) found out that students preferred the blueprint metaphor and linked this metaphor with more fixed, more determined, more static, less active and less variable, which corresponds with the deterministic frame of Carver et al. (2008) It is not known whether these students also have a deterministic image of the genome in different situations. For that reason, in this research we will study whether the meaning of genome metaphors is dependent on the situation it is used in.

Method section

Participants

For this study, the same schools and classes that participated in the study of Heijkoop (2013) have been approached, in order to link the results of this research to the former study. Four of the seven schools gave permission to participate in this study, namely Marnix College (Ede, religious denomination), Scholengemeenschap Reigersbos (Amsterdam, public), Koningin Wilhelmina College (Culemborg, Christian), CSG Dingstede (Meppel, Christian). In total, 12 students of these 4 schools were interviewed. The students, in 5th class of pre-university education, were taught genetics in 4th class.

Sampling is done by theory based sampling, according to Condit and Condit (2001) and Condit et al. (2002), which suggests that there might be a difference between boys and girls, and between students with different religious background. Six boys and six girls were interviewed. One girl had a religious background (Christian), while one boy was baptized but was not religious himself. The other ten students did not have a religious background.

Research design and instruments

For this study, an individual interview is chosen as method because insight is needed in the individual argumentation of students of their use of genome metaphors. An interview will give a better and more detailed insight and is therefore a valid method. An interview scheme is developed that used the recommendations of Annelotte Lammers (2010), such as an open way for asking the meaning students have of the genome and to ask to which extent students think the genome influences life of students. Prior to conducting the interviews, a pilot interview is held. Based on the results, the interview scheme is improved (see appendix 1 for the interview scheme).

The interviews were semi-structured and open-ended. These choices are made because the students are asked to elaborate in depth on the issues. The interview scheme is divided into two components, each of them matching with one of the sub questions. During the interview, a scheme is made representing the comparisons between the metaphor and the genome (for example, see Table 2). These schemes were made as a reminder for the students, and to refer to comparisons that are made early in the interview. Interviews were held at the schools of the students, in a quiet room. The interviews lasted between the 25 and 45 minutes.

Table 2

Example of scheme that is made during the interview.

Genome	Blueprint
	Part of blueprint that cannot be related with the genome
Part of genome which is related with part of the blueprint	Part of blueprint which is related with part of the genome
Part of the genome that cannot be related with the blueprint	

Questions for answering sub question 1: How do students match genome characteristics with characteristics of the metaphor?

To answer this sub question, two different methods are used. With method 1, parts of the genome and metaphor are compared, for example: proteins of the genome are compared with construction workers of the blueprint. With method 2, characteristics of the genome and the metaphors are compared, for example: students are asked whether they thought the genome changed in time or not, and whether this was also the case with the blueprint.

Method 1

The students are first asked to choose for the metaphor they prefer; blueprint or recipe (these same students have already made this choice earlier in the research done by Heijkoop (2013)). After this decision, they are asked to formulate different aspects of the blueprint or recipe metaphor with the use of a word web, yet without reference to the genome. After writing down these parts, the students are asked how they can explain genome function using the metaphor they have chosen and how they could relate parts of the metaphor with parts of the genome; these parts are put in a scheme, just like table 2. A list with parts of the genome was used in the interview, to ensure that all the important parts of the genome are discussed. Students were asked to clarify their answers.

Method 2

Next to comparisons of parts of the genome with parts of the metaphors, also characteristics are compared. The characteristics studied in this research are based on the article of Cohen et al. (2009) as indicated above, which gives an overview of recent views on genome function. They discussed which processes of the genome can modify the function of DNA sequences and which characteristics the genome possesses. Biology textbooks were used to determine which processes were already taught to students (Bax et al., 2004). Processes that were both present in biology textbooks and in Cohen et al. (2009) are defined in statements and are discussed in the interview. Research of Heijkoop (2013) has shown that the blueprint metaphor was mainly related to the deterministic frame. In order to study whether a deterministic frame of the metaphor also leads to a deterministic view of the genome or not, the statements are divided in the gene frames of Carver et al.(2008).

1. When the input is known, the output is known (deterministic).
2. The input changes in time (evolutionary/materialistic).
3. The input changes by environment (evolutionary/materialistic).
4. The moment of change is important (evolutionary).
5. One can predict what happens when the input changes (relativistic/deterministic).
6. Every change of input leads to change in output (evolutionary).
7. Change depends on the place (evolutionary).
8. When there is a change in input what can lead to change in output, this can be prevented/restored by changing the input (relativistic/evolutionary).
9. Every part has a function (materialistic).
10. A part can have more functions (deterministic).
11. A characteristic can be determined by one or more components (deterministic).

With input, the code component is meant, such as genome/blueprint/recipe, with output the translated component is meant, such as organism/building/meal.

All these points are discussed in the interview, with the genome and metaphor discussed separately. After this, students are asked how much they think the metaphor and the genome are related, and what the main shortcomings and agreements are.

Questions for answering sub question 2: to what extent does the meaning that students attribute to a metaphor depend on the context in which the genome is discussed

The students are asked to which extent the metaphors fit with the genome in life and in different contexts:

- Color of eyes
- Intelligence
- Taste in music

These contexts are used in the study of Forissier and Clément (2003). The contexts were considered to be different in the degree of hereditary and whether they were defined on the DNA. The 'color of eyes' was considered to be most hereditable and most defined on the DNA, while 'taste in music' satisfied these characteristics the least. 'Intelligence' is situated in between.

Students are asked to indicate the relative importance of the genome and the environment for these characteristics by choosing a number between genome and environment (see appendix 1).

Genome 1 2 3 4 5 Environment

Hereafter they are asked to argument whether they thought the metaphor fits the genome in this context, and why (not). Table 2, which was made during the comparisons between genome and metaphor, helped the students to think about the deficiencies the metaphor and/or genome had.

Data collection

Interviews were audio taped with consent of the interviewees and transcribed verbatim.

Data analysis

First individual interviews were analyzed, hereafter all the analyses are combined.

Analysis for sub question 1

Method 1

Individual

Parts of the genome and the metaphor that are related with each other were selected and put in a scheme. Some students had more than one association with some parts, and both parts were filled in the scheme. This analysis was based on the systematic metaphor analysis of Schmitt (2005), who suggested to identify all the metaphors that are present, and cluster the target (genome) parts with the source (blueprint/recipe) parts. For that reason, all the sentences of students were put in a scheme, with parts of the genome compared with parts of the blueprint/recipe. For example, proteins (of the target domain) were compared with construction workers (of the source domain).

General

First, all the individual schemes with the parts of the genome that are related with the metaphor are put in schemes, so that the parts of the genome which were compared for example with the blueprint metaphor, are for all students summarized. After this, answers of the students were categorized in input (genome/blueprint/recipe) and output (organism/building/meal). This resulted in two schemes per metaphor: one scheme for the parts of the genome/organism that are related with blueprint/building, and one scheme for the parts of the blueprint/building that are related with

genome/organism. The same is done with the recipe metaphor: one scheme is made with parts of the genome/organism that are related with recipe/meal, and one scheme with parts of the recipe/meal that are related to the genome/organism (for example, see table 3).
With the help of these schemes, determined is whether parts of the genome are related with parts of the blueprint/recipe and parts of the organism are related with parts of the building/meal. When parts of input of the genome were compared with parts of input of the metaphor, or when output with output was compared, the comparison was determined to be a correct comparisons. When input was compared with output, it was determined to be incorrect comparisons.

Table 3
Example of scheme that is made of comparisons between input and output

	Parts of the blueprint (input)	Parts of the building (output)
Parts of the genome (input)	Correct comparisons (DNA ↔ building on the blueprint)	Incorrect comparisons (DNA ↔ materials)
Parts of the organism (output)	Incorrect comparisons (protein ↔ building on the blueprint)	Correct comparisons (protein ↔ materials)

Method 2

Individual

Answers to the questions/statements that are asked, are put in a scheme with citations. After this, answers are categorized in agreement with the statement for both the genome and the metaphor.

General

Second, the answers that are categorized in agreement with the statement are put in a general scheme. In this scheme, the right answers are specified (Bax et al., 2004; Cohen et al., 2009). Answers of students are compared with the correct answers, and defined is whether the answer of the students is correct or incorrect, and whether the answer for the metaphor is the same as for the genome.

Analysis for sub question 2

Individual

The students were asked to fill out the scale; these answers are put in a scheme. Hereafter, the motivation is cited, and the citation whether the metaphor fits with the genome.

General

All answers of students are grouped. The mean of the involvement of genome and environment are calculated. The mean and standard deviation of the percentage that students think the metaphor fits with the genome are calculated. At last, the results are summarized how the students think the metaphor fits with each situation that is posed in the interview.

Results

In the interviews, students had to choose for the blueprint or the recipe metaphor. Study of Condit et al. (2002) suggested that females were more familiar with the recipe than with the blueprint, and therefore would have a slight preference for the recipe metaphor. In these interviews, only one boy and one girl chose the recipe metaphor (from the same school). Five boys and five girls chose the blueprint metaphor. There were no differences between religious backgrounds. Arguments for choosing the blueprint metaphor were mainly that the blueprint is structured and like a summary, just like the genome. When students were asked to write down words that came up when they thought about the blueprint, they mainly thought as it as a plan or design and as something they were able to see:

> Student 9: Yes… it's just luck that I chose the blueprint, it is just like… a summary.
>
> I: […] Can you put words in a word web, with words you think about when you think about the blueprint?
> Student 10: Okay. A plan.
> I: A plan, all right. [students writes a word down]. A design.
>
> Student 7: Oh, yeah, and this [blueprint] is just like the genome. I'm more one of this one [blueprint], because I can imagine more about it.
> I: Okay, because it is visual?
> Student 7: Yes.

Sub question 1: how do students match genome characteristics with characteristics of the metaphor?

Two types of data give information on this sub question: first the comparisons students made between parts of the genome/organism and parts of the blueprint/building and recipe/meal (method 1). Secondly the characteristics students attribute to the genome and the metaphors (method 2).

Parts that are related between genome/organism and blueprint/building and recipe/meal

Previous research showed that each metaphor appeared to have different associations, depending on the user (Condit et al., 2002). For that reason, the comparison between parts of the genome and parts of the metaphor are studied.

In the interviews, students were asked to write down a word web with words they came up when they would think of the metaphor. This was a difficult task for the students, because they had difficulty to express in words what to relate with the metaphor, for example the blueprint:

> Student 3: Yes. Ehh… I find it a little bit hard to explain. I guess I mean in terms of blueprint… that you see how it looks together and then you… then that indicates what's what. That… I think that's a characteristic of a blueprint.

Students especially came up with characteristics of the blueprint such as a plan or information , but not with parts of the blueprint such as a materials or construction workers. For that reason, the interviewer helped the students by asking which parts the blueprint possesses. With this help, the students came up with parts of the blueprint too. With the recipe metaphor this was not the case: students quickly came up with parts, and not with characteristics. Together with the interviewer, these parts were put in a scheme, where the parts could be compared with parts of the genome. However, some students had difficulty and found it hard to come up with many parts. For that reason, when all the words of the metaphor were compared with the genome, and not all parts of the genome were discussed, the interviewer asked whether the students could come up with parts of the genome. When this was difficult for the students, the interviewer asked questions to get the students in the right direction. Especially for the concepts 'gene' and 'proteins' this was necessary. After the instructions, most students could come up with the different concepts. However, four students did not come up with proteins, so that the interviewer had to tell it. One student did not know anymore what proteins were, and said that he was not able to remember what the different parts of the genome were. Some students compared one component of the genome with several parts of the metaphor. All these components are compared and concluded in the results.

Comparisons between input (genome, blueprint/recipe) and output (organism, building/meal) are structured as in table 4. In total, eight out of ten students who preferred the blueprint metaphor, compared the input (genome) aspects with output (building), which are incorrect comparisons (see table 3). Answers of one student consisted of only incorrect comparisons. The gray areas in table 4/table 9 shows the incorrect comparisons. The two students, who preferred the recipe metaphor, made only good comparisons.

Table 4
Comparisons between input and output

	Blueprint/recipe comparisons	Building/meal comparisons
Genome aspects	23	11
RNA	3	3
Organism aspects	0	35

Note. Answers that correctly relate input aspects or output aspects with each other are in the white areas. RNA is an intermediate of the genome and organism and therefore separate in the table.

Because the comparisons of students were different from each other, not only the comparison is made from genome/organism to blueprint/building, but also from blueprint/building to genome/organism. Table 5 and table 6 both show a major diversity between students. Comparisons that stand out are parents with architects, body with building, ribosomes with construction worker and amino acids with materials;

> Student 11: [about comparison parents and architect] Because the parents the genome… because the parents put the genome together, as it in the end supposed has to be.

Table 5

Comparisons students make of parts of the genome/ organism with parts of the blueprint/building

	Parts of the blueprint	Parts of the building	Amount of different comparisons (with amount of students who could not compare the part)
Genome			
Chromosome	Part of the blueprint (2) Summary User	Construction Materials	5 (2)
Strands of DNA	-	Supporting beam	1
Base	Copy of a part of the blueprint Part of the blueprint	Materials (2) Material between supporting beam	4
DNA	Building on the blueprint	Construction worker Materials	3
Genetic information	Building on the blueprint (2)	-	1
Gene	Part of the blueprint (3) Summary (2)	Building Material between supporting beam	4
Allele	Part of the blueprint Summary	Materials	3
Parents	Architect (2)	-	1
Nucleus	Architect Architect office (2)	-	2
RNA	Architect Copy of the blueprint	Building Materials Transport	5 (1)
Organism			
Meiosis	-	Build Cement mill	2 (1)
Mitosis	-	Build	1 (1)
Process	-	Method	1
Centromere	-	Cement	1
Ribosome	-	Construction worker (4) Consultation center	2
Brain	-	Construction worker	1
Body	-	Building (3)	1
Amino acid		Materials (2)	1
Protein	-	Building (3) Materials (2) Construction worker Part of the building	4
Cell	-	City Building Materials	3 (2)

Note. The gray areas indicate wrong source-target relations, for example genome-building comparisons. Some students compared one part of the genome/organism with more than one part of the blueprint/building. Some students could not compare a part of the genome with a part of the blueprint. These students are noted in the last column.

Table 6

Comparisons students make of parts of the blueprint/building with parts of the genome/organism

	Parts of the genome		Parts of the organism	Amount of different comparisons (with amount of students who could not compare the part)
Blueprint				
Building on the blueprint	DNA Genetic information		-	2
User	Chromosomes		-	1
Architect	Parents (2) RNA Nucleus		-	3 (1)
Component of the blueprint	Gene (3) Chromosome (2) Allele Base		-	4
Copy of the blueprint	Base	RNA	-	2
Summary	Genes (2) Alleles Chromosomes		-	3
Architect office	Nucleus (2)		-	1
Building				
Materials	Base (2) DNA Chromosomes Alleles	RNA	Amino acids (2) Proteins (2) Cell	8 (1)
Construction worker	DNA		Ribosome (4) Brain Proteins	4
Build	Chromosomes		Meiosis Mitosis	3
Building	Genes	RNA	Body (3) Proteins (3) Cell	5 (1)
Methods	-		Process	1
Supporting beam	Strands of DNA		-	1
Material between supporting beam	Base Genes		-	2
Cement	-		Centromere	1
Component of building	-		Protein	1
Cement mill	-		Meiosis	1
Transport	-	RNA	-	1
City	-		Cell	1
Consultation center	-		Ribosomes	1

Note. The gray areas indicate wrong source-target relations, for example genome-building comparisons. Some students compared one part of the blueprint/building with more than one part of the genome/organism. Some students could not compare a part of the blueprint with a part of the genome. These students are noted in the last column.

In total, 19 parts of the genome were compared with parts of the blueprint. Out of these 19 comparisons, 10 of the mentioned parts of the genome are compared with more than one part of the blueprint. In some cases, 5 different comparisons were made. When there was only one comparison (9 times), mostly there was just one student who compared this part, for example: only one student compared the centromere with a part of the blueprint.
In total, only 4 parts of the genome of 19 comparisons were compared with only one part of the blueprint by more than one student. This means that solely 21% (4 out of 19) of all comparisons that are made between the genome and blueprint were thought up by several users, without another comparison. RNA is not included in this calculation, because of the fact that this is not found as a part of the genome or organism.

Some students had difficulty to compare parts of the genome with parts of the blueprint. Students compared 'materials' from the blueprint with 'base' from the genome, but later they also thought about 'amino acids' as materials.
Other students could not compare parts of the genome with parts of the blueprint. One student could not compare RNA with a part of the blueprint. Two other students could not compare chromosomes and the cell.

One student made in total three comparisons (he could not compare the other components of the blueprint with the genome), and all three comparisons were incorrect because input was compared with output.

> I: […] You wrote down building blocks. Could you compare this with something in the genome?
> Student 6: Yes, just as… as the carbon and the… and the other kinds of atoms that is in it.
> I: Of the DNA?
> Students 6: Yes.
> I: Okay, and the supporting beam for example. Can you compare it with something?
> Students 6: Yes, that's the… well, I don't know exactly how it's named, but that's the… the… when I see the DNA, I see it like a stairs, and that's… two long side stairs, I call it. And between it, that's the DNA. What your… your specific things holds.
> I: Yes. And do you mean… are these building blocks, is that the precise DNA what you mean?
> Student 6: Yes, well, building blocks can also fall under the support beams.
> I: Okay, so the supporting beams are only those strands?
> Student 6: Yes.
> I: Yes, and you would… you mean… this… if you mean specifically?
> Student 6: Yes, that would then be the supporting beams, what is between it. That does not really support, but that is the DNA that makes you unique.

The architect and architect office are often related with parts of the genome. Two students said the parents are the architect, because 'they make the genome'. Three other students related it with the nucleus for the same reason, which indicated that students think the genome is made up.

The cell has three different comparisons, namely the city, the building and materials, which are three different organizational levels. This shows that there is a difference between students: different students have different comparisons of different organizational levels. This is comparable with comparisons that are made with proteins, namely materials, construction worker and part of the building. These comparisons are all understandable, because the fact that proteins are ‘materials’ for enzymes and different components of the cell. When a protein is an enzyme, it is also a construction worker. However, these comparisons are of different levels too.

Many wrong comparisons are made with the materials of the blueprint. Materials are compared with bases (two times), DNA, chromosomes and alleles, because these components are a part of the genetic information: ‘the materials’ for genetic information. Together it forms the genetic information of one person:

> I: […] And the… the materials?
> Student 5: Ehh… Yes, these are… the alleles, and together they define the genes.

Six students came up with the construction worker, and only one compared it with a part of the genome (DNA). The other students compared it with proteins, ribosomes or the brain. Other students compared the proteins with the building, because of the fact that proteins are the end result of the genome, and the building is the end result of the blueprint. One student however, could not relate the proteins with the building, because they both have other characteristics:

> Student 9: Proteins […]
> I: And could you compare these with something in the blueprint?
> Student 9: No, actually not, because this [blueprint]represents what is made, a house. And that is the intention, but with a blueprint from the DNA, the DNA is intended, and DNA makes proteins, but houses cannot make something.
> I: And proteins do make something?
> Student : Yes.

Only two students did choose the recipe metaphor (see table 7 and table 8). One student mentioned that there were two cooks, in which there had to be a clear difference. Like with the blueprint metaphor, the meaning between students is different.

Table 7
Comparisons of parts of the genome/organism with parts of the recipe/ meal

	Parts of the recipe	Parts of the meal
Genome		
Gene	Components of the recipe Cook who says how to make it	-
RNA	Copy of the recipe	-
Organism		
Translation	-	Pan
Glucose	-	Ingredients
Body	-	Cook who cooks (2)
Amino acid	-	Ingredients
Protein	-	Meal (2)
Cell	-	Cook who cooks Pan

Note. Some students compared one part of the genome/organism with more than one part of the recipe/meal.

Table 8

Comparisons of parts of the recipe/meal with parts of the genome/ organism

	Parts of the genome	Parts of the organism
Recipe		
Components of the recipe	Genes	-
Cook who says how to make it	Genes	-
Copy of the recipe	- RNA	-
Meal		
Ingredients	-	Glucose (2) Amino acids
Meal	-	Proteins
Pan	-	Translation Cell
Cook who cooks	-	Body (2) Cell

Note. Some students compared one part of the recipe/meal with more than one part of the genome/organism.

Table 9 shows the relation students make between genome and metaphors. With the blueprint metaphor, 58 correct comparisons are made, versus 11 incorrect comparisons. Only incorrect comparisons are made between genome and building.

Most comparisons are made between organism and building. In total, eight out of ten students made at least one wrong comparison. The two students who preferred the recipe metaphor made correct comparisons.

Table 9

Comparisons between relation genome/organism and blueprint/building and recipe/meal

	Blueprint metaphor		Recipe metaphor	
	Blueprint	Building	Recipe	Meal
Genome	21	11	2	0
RNA	1	3	1	0
Organism	0	26	0	9

Note. A comparison between genome and blueprint/recipe, and organism and building/meal is determined to be correct.

Comparisons between characteristics of genome and metaphors

Study of Heijkoop (2013) showed that students often showed a preference for the blueprint metaphor, while they had a deterministic view of the metaphor. It was not clear if a deterministic view of the metaphor means the students have a deterministic view of the genome too. Therefore several statements are discussed, which are related to the gene frames from Carver et al. (2008)(see table 10). Statement 1, 5, 10 and 11 are about the deterministic character of the genome, statements 2, 3, 4, 6, 7, 8 and about the evolutionary character, statements 5 and 8 about the relativistic character and statement 2, 3 and 9 about the materialistic character.

When students think the blueprint has a deterministic character (see question 1), this doesn't mean that they think the genome is deterministic (5 students think input of genome does not determine precisely the output, while they think it is the case with the blueprint). Six students think that one can predict what happens when the input changes, what is a deterministic characteristic, while three students do not think this is the case. Three students are not sure about it.

Table 10

Student answers whether the statement is true for the genome and for the metaphor

B+/R+ means the answer for the metaphor (blueprint or recipe) is equal to the answer for the genome, B-/R- means the answer for the metaphor is not equal to the answer for the genome, BV/RV means that the answer for the metaphor is vague, undetermined or not answered.

	Genome right						Genome wrong						Genome vague			
	B+	R+	B-	R-	BV	RV	B+	R+	B-	R-	B V	R V	B+	R+	B-	R-
1. When the input is known, the output is known.	2	-	5	-	-	-	3	2	-	-	-	-	-	-	-	-
2. The input changes in time.	3	1	4	-	1	-	1	-	-	1	-	-	1	-	-	-
3. The input changes by environment.	7	1	2	-	-	-	1	-	-	1	-	-	-	-	-	-
4. The moment of change is important.	6	1	1	-	1	1	-	-	-	-	-	-	2	-	-	-
5. One can predict what happens when the input changes.	2	-	2	1	1	-	1	1	-	-	1	-	1	-	2	-
6. Every change of input leads to change in output.	4	2	1	-	2	-	2	-	1	-	-	-	-	-	-	-
7. Change depends on the place.	8	1	-	-	2	1	-	-	-	-	-	-	-	-	-	-
8. When there is a change in input what can lead to change in output, this can be prevented/restored by changing the input.	-	-	1	-	2	-	-	-	-	-	-	-	-	1	7	1
9. Every component has a function.	-	-	5	-	-	-	5	-	-	-	-	1	-	1	-	-
10. A component can have more functions.	3	1	2	-	-	-	2	1	3	-	-	-	-	-	-	-
11. A characteristic can be determined by one or more components.	2	-	3	-	-	-	4	1	1	1	-	-	-	-	-	-
Total	37	7	26	1	9	2	19	5	5	3	1	1	4	2	9	1

Many students have an evolutionary idea of the genome. For example, statement 3 is: 'the input changes by environment'. Two students think that this is not the case, with one of them thinks that the metaphor does not change by the environment either. However, eight students think the genomes changes by the environment, just like the blueprint. Two students also think the genome changes, but not the metaphor. This proves that the majority matches the genome with the evolutionary/materialistic frame. It is not sure which frame fits best, because it is not clear whether students think changes are due to mutations or not.

Statements 2, 4, 6 and 7 confirm the fact that students know that the genome changes, which suggests that not all students have a deterministic view of the genome when they have a deterministic view of the metaphor. For example, one student explained why s/he had a deterministic view of the blueprint, but not of the genome:

> Student 5: And the older the building, the less it can handle maybe. […] On the other side, you can also easily renovate a building.
> I: And that is not possible in humans?
> Student 5: Yes, some do, but you can replace things, but it's not like that you can let a person stay young. Like you just slay him and build another person. You can do that with a building.

One student however, had a deterministic view of the genome, since s/he said that the genome is a sort of blueprint of an organism:

> Student 4: Because what's in that genome, say kind of… construction plan for what you will become. So when you read it, it's like: oh, this is in it, and that, and that, and then it's put together sort of, and that will become an organism.
> I: And what is put together?
> Student 4: Well, for example, if that person has blue eyes, since it is in the plan. So basically all is… well, determined.

Some answers differed between the students, like with statement 5. Some students think one can predict what happens when the input changes, where some see an agreement with the metaphor. Other students think this cannot happen, while other do not know it for sure. Nine students do not know whether errors in the genome can be solved in the genome itself, while three students think it is possible. Statements 10 and 11 are about the complexity of the genome, and whether one gene results in one cause. Only six people think a gene can have more functions, and only five students think several genes can work together, which suggests that almost the half has a deterministic view of the genome. Only five students know that not all parts of the genome have a function, which is placed in the materialistic frame.

In total, 56 times the students think the genome and the blueprint are the same, while, 31 times the students think they differ. Because only two students chose the recipe metaphor, it is hard to say whether these students have a different view of the genome metaphors. In total, 26 times the students had a correct view of the genome, and had another view of the blueprint. Therefore, for example, a deterministic view of the genome does not immediately leads to a deterministic view of the genome.

Sub question 2: to what extent does the meaning that students attribute to a metaphor depend on the context in which the genome is discussed?

Condit et al. (2002) showed that metaphors had a different meaning in different contexts. For that reason this aspect is studied in this research. The students are confronted in the interviews with three contexts of the study of Forissier and Clément (2003), namely color of eyes, intelligence and taste in music. First, students had to give an answer to the question to which extent the genome and environment were involved in whole life, and then with the different contexts. They were also asked whether they thought the metaphors fitted with the genome.

As seen in table 11, the fitness of the metaphor differed within the different contexts. In total, the recipe was suitable for about two-third, and with the blueprint an average rate of 60,5% (with a standard deviation (σ) of 26,40%). Meaning of the students differed a lot: some students could compare the blueprint with the genome for 10%, while other students could compare it for 85%.

When the genome is more involved, the metaphor appeared to be more suitable than when the environment was involved. Only one student did not think the blueprint was suitable for the genome;

> I: Do you think the blueprint metaphor does fit well with these situations?
> Student 3: No.
> I: All of them not?
> Student 3: No, because… this [genome] has more to do with characteristics, and with… the construction of the body. The construction… this is more general. It is specific… focused on something. So than the blueprint has not a lot of… agreements with these situations.

Table 11

Comparisons of parts of the genome/organism with parts of the blueprint/building and recipe/meal

	Involvement of genome/ environment (mean)	Suitability with blueprint (n=10)			Suitability with recipe (n=2)		
Life	3,2	60,5% (σ=26,40%)			70% (σ=14,14%)		
		Yes	Partly	No	Yes	Partly	No
Color of eyes	1,1	9	-	1	1	-	-
Intelligence	3,0	5	1	4	-	1	-
Taste in music	4,4	2	1	7	-	1	-

Note. One student who chose the recipe metaphor could not decide whether the metaphor was suitable for the different situations.
Involvement of the genome is stated as 1, involvement of the environment is stated as 5.

Many students indicated differences between the genome and the metaphors. Three students said that they missed the copy in the blueprint (what is available in the genome, namely the RNA). Two other students mentioned that you can change a blueprint deliberately, what is not the case with the genome:

> Student 8: [talks about differences between genome and blueprint] Well, I think the nucleus and the architect. Because the genome is in the nucleus, and the architect has a greater influence on it. Because… you get your genome from your parents, so you don't have a lot of influence, and the architect can change the blueprint to his wishes, so that it will be perfect. So that's a great difference.

Several students said that the blueprint has to include the environment to fit more with the genome. This can be by a legend or something else that includes the environment in the blueprint:

> Student 4: Oh, just put influences of the environment in the blueprint. Where you grow up, that kind of things.

Ten out of twelve students think metaphors can help in education to learn concepts. However, to a certain degree: at some point, you should release the metaphor.

Conclusion and discussion

In total, ten out of twelve students preferred the blueprint metaphor above the recipe metaphor. As many boys as girls chose the blueprint metaphor, which is not in line with study of Condit et al. (2002). There was no difference in religious background. However, this was not a quantitative study, so results were not significant. Most students preferred the blueprint metaphor, because it was like a plan or a design, just like the genome. This is in line with Condit et al. (2002) and Heijkoop (2013).

Sub question 1: how do students match genome characteristics with characteristics of the metaphor?

Comparisons between parts

Condit et al. (2002) concluded that metaphors can have different associations, depending on the user. For that reason, this aspect is studied in this research. The students were asked to match genome parts with parts of the metaphor. This resulted in comparisons between the genome/organism and blueprint/building and recipe/meal. It appeared that some students sometimes could not come up with comparisons of parts of the genome with parts of the metaphor, while sometimes more than one comparison was given. Vice versa this is also the case (comparisons are made from the metaphor to the genome). In total, more than half of the mentioned parts of the genome are compared with more than one part of the blueprint. Only 21% of the parts of the genome that are compared without another comparisons, was thought up by several users. This small number indicates that different students compare the genome and the metaphor in a different way.

Interviews also showed that students compared parts of the genome with different parts of the metaphor, of different organizational levels. These conclusions are in line with Condit et al. (2002), which suggested that metaphors can have different associations, depending on the user, and that metaphors are pluripotent.

It was remarkable that some students compared parts of the genome (input) with parts of the building (output). This was not the case in the recipe metaphor. Many wrong comparisons are made: in total eleven comparisons, against 58 correct comparisons. In total, eight out of twelve students made incorrect comparisons. One student did only make incorrect comparisons. This indicates that students do not know how they can use the metaphor in a correct manner, or that they have the wrong image of the genome or metaphor.

A few components were hard to determine whether they were input or output. With the genome this was the case with RNA. Decided is that this is an intermediate between the genome and the organism. Those components are not included in the calculation how many comparisons were correct or incorrect. Another point that has to be considered is the ingredients in the recipe metaphor. Ingredients are both present in a recipe and in the preparation of the meal. Decided is that ingredients are a component of the meal: however, in a following study this should be taken into account. During the interviews, it appeared that students talked about several buildings in different senses: the building on the blueprint and the realized building. This is an important finding, since talking about ‘a building’ can be confusing for students. For that reason, this should be considered when the blueprint metaphor is used.

Comparisons between characteristics

Study of Heijkoop (2013) and Condit et al. (2002) both showed that students mainly had an deterministic view of the blueprint metaphor, and that the recipe metaphors was less fixed and determined. To study whether the use of deterministic metaphors indicates a deterministic view of the genome, eleven statements are discussed, both for the genome and the metaphor. It appeared that while most students had a deterministic view about the blueprint (for example, when they thought that when you see the blueprint, you already know the characteristics of the building), not all students had a deterministic view of the genome. This was the case with five students. Also other questions indicated that students did not have a real deterministic view about the genome. However, about the half of the students think that one gene leads to one characteristics, and they do not know that genes work together. They have the same thought about the metaphor, so this results in a deterministic view of the blueprint and the genome. For that reason, students sometimes have a deterministic view about the genome, but not about all characteristics.

Despite the fact that students sometimes have a deterministic view of the genome, they also know that the genome can change, by influence of environment or time. In total, 10 students said that the genome can be influenced by the environment, making the deterministic view of the genome more evolutionary/materialistic. To study whether their view was real evolutionary, the students should have been asked how these changes were caused by environment: by mutations or not, because mutation fits with the materialistic frame.

In total, 26 times students had the correct view of the genome, while they found the characteristic of the blueprint was different. This shows that the meaning that students contribute to a metaphor, not immediately the meaning is they attribute to the genome. Thus: a deterministic view of the blueprint (like in the study of Heijkoop, 2013), is not immediately a deterministic view of the genome.

Sub question 2: to what extent does the meaning that students attribute to a metaphor depend on the context in which the genome is discussed?

Condit et al. (2002) concluded that the meaning of a metaphor is dependent of the context in which it is used. In this study, the students were asked how they thought the environment and the genome are involved in personal life, and how they were involved in different contexts (color of eyes, intelligence and taste in music). It appeared that students thought that the environment had a little bit more influence on life than the genome (with a mean of 3,2, where 1 was a great influence of the genome and 5 was a great influence of the environment). With color of eyes, there was almost no involvement of the environment (1,1). In intelligence, there was an equal influence of genome and environment (3,0), and with taste in music there was a great influence of the environment (4,4). It appeared that when the environment had an greater influence in the different contexts, the metaphor did not match anymore. Nine out of ten students thought the blueprint metaphor fits with the color of eyes. However, with taste of music this was only 2 students. In total, the blueprint metaphor fitted for 60,5%. The opinion of the students differed a lot: some students found an agreement of 85%, while one student just saw an agreement of 10%. This also suggests that the meaning between students differs a lot. When students were asked how the metaphor could be improved, they stated that the influence of the environment had to be greater. This could be done by making a legend in the blueprint.

Ten out of twelve students think that the use of metaphors could help them in biology class. However, this was only the case when parts are related correct. When parts are not related correct anymore, you need to step away from the metaphor and point to the differences between the genome and the metaphors. For two students metaphors could not help, which suggests that not all students do use metaphors.

Implications

Use of metaphors and wrong relations sometimes produces misinterpretations, which indicates that the metaphor does not automatically lead to better understanding. However, talking with students about their interpretations and relations between metaphor and genome can be a strong instrument both to detect errors in understanding and to construct better metaphor-genome relations.

Teachers can use genome metaphors in biology class, because of the fact that most of the students think it is an important value in education and can help them. Metaphors should be used correctly: Niebert et al. (2012) stated when the source domain of the metaphor is not equal with the source domain of the students; also the target will not be the same. The teacher should be aware that metaphors can have different meanings between him/herself and students, but also between students. It is also important to realize that not all students think use of metaphors is useful. It is important that teachers discuss the differences between the metaphor and the genome and the limitations of the metaphor also. Questions as used in this research could help to structure the comparison between metaphor and genome. The teacher should check whether students compare the correct parts of the genome with the correct parts of the metaphor.
Explanation of the correct use of metaphors can be taught in teacher training or used in educational materials.

When a student was asked if a metaphor should help in biology education, she said:

> 'Well, when I use metaphors, I think about the genome in a different way. I always saw it as a blueprint, and by developing another metaphor, you are busy with thinking about how it works, and how you compare it. So I think it is a nice task for students who are learning about the genome, to make… as homework or something… to make a metaphor itself. […] Yes, I think in this way, concepts are better learned.'

Developing a metaphor, or match parts of the metaphor with the correct parts of the genome can be a nice and useful task for students. It can also be a task to check the foreknowledge.

Future research

Further research can be a directed to the design of effective combinations of metaphors which allow for current views on structure and function of the genome. With a full explanation of the characteristics, it can lead to a productive comparison between the genome and the metaphor. This research can also include how students think the blueprint and recipe metaphor can be further improved.

Acknowledgements

First, I would like to thank my supervisor, Dirk Jan Boerwinkel for all the feedback and ideas for this research. I would like to thank the teachers and students that participated in schools, for having informative and nice interviews: Marnix College (Ede), CSG Dingstede (Meppel), Scholengemeenschap Reigersbos (Amsterdam) and Koningin Wilhelmina College (Culemborg). Last, I would like to the students I worked together in the 'flexruimte', who made doing research 'gezellig'.

References

Bax, W., Bijsterbosch, J., Domis, M., van Eijck, M., Kievits, L., Maier, E., … van Wijk, P. (2004). Nectar vwo bovenbouw biologie deel 1. Wolters-Noordhoff bv Groningen/Houten.

Boerwinkel, D. J., Knippels, M. C., &Waarlo, A. J. (2011). Raising awareness of pre-symptomatic genetic testing. *Journal of Biological Education, 45*(4), 213-221.

Cameron, L. (1999). Operationalising ‘metaphor’ for applied linguistic research. *Researching and applying metaphor,* 3-28.

Campbell, N, & Reece, J (2002). *Biology 6th edition, AP*. San Francisco, CA: Pearson, Education Inc..

Carver, R., Waldahl, R., & Breivik, J. (2008). Frame that gene. *EMBO reports, 9*(10), 943-947.

Ceccarelli, L. (2004). Neither confusing cacophony nor culinary complements: a case study of mixed metaphors for genomic science. *Written Communication. 21*(1), 92-105.

Cohen, I.R., Atlan, H., & Efroni, S. (2009). Genetics as explanation: limits to the human genome project. In: eLS. John Wiley & Sons, Ltd: Chichester.

Condit, C.M. & Condit D.M. (2001). Blueprints and recipes: Gendered metaphors for genetic medicine. *Journal of Medical Humanities.22*(1), 29-39.

Condit, C.M., Bates, B.R., Galloway, R., Brown Givens, S., Haynie, C.K., Jordan, J.W., Stables, G. & West, H.M. (2002). Recipes or blueprints for our genes? How contexts selectively activate the multiple meanings of metaphors. *Quarterly Journal of Speech.88*(3), 303-325.

Duncan, R.G., & Reiser, B.J. (2007). Reasoning across ontologically distinct levels: students’ understandings of molecular genetics. *Journal of Research in Science Teaching. 44*(7), 938-959.

Forissier, T., & Clément, P. (2003). Teaching ‘biological identity’ as genome/environment interactions. *Journal of Biological Education. 37* (2), 85-90.

Heijkoop, M.E.A. (2013). The meaning secondary school students attribute to genomic metaphors (Master thesis). University of Utrecht, Freudenthal Institute for Science and Mathematics Education.

Knippels, M. C. P. J. (2002). Coping with the abstract and complex nature of genetics in biology education: The yo-yo learning and teaching strategy.

Knudsen, S. (2005). Communicating novel and conventional scientific metaphors: a study of the development of the metaphor of genetic code. *Public Understanding of Science. 14*, 373-392.

Konopka, A. K. (2002). Grand metaphors of biology in the genome era. *Computers and Chemistry*. *26*, 397-401.

Lakoff, G., & Johnson, M. (2008). *Metaphors we live by*. University of Chicago press.

Lammers, A. (2010). *Genoombeelden bij leerlingen* [bachelorscriptie]. Universiteit Utrecht, Faculteit Bètawetenschappen.

Martins, I., & Ogborn, J. (1997) Metaphorical reasoning about genetics. *International Journal of Science Education.19*(1), 47-63.

Niebert, K., Marsch, S., & Treagust, D.F. (2012). Understanding needs embodiment: A theory-guided reanalysis of the role of metaphors and analogies in understanding science. *Science Education. 96*(5), 849-877.

Pigliucci, M., & Boudry, M. (2011). Why machine-information metaphors are bad for science and science education. *Science & Education. 20*, 453-471.

Schmitt, R. (2005). Systematic metaphor analysis as a method of qualitative research. *The Qualitative report, 10*(2), 358-394.

Venville, G.J., & Treagust, D.F. (1998). Exploring conceptual change in genetics using a multidimensional interpretive framework. *Journal of Research in Science Teaching. 35*(9), 1031-1055.

Wilbers, J., & Duit, R. (2006). Post-festum and heuristic analogies. In *Metaphor and analogy in science education* (pp. 37-49). Springer Netherlands

Appendix: interview scheme

Onderdeel 1: introductie

- Voorstellen
- Doel van het onderzoek vertellen en waarom het relevant is.
- Vertellen dat het interview vertrouwelijk is
- Er wordt niet op kennis getest.
- Vragen of het interview opgenomen mag worden

Eerst wat achtergrondvragen.
1. Heb je een religieuze achtergrond? Zo ja, welke?
2. Vond je het onderwerp genetica interessant?
3. Kan je aangeven op een schaal van 1 t/m 5 aangeven hoe interessant je het onderwerp vond?
(En geslacht opschrijven).
4. Welk biologieboek hebben jullie gebruikt in de bovenbouw?

Onderdeel 2: bestaande metafoor

In dit interview gaat het vooral over het genoom. Het genoom is het geheel van erfelijke informatie in een cel, dus de complete set van genen. In de genetica worden er vaak metaforen gebruikt om het duidelijker te maken.

1. Weet je wat een metafoor is?
2. Is er in de klas, tijdens het onderwerp genetica, wel eens gebruik gemaakt van een metafoor?
    1. Een vorm van beeldspraak. Bijvoorbeeld dat de stikstofbasen (A, C, T, G) als letters worden aangegeven.

Afgelopen jaar heb je een vragenlijst ingevuld over twee metaforen die vaak worden gebruikt in de genetica: de blauwdruk en het recept. (Informatie over blauwdruk geven)

3. Kan je je nog herinneren welke metafoor je het meest passend vond om het genoom te beschrijven?
4. Kan je zeggen een woordweb maken met woorden waar je aan denkt als je aan een blauwdruk/recept denk? Denk hardop na.
    a. Welke onderdelen zijn hiermee betrokken? Als je kijkt naar de blauwdruk voor een gebouw/recept voor een gerecht? Welke kenmerken/eigenschappen bevat de blauwdruk/recept?

4. Hoe kan je het genoom (dat in relatie staat met het organisme) uitleggen aan de hand van deze metafoor (dat in relatie staat met gerecht/gebouw)?
Zelf het schema invullen. Beginnen met voorbeelden die zorgen voor een goede wending van het gesprek (eerst hebben over de onderdelen, dan over de eigenschappen). Als de eigenschappen/onderdelen van de metafoor zijn besproken, de eigenschappen/onderdelen van het genoom bespreken (DNA, cel, chromosoom, nucleotiden, gen, eiwitten (product en bij transcriptie/translatie(ribosomen)).

a. Als je het genoom, recept, blauwdruk hebt, kan je dan precies aangeven wat de uitkomst is (eigenschappen, gerecht, gebouw)(gebruik maken van blaadje).
    - Ingaan bij het genoom op eiwitten én eigenschappen.

b. Verandert het genoom/recept/blauwdruk in de loop van de tijd, of ligt alles vast?
c. Hoe gaat het genoom/recept/blauwdruk om met veranderingen in de omgeving?
    - Is het moment van de verandering bepalend voor de verandering in de eigenschappen/gerecht/gebouw?

    - Wat verandert er, als het genoom/recept/blauwdruk verandert?
    - Kan je voorspellen wat er gaat gebeuren in eigenschappen/gerecht/gebouw, als er één gen/onderdeel/ingrediënt verandert?
    - Leidt elke verandering van het genoom tot een verandering in eigenschappen/gerecht/gebouw? Of zijn er meerdere veranderingen in het genoom/recept/blauwdruk nodig?
    - Zijn dit grote veranderingen?
    - Ligt het aan de plaats/gen/onderdeel/ingrediënt of de veranderingen groot zijn?

d. We hadden het net over verandering, maar als je weet waar een foutje zit, die zorgt voor een ziekte/vieze taart/verkeerd gebouw, weet je aan de hand van het genoom/recept/blauwdruk ook hoe je dit kan herstellen?
    - Is een foutje makkelijk te herstellen?

e. Heeft elk stukje van het genoom/recept/blauwdruk een functie?
f. Heeft elk gen/ingrediënt/onderdeel één functie? Of kunnen dit er ook meer zijn?
    - Kan je een voorbeeld geven?
g. Zijn alle eigenschappen door één gen/ingrediënt/onderdeel bepaald? Of kunnen dit er ook meer zijn?

5. In hoeverre vind je het genoom en de metafoor bij elkaar passen?
    a. Kan je dit uitdrukken in een percentage?
    b. Wat zijn de grote overeenkomsten tussen het genoom en de metafoor?
    c. Wat zijn de punten waarbij het genoom en de metafoor niet bij elkaar passen?

Onderdeel 3: eigen metafoor

1. Heb je een eigen metafoor voor het genoom?
2. Kan je op papier aangeven hoe je de relatie ziet tussen jezelf en het genoom?
3. Hoe staat het genoom dan met jou in relatie?
    a. Hoe wijkt deze metafoor af van de blauwdruk/recept?
    b. Wat zijn de verschillen?

Onderdeel 4: situaties

1. Kan je aangeven hoe belangrijk je de invloed van de omgeving en het genoom vindt op je leven? (m.b.v. semantische schaal).
2.. In hoeverre spelen het milieu en het genoom bij de volgende kenmerken? (m.b.v. semantische schalen)
    - Oogkleur
    - Intelligentie
    - Muzieksmaak
        - Wat voor iets in het genoom bepaalt intelligentie/
3. Passen deze situaties bij de metaforen? (m.b.v. semantische schalen)
4. Wat zou er nog toegevoegd aan deze metafoor moeten toegevoegd worden, zodat het een goed passende metafoor is?
    - Deze toevoeging, wat zou dat dan in het genoom zijn?
5. Denk je dat metaforen jou zouden helpen om na te denken over het genoom?

Appendix with interview scheme

Het onderwerp genetica vond ik interessant

Helemaal mee oneens	1	2	3	4	5	Helemaal mee eens

Schaal: voorbeeld

Snoep

Zuur	1	2	3	4	5	Zoet

Schaal: invloed op je leven

Genoom	1	2	3	4	5	Omgeving

Schaal bij oogkleur

Genoom	1	2	3	4	5	Omgeving

Schaal bij intelligentie

Genoom	1	2	3	4	5	Omgeving

Schaal bij muzieksmaak

Genoom	1	2	3	4	5	Omgeving