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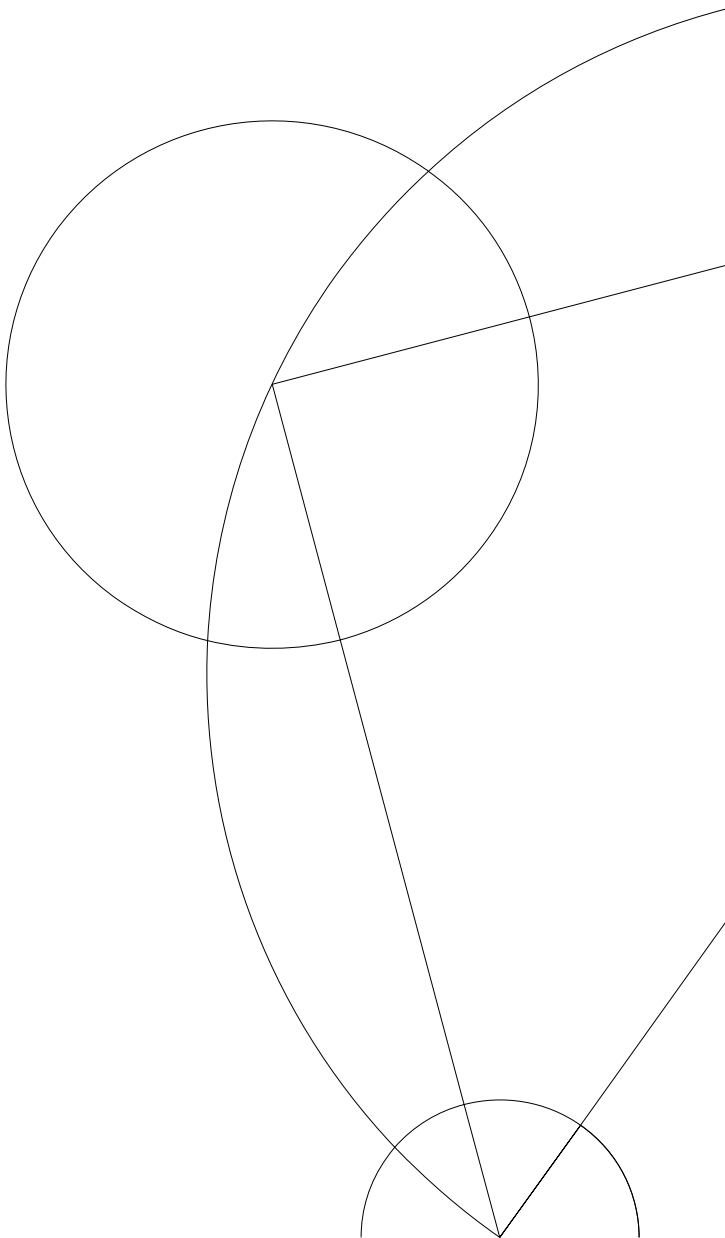
Teaching authentic cutting-edge science to high school students



Leonora Simony
Kandidatspeciale

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Abstract

Laboratory work is an important part of many scientific subjects, such as physics, chemistry or biology. As a result laboratory work is also an important part of science education. Even so many didactic studies questions the effect of laboratory work on students ability to acquire scientific knowledge.

In this thesis the Theory of Didactic Situations and Didactic Transposition theory are used and combined in order to analyse the educational program 'DNA and Life', offered by The Natural Museum of Denmark. This program invites high school students to spent a day in a modern laboratory, where they try a newly developed molecular method in order to examine biodiversity.

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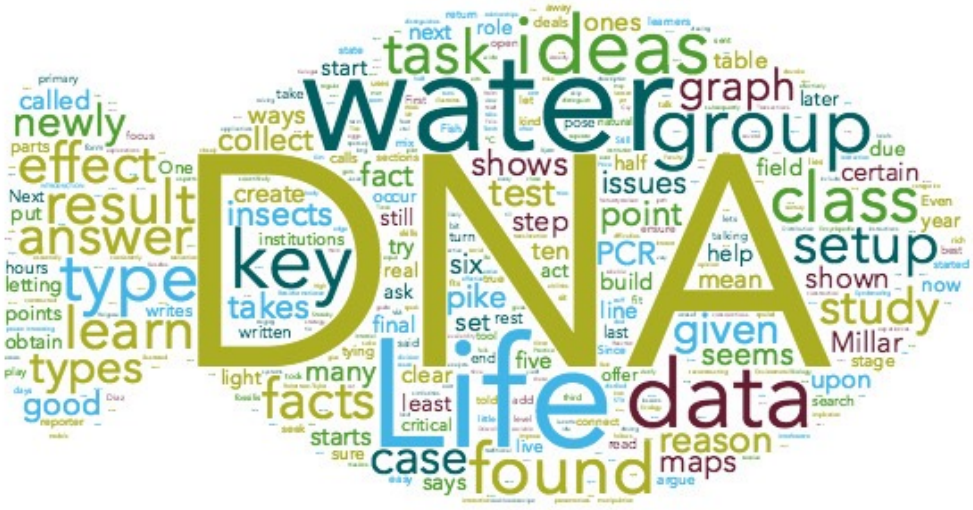
Teaching authentic cutting-edge science to high school students

An analysis of the educational program 'DNA and Life' using two didactic theories

A masters thesis
by Leonora Simony



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Submitted 4th of March 2016

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Name of department	Department of Science Education
Author	Leonora Simony
Title	TEACHING AUTHENTIC CUTTING-EDGE SCIENCE TO HIGH SCHOOL STUDENTS - An analysis of the educational program 'DNA and Life' using two didactic theories.
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Laboratory work is an important part of many scientific subjects, such as physics, chemistry or biology. As a result laboratory work is also an important part of science education. Even so many didactic studies questions the effect of laboratory work on students ability to acquire scientific knowledge.

In this thesis the Theory of Didactic Situations and Didactic Transposition theory are used and combined in order to analyse the educational program 'DNA and Life', offered by The Natural Museum of Denmark. This program invites high school students to spent a day in a modern laboratory, where they try a newly developed molecular method in order to examine biodiversity.

There were two aims of this study. First I wanted to examine how students work in the laboratory and if this work could be optimised? Second I wanted to examine if a newly developed method would increase the students enthusiasm towards science?

Theory of Didactic Situations was used to examine the programs structure and this work became the point of departure when analysing the Didactic Transposition, thus combining these two theories in one theoretical framework. These analyses created my reference model, which in this thesis functions as a result, as it became an idealised version of 'DNA and Life'. Through the analyses I found that if students are to achieve the optimal learning outcome from cookbook-styled laboratory exercises, the exercise needs to be followed by other types of tasks, where students, without interference from an educator or teacher discuss and evaluate the work done in the laboratory. The results in this thesis also indicates that an open-ended evaluation of the laboratory exercise and not the usage of a new method engaged students in laboratory work.

ACKNOWLEDGEMENTS

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Acronyms

TDS	Theory of Didactic Situations
DNA	Deoxyribonucleic acid
eDNA	environmental DNA
PCR	Polymerase Chain Reaction
qPCR	quantitative Polymerase Chain Reaction

1. INTRODUCTION

1.1 Objectives

In recent years much has been done to prevent the decline in young peoples interest in science. In this context the term *authentic science* has been presented as a way of improving science education and students scientific literacy. Authentic science refers to an experience with science, which demonstrates more aspects of actual or real science(Crawford 2015). When it comes to teaching authentic science museums has unique possibilities because of their role as a place of science and research as well as being a place with a social and educational responsibility (Hein 2006, Delicado 2010). Out-of-school science education have also proven to play an important role when it comes to increasing young peoples interest in science (Rocard 2014).

In 2012 the Natural History Museum started to develop an educational program called 'DNA and Life', which is based on a method developed that same year by scientists at the museum. This newly developed method use environmental DNA to monitor biodiversity in freshwater. This is a clear example of how taught science originates from the scientific discipline itself (Achiam 2015). All scientific disciplines have traditions, ways of doing experimental work, of presenting data etc., even within a scientific discipline there is variation depending on the exact topic. In biology, which is the subject underlining the educational program 'DNA and Life', there is many different practices regarding experimental and practical work. Practical work is an essential element in all types of biology and students studying biology therefore needs to engage in the practical work that defines this field. The importance of practical work is reflected in its widespread use in science education (Abrahams, Millar et al. 2008) and in the emphasis made on practical work in curricula (Retsinformation 2013).

A central part of 'DNA and Life' is laboratory work, as the students use the newly developed method to test water samples for different organisms. Laboratory work has been discussed in science education, as it has proven difficult to get students to transform laboratory work into knowledge (Millar 2004, Abrahams, Millar et al. 2008). Another aspect of laboratory work is whether or not it makes students exited about science? (Hofstein, Cohen et al. 1996, Berg, Bergendahl et al. 2003).

In this thesis I seek to analyse the educational program 'DNA and Life' in order to investigate how students work in a laboratory and to investigate if working with a newly developed method could increase the students engagement towards science. I will do this by combining two different didactic theories in the creation of my theoretical framework. The theories used is Theory of Didactic Situations and Didactic Transposition theory. Didactic transposition was chosen because it connects the educational with the scientific. Through Didactic Transposition one looks at the processes that transform knowledge from a scientific setting into an educational one. Theory of Didactic Situations has been chosen as a analytical tool to understand the educational program 'DNA and Life', and this analysis is used as a point of departure to understand the transposition.

In this thesis the adjective 'didactic' refers to the processes that have to do with creating knowledge for teaching, and the noun 'didactics' is used to describe the science of teaching specific bodies of knowledge (Achiam 2014).

1.2 Structure of thesis

Figure 1 gives the reader a schematic overview of the thesis' structure.

After this introduction I will present the general method, which contains three sections. The first section will explain the biology used in the educational program under investigation. In the second section I will present the programs structure and in the third I will explain how I chose to collect my data.

From the method section we move to Chapter I, where the theoretical framework of Theory of Didactic Situations is used to analyse the structure of 'DNA and Life'. This chapter contains its own theory, method, analysis and discussion section, which deals with the composition of the program. It also addresses what the students have a possibility to learn and how the students act within the environment that is the laboratory.

From Chapter I we move forward to Chapter II, which deals with the science behind 'DNA and Life' and the decisions behind the transformation of a newly developed scientific method into a educational program. This is done through the notion of Didactic Transposition, and this chapter also contains its own theory, method,

analysis and discussion section.

The next section is an overall discussion of the usage and combination of two different theories into one didactic framework. It is also where the overall research questions will be discussed.

Lastly I will conclude on the aims and the implication of this thesis.

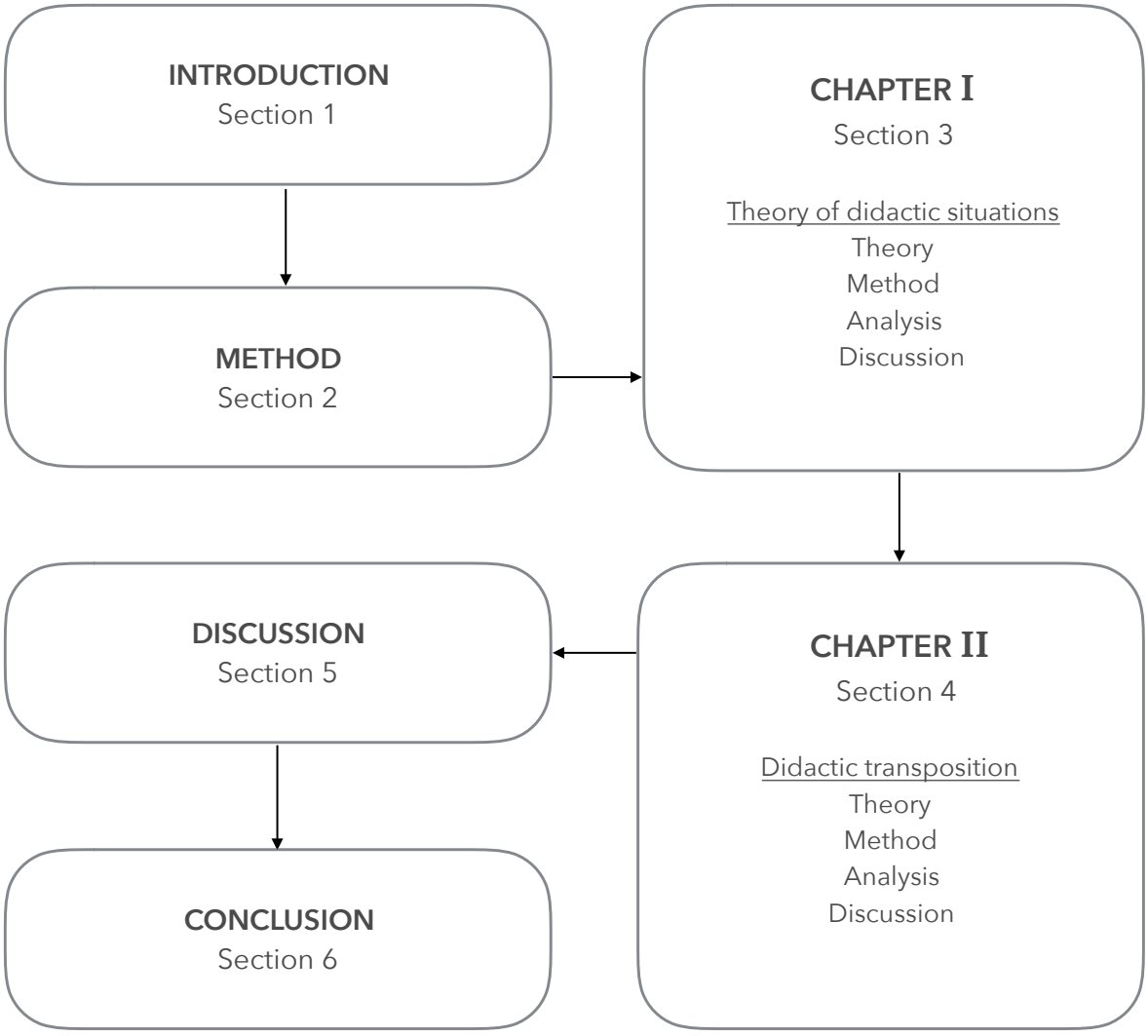

Figure 1. This figure shows how I have chosen to structure the thesis.

2. METHOD

The data for this study is based on six classes of STX high school[1], who participated in the educational offer 'DNA and Life'. In this section I will describe three things. First I will explain biological and technical terms in connection with the biology used in 'DNA and Life'. Second I will describe the structure of 'DNA and Life' and third I will describe how I collected the data for this thesis.

2.1 Explaining the biological and the technical terms

The educational program examined in this thesis uses a wide variety of different technical terms and processes from the field of biology. To make sure that all who reads this thesis are able to follow and understand the points given, I will in this section explain the terms and processes necessary for the overall understanding.

2.1.1 Biodiversity

The word biodiversity is a fusion of the words 'biological diversity' (Maclaurin and Sterelny 2008) and refers to the variety of life on Earth. Variety in turn refers to the variety on an organism, species and population level, their genetic variation and the composition of communities and ecosystems (Harper and Hawksworth 1994). Biodiversity is not evenly spread around the world, but is highest around equator due to the warm and humid conditions creating a high primary production[2].

2.1.2 Environmental DNA

All living things release DNA into their environment. This can be from faeces, urine, eggs, skin cells etc. This type of DNA is called environmental DNA (eDNA) (Herder, Valentini et al. 2013). eDNA can be extracted from the environment whether it is from water, soil or faeces and due to its unique composition we can use it to detect species at any life stage. One important thing when talking about eDNA is the fact

[1] In this thesis high school refers to the final three years students spent on their youth eduction before starting further education. E.g. university

[2] Primary production is the production of organic matter in plants, algae and cyanobacteria as the first (primary) step in the food chain

that it decomposes. How fast depends on the environment, but the possibility of detecting a species, that is no longer present, is very unlikely (Ficetola, Miaud et al. 2008). Therefore it provides us with a species snapshot of the location under examination.

2.1.3 PCR

PCR stands for polymerase chain reaction, and is a method used to amplify DNA molecules, in order for it to be visualised or used in other processes, for example sequencing (Herder, Valentini et al. 2013). DNA is a double α-helix with two complementary strands built from combining the four bases Adenine, Thymine, Cytosine and Guanine (see figure 2). In PCR the DNA strand is first split into two half strands by heating the strand to around 94°C (see figure 3). This is called denaturation and the end product we call single-stranded DNA. In the next step

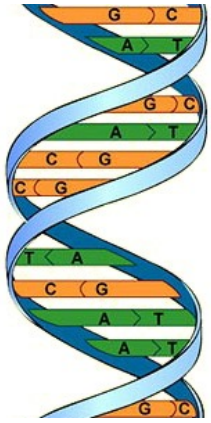

Figure 2. This figure show double-stranded DNA, folded in an α -helix

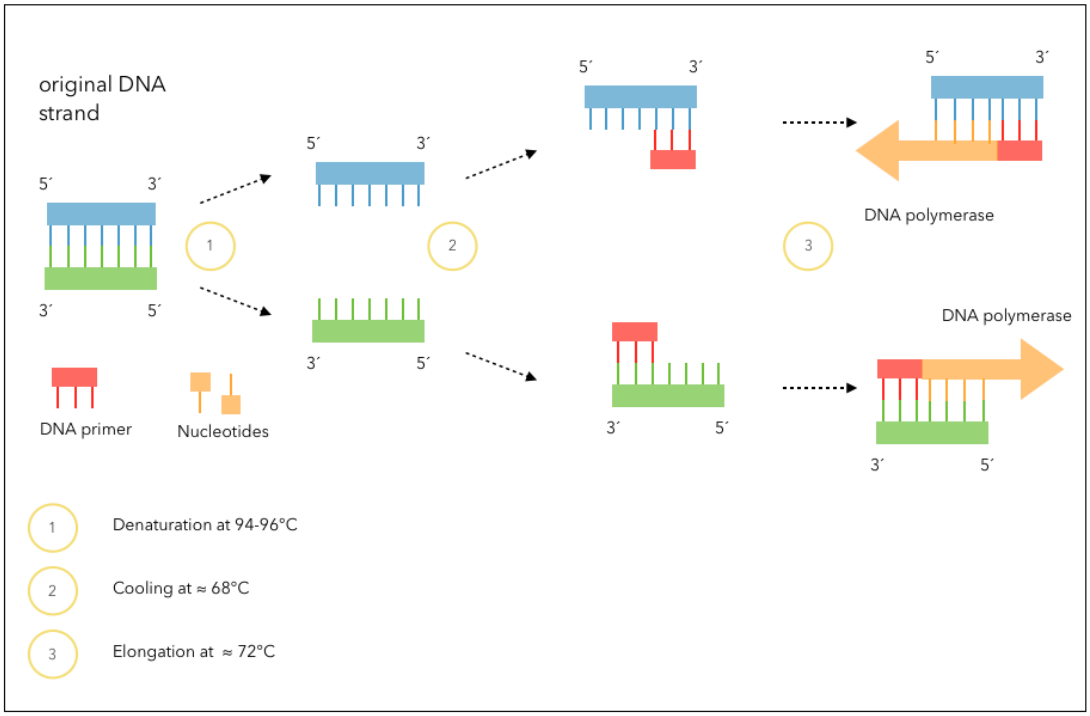

Figure 3. This figure shows what happens during the first cycle of PCR. The end product is two new strands that during the next cycles are submitted to the same treatment as the the first, resulting in the exponential amplification of the DNA molecule

these single strands are cooled to around 68°C, in order for the primers to anneal to them. If the temperature is not correct we risk incomplete binding of the primers. Primers are small single strands of DNA ,that are specifically produced to bind to at specific set of nucleotide, and they therefore "select", which part of the DNA strand we wish to copy. This means that it is via the primers we choose what we search for, and it is therefore vital that they bind properly to the single stranded DNA. In the third and final step we increase the heat to 72°C, which is the optimal temperature for the enzyme DNA polymerase. DNA polymerase is the enzyme that synthesises the new DNA strand by adding the complementary nucleotide (A binds to T and C to G). These three steps are repeated for at set number of cycles or till the reactants and enzymes are consumed, creating an exponential amplification of the DNA molecule.

2.1.4 qPCR

qPCR stands for Quantitative PCR and refers to the fact that this method is able to quantify the number of DNA molecules from the species one is looking for. This is possible because we not only ad primers, nucleotides and polymerase, but also what is called a probe (see figure 4). A probe is a small string of DNA designed so it fits in between, what the two primers "cut" out. Attached to this small piece of DNA are a fluorescent reporter and a quencher. As long as the florescent reporter and the quencher is attached to the same DNA molecule the fluorescent reporter does not emit light. If we go back to the regular PCR, step 3 DNA polymerase adds the

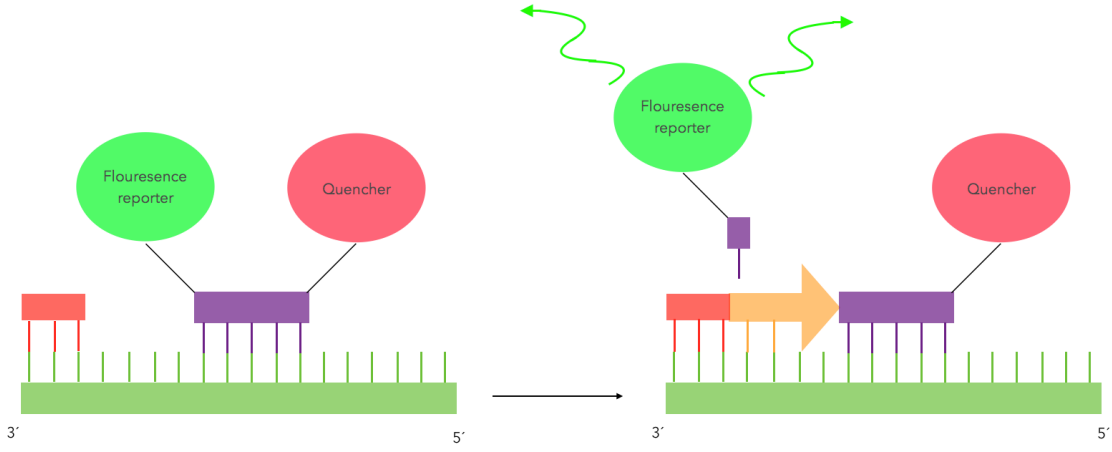

Figure 4. This figure shows the principle behind qPCR. When DNA polymerase encounters a double strand on the single strand, it cuts it off separating the fluorescence reporter from the quencher allowing it to emit the fluorescence light, that the qPCR machine can measure.

complementary nucleotides to the single strand, but if it encounter a double strand, as it would do, when the probe attach to the single strand, it "cut" this part away. When this happens the fluorescence reporter is detached from the quencher allowing it to emit its florescence light, and it is this light that the qPCR machine measures. The more of the DNA molecule there is the more light is emitted, which is why this is a quantitative method.

2.3 Describing the structure of 'DNA and Life'

In the educational program 'DNA and Life' offered by the National History Museum of Denmark, the students work with at method first published in 2012, by scientist working at The Natural History Museum of Denmark (Thomsen, Kielgast et al. 2012). This newly developed method was also the starting point of the development of this educational offer, meaning that the museum started developing the educational offer the same year the method was published. In this section I will try to explain how the educational program 'DNA and Life' came to be structured, so the reader has an understanding of the programs design.

2.3.1 Collecting water samples

Before arriving at the laboratory DNALab the students have been to a freshwater site, where they have collected the water samples they later test using qPCR. The students collect 3x15 ml water samples, which must be collected during July or August (see appendix 1), and then send them to the museum to be stored and frozen until the class planned visit at DNALab. If the class have not had the chance to collect their own water samples (this could for example be the case if the class have signed up for participation after the time they could collect the samples) an employee at the museum have collected the water sample. These samples were collected in the same way as the students.

In the data comprising this thesis, two classes have collected their own samples and four have tested samples collected by the museum.

2.3.2 Introduction

When first arriving at DNALab the educator, that follows the student throughout the day, gives an introduction, that takes place in the laboratory. First the students are asked to put on a lab coat and the rules of the laboratory are explained. Next there is an introduction to the laboratory 'DNALab', where the students sit. The students are first introduced to the Natural History Museum as an institution. They are told that the museum covers three different fields of science (Botany, Geology and Zoology), and that it is a place of both research and education. Secondly the term and field of research related to biodiversity is presented and explained. The students are told about the three Danish scientists, who have developed the method they will be using today and that this method is used to monitor biodiversity in freshwater. This is done by using water samples. Furthermore the students are informed that they will be introduced to keying, which is an older way of monitoring biodiversity. This introduction takes about 50-60 minutes and is followed by a ten-minute break.

2.3.3 Laboratory work

In this part of the program the students prepare a qPCR setup, in order to test a freshwater sample for a specific species of fish, amphibians or freshwater insects. In the following I will explain how this is done.

After the break the educator gives another introduction. This introduction includes a laboratory exercise, where the students have to pipette five different volumes of distilled water into an Eppendorf tube. These five volumes are selected so all students get experience in using the types of pipettes they need in the upcoming laboratory work. Next comes an introduction to primer design, PCR in general, qPCR and at last an introduction to the laboratory equipment. The students are asked in groups of two, to start with the first step in the laboratory manual provided (see appendix 2), creating the PCR mix. When all groups have finished with step one, step two is explained. The groups then carry out the final step preparing three PCR-tubes for testing in the qPCR machine. The tubes are placed inside the machine and the educator starts the sequencing program. The sequencing takes approximately two and a half hours to complete. During this time the students have a 45 min lunch break and then proceed with the two following exercises.

2.3.4 Keying out fish

The main aim of this exercise is for the student to try an older way of determining species by keying out ten different alcohol preserved fish.

This is done after the lunch break and while the qPCR is running in a room adjacent to the DNALab. The students are now told that they are going to try another method to identify fish. In relation to this the diversity of fish in Denmark is discussed, through questions like "how many freshwater types of fish do we have in Denmark?" and "what types of methods do scientists use to figure this out?" A key aspect when it comes to keying out fish is the ability to observe its external features. The students and the educator discuss what types of characteristics that are important, when trying to key out a fish. This is done by presenting a drawing of a fish with all the characteristics the students need to be aware of (appendix 3). The students are then introduced to the key (Muus 1998). Together they key out an alcohol preserved fish, the Tench (*Tinca tinca*), and the educator gets one student at a time to read aloud from the key. Through plenary discussion all students decide, which entry in the key is the correct one. This is done until they arrive at the correct species. Next the students are divided into groups of five or six and asked to determine ten species of alcohol preserved fish. The students' results are subsequently reviewed on the board.

2.3.5 Fish facts

In this exercise the students are asked to gather information about one of the alcohol preserved fish, and thereafter present that information to the rest of the class. This is done after examining the results from the keying, and the information source used is the key from the previous exercise. The provided fish is one of the ten alcohol preserved fish they just keyed out, but also one the students are looking for in the laboratory using the new eDNA method. This could be the Northern pike (*Esox lucius*) or the Three-spined stickleback (*Gasterosteus aculeatus*). After gathering information all groups present their findings to the rest of the class.

Not all the observed classes were asked to do this task. Students from one school did not do it at all and from another school only two students were asked to do this task. In the other four classes observed, all students were asked to carry out this task.

2.3.6 Reviewing the results

After the presentation of the fish facts found in the previous assignment, the students go back to the DNALab where the qPCR has completed sequencing the samples. At this point all the graphs produced are examined and discussed on the board letting each student group present and interpret their results, in turn. The results are after each presentation written into the results table (see appendix 2, page 3). It is possible for the students to get one out of three possible results. The first one is that they find DNA in their water sample from the organism they tested for (see figure 5 graph a). Here the positive control and the water samples graph go above the threshold, seen as the clear blue line. The second possibility is that they do not find the organism they tested for, but otherwise the qPCR setup was correct (See figure 5 graph b). Here the only line going above the threshold is the positive control. Finally they can get a result as shown in figure 5 graph c. This graph indicates that something has gone wrong in the students setup, since the positive control did not move above the threshold.

One by one each group review their

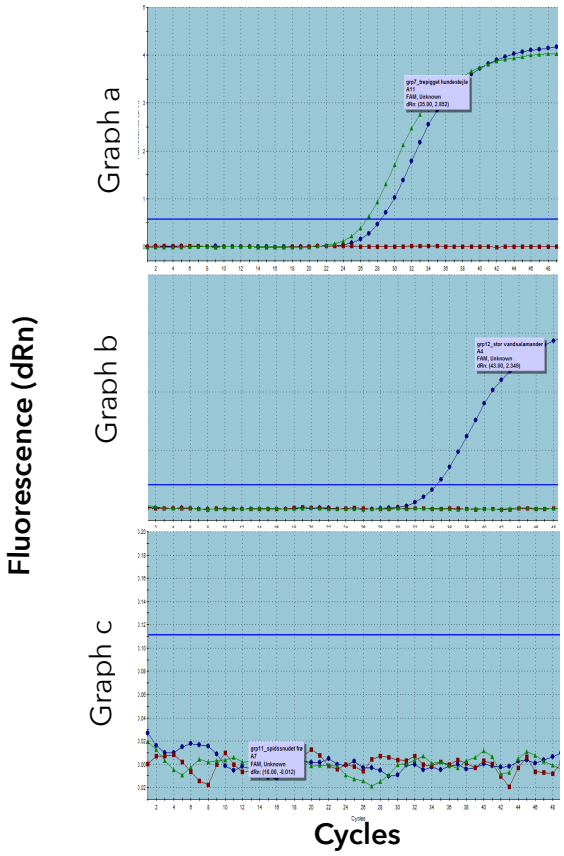

Figure 5. *This figure shows three possible results. Graph a shows what it looks like when the students find the organism they tested for and graph b shows what it looks like when they do not. Graph c shows what it can look like when there is a flaw in their qPCR setup. The values on the y-axis change from graph a or b to graph c. This merely means that we have "zoomed in" on the lines below the threshold value, because no DNA has been copied.*

graph and discuss the method and its further implications regarding biodiversity monitoring and research.

2.3 Data collection

The data that comprise this thesis was collected from the 11th of March to the 9th of April 2015. I collected my data by observing six high school classes following the educational program 'DNA and Life'. The program takes place at the museum's laboratory called 'DNALab' and also in another adjacent room, and it takes approximately six and a half hours. During this time the students work in groups of two in the laboratory and in groups of five or six in the two subsequent tasks. Besides this there is many plenary discussions and explanations. I therefore chose to record the students' process throughout the entire day, but focus on selected groups during independent work and the entire class during introductions, class discussions and presentations. Studies have shown that it differs where certain type of students choose to sit in classrooms (Sommer 1967, Haghighi and Jusan 2015). In order to counter this problem and try to get a wide range of students in my dataset, I chose to film half of the groups from students sitting in the back of the laboratory and the other half from students sitting in the front of the laboratory. Otherwise the groups were chosen at random. In the laboratory the students sit at desks with two groups facing each other. I could therefore focus on two groups of two during the independent work. I made sure that these two groups were also part of the group followed during independent work on keying and finding facts about fish. My role throughout the day was as a silent observer, who did not partake in any aspect of the educational program.

All classes observed studied biology on either an intermediate (B) or an advanced (A) level in STX high schools. All students where on either their second or third year, meaning that their ages spanned from 16 to 18 years old approximately.

I used a Sony HDR-CX250E Digital HD camera on a tripod to film the class throughout the day. In addition I also placed an Olympus VN-8500OC digital voice

recorder on the table in front of my focus group, in order to be sure to capture the audio from these students, since the acoustics in the laboratory were not very good.

3. CHAPTER I

Analysing the educational program 'DNA and Life'

In this chapter I will analyse the structure of the educational program 'DNA and Life', using the Theory of Didactic Situations.

3.1 Theory - Theory of didactic situations

French didactic and theoretician Guy Brousseau developed the theory of didactic situations (in short TDS), which is a didactical theory first developed for the didactics of mathematics. It has since been used for many other disciplines such as physics and biology (Tiberghien, Vince et al. 2009, Evans and Winsløw 2012). TDS it is a theory, that states that knowledge can not be acquired in reference to authority, but has to be acquired through personal conviction and realisation (Brousseau 2006). Brousseau distinguishes between two types of knowledge, the official knowledge and the personal knowledge. Official knowledge comes from the scientific community and from the people working within this community, the scientists. It is the type of knowledge we find in published articles and textbooks. The personal knowledge is individual and tightly connected to a person's conceptions and ideas (Winsløw 2006). These are in turn connected to specific types of situations experienced by a person and he or she is dependent on these situations in order for him or her to make the official knowledge personal. These situations and the student's interaction within these, have to be carefully planned by the teacher, so the student gains the intended knowledge. Otherwise the student is placed in a situation, where he or she cannot acquire new knowledge and skills.

3.1.1 Didactical and adidactical situations

Brousseau distinguishes between two types of situations, the didactical and adidactical. The didactical situation is controlled by the teacher and the adidactic situation is controlled by the students. To guarantee the students' understanding of the intended knowledge, they must construct, acknowledge and accept it themselves. According to Brousseau, construction of knowledge can only happen through action. One could say that it is through action that the students teach

themselves. They draw knowledge from their own experience and by their interactions in a milieu created by the teacher. It is the adaption to the milieu that results in knowledge and creates new types of responses to a problem. Students need to act, speak, think, evolve and construct new ideas by their own motivation, and the students will only truly have acquired new knowledge, when they are capable of using it in new situations outside the teaching sequence (Brousseau 2006). This is what Brousseau calls adidactical situations, and it is primarily in these situations the learning occurs (Winsløw 2006). But an adidactical situation does not occur out of nothing. It is a situation that has been carefully planned by a teacher, and we cannot expect students to make sense of the adidactical situation without aid and assistance. The teacher needs to communicate the problem to be solved and help the students to tie everything together in order for the students to see the intention and the broader context of the knowledge taught. This is what Brousseau calls a didactical situation. When establishing the situation and the milieu, the teacher and the students must have a mutual understanding of the rules, and who holds which responsibilities. Brousseau calls this the didactical contract.

3.1.2 The didactical contract

The teacher has certain responsibilities regarding the creation of the assignment and he needs to create a milieu in which the student can navigate and learn. Even so it is not only the teacher, who has responsibilities. Responsibility also lies on the students, in accepting the milieu and the tasks the teacher introduces (Winsløw 2006). This is called the didactical contract. What do I, as a teacher, want from you, the student, and what do I as a teacher, promise you in return? (Brousseau 2006). The situation and the milieu can change during a lesson and it is the teacher's responsibility to modify and renegotiate the contract with the students, and thereby create new situations for learning. A teacher can use this modification on purpose adding additional information, while the students work on solving the problem. Adding information in its very nature changes a situation and can make room for the students to create other and new ideas, solutions or hypothesis, but when the situation changes, so does the didactical contract. The contract therefore has to be

renegotiated. The contract closely depends on the knowledge in play and if the knowledge changes character or form, so does the didactical contract.

3.1.3 The milieu

The milieu is an important part in 'Theory of didactic situations'. Brousseau describes the milieu as everything that acts on the student or anything the student acts upon (Brousseau 2006). It could be the teacher or another student, but also problems, assignments, objects etc. The milieu is created by the teacher with the purpose of letting the student personalise the intended knowledge (Winsløw 2006). The milieu should be rich enough for the student to realise, when they have found a sufficient solution to the given problem. The certainty of the solution should come from the milieu rather than the teacher. Even so it is permissible for the students to seek confirmation of their solution with the teacher (Achiam, Solberg et al. 2013). One could also say, that the milieu should give the students a type of independent and unaided validation or rejection of possible solutions or hypotheses. The tradition of mathematics, to which the theory has been developed, are very different from biology (within which the present thesis operates) as there in the field of biology rarely is just one solution to one given problem (Evans and Winsløw 2012). In biology many ideas and solutions may be plausible answers to a single question, and the milieu will therefore normally not allow just one solution but many. Creating a milieu in biology is therefore not easy. It needs to be carefully planned in order to provide the students with just enough information to successfully obtain a specific body of knowledge. If the milieu lacks necessary information the students will not gain the desired knowledge. On the other hand, a milieu with to much information will do exactly the same. This is called the Topaze effect and is a paradox of the didactical contract.

3.1.4 The Topaze effect

In discussions about the milieu and the didactical contract, the Topaze effect poses a paradox. Let us say a teacher poses a problem or a question, where the student cannot come up with a possible and valid answer. Then the teacher must re-evaluate

the situation and thereby the contract and milieu. In an attempt to do so, the teacher can pose new questions in order for the student to come up with an answer. When doing so the teacher has to be careful. If these questions simplify the problem too much and make it too easy, they can change the situation in such a way that the knowledge first intended for the students to learn, is removed from the situation, and thus result in the student not obtaining the knowledge the teacher intended. In this situation the didactical contract has not been broken since the student, and not the teacher, produced the expected answer. Still the knowledge it took to produce that answer is different from the knowledge the teacher originally meant for the student to construct and obtain (Bikner-Ahsbahs, Artigue et al. 2014). This is called the Topaze effect.

3.1.5 The Jourdain effect

The Jourdain effect is a form of Topaze effect, but where the Topaze effect underestimates the students abilities the Jourdain effect overestimates. This could appear, when a teacher recognises scientific knowledge in a students behaviour or answer even though these are derived from something of ordinary cause or meaning (Brousseau 2006). This can for example be seen in laboratory exercises, where the students follow a cookbook-recipe in a scientific experiment and therefore has obtained the knowledge and know-how regarding scientific discipline or method (Winsløw 2006). In an attempt to secure the students' success in the experiment the teacher can be led to believe, that the students have gained the knowledge behind the experiment. Perhaps the Jourdain effect can also reduce the students' ability to obtain the intended knowledge?

3.1.6 The phases in TDS

In order for the student to personalise a specific piece/object of knowledge the teacher must, as stated, create a milieu, where the student can navigate and evaluate and thus independently accept or reject solutions and hypothesis. Brousseau describes five different phases that need to be present in a lesson in order for the student to have the possibility to obtain a piece of official knowledge and thereby

make it personal. These phases are the devolution, the action, the formulation, the validation and the institutionalisation phase.

Devolution

The devolution is the so-called introduction phase, where the teacher explains the assignment and the problem and hands it over to the students. It is in this phase that the didactical contract and the didactical milieu are established. When the teacher explains the assignment it must be explained in such a way, that the students can internalise and apply it (Brousseau 2006). The teacher governs this (a didactic situation), but it does not mean that the students cannot have an active part in the process. Brousseau writes

> *…The aim of this sequence is still the communication of an instruction but it has slipped into an action phase (Brousseau 2006, page 7)*

When handing over the assignment it is the teacher's job to hand it over in such a way, that the students are able to act in the milieu provided. This can be done by including some or all of the students in the devolution of the problem. In doing so the rules are explained by showing rather than telling, what the students need to do next. It is the teacher's job to provide the milieu and the assignment for the students, but it is the students' job to receive and understand the assignment, and accept the terms and their role and responsibility.

Action

In this phase the teacher lets the students act within the established milieu and attempt to find probable and valid solutions to the given problem or assignment. Brousseau writes

> *The sequence of "situations of action" constitutes the process by which the student forms strategies, that is to say, "teaches herself' a method of solving her problem (Brousseau 2006, page 9)*

This means that the action phase is an adidactic situation, where the teacher takes a step back, letting the student act without interference. If the problem or assignment proves to be too difficult for the student, the teacher can devolve again and thereby

change the milieu to help the student learn the intended knowledge. There is a risk of creating the topaze effect and the teacher must therefore be careful not to change the situation in such a way, that the student cannot obtain and personalise the intended knowledge. At the same time the students must be provided with enough information in order to make and validate their own solutions, a paradox that come with the didactical contract.

Formulation

In the formulation phase the students discuss, with themselves or with others, the right strategy to solve the assignment or problem. Here the students take the objects and the relevant relationships in the situation and milieu into account using reasoning and the experience they got in the action phase. This phase can be both didactic and adidactic, meaning that the formulation process can be managed by the teacher or the students themselves. No matter who governs it, the point of this process is to have the students specify and clarify their solutions and hypothesis in order to be able to discuss and share them. Brousseau writes

A dialectic of formulation would consist of progressively establishing a language that everyone could understand, which would take into account the objects and the relevant relationships of the situation in an adequate way…(Brousseau 2006, page 12)

The formulation process is where the students consider all the experiences they had in the action phases. Here they try to concretise it into valid solutions and hypothesis. Brousseau states that we can see elements of the validation phase in the student's attempts to argue for or against their solution or hypothesis.

Validation

Here at least two people discuss the solution or hypothesis they have obtained regarding the given problem or assignment. It is in this phase that the students and teacher seek to confirm or deny the proposed solutions. Brousseau writes

…it is to declare oneself ready to support an opinion, to be ready to prove it (Brousseau 2006, page 15)

In this phase the students try to answer the problem given in the devolution phase. The teacher or the students themselves can do the validation making this phase didactic or adidactic (Winsløw 2006). It does not necessarily need to be either one or the other. It is possible to see elements of both didactic and adidactic situations in the validation phase.

In the validation phase the student's ideas must be tested, discussed and agreed upon. The student must make statements about, what he or she believes are possible solutions. These solutions will be subject to judgment and discussion. Through discussion it is possible for the students to see potential errors in their own arguments. A process that is necessary in order to construct and acquire knowledge. Through this discussion elements of the action and formulation phase can occur. This is only natural since the solutions presented in this phase are derived from the formulation phase, which in turn is derived from the action phase. To sum up, the validation phase permits the organisation of solutions and hypotheses, and it is in this phase they are accepted or rejected.

The phases in Theory of Didactic Situation

	TEACHERS TASK	**STUDENTS TASK**	**MILIEU**	**SITUATION**
DEVOLUTION	Initiate Clarify	Receive and understand the task	Being established	Didactic
ACTION	Observe Reflect	Act Reflect	Problem field Exploration	Adidactic
FORMULATION	Organize Ask/prompt	Formulate Clarify	Open discussion	Adidactic or didactic
VALIDATION	Listen Evaluate	Argue Understand	Steered discussion	Normally didactic
INSTITUTIONALISATION	Present Explain	Listen Understand	Official knowledge	Didactic

Table 1: *This table shows the different phases in TDS with the phases explained in short, from Winsløw, 2006*

Institutionalisation

This is the phase where the teacher takes the students' newly acquired knowledge and unfolds the subject, explaining the broader context. This is where the official knowledge is presented to the students and the newly obtained knowledge is confirmed, tying all the other phases together. The institutionalisation is necessary to support the validated solutions and hypotheses and support their usage outside the classroom. In table 1 all the phases are gathered and explained in brief.

It is important to emphasise that the phases do not necessarily occur in this order. That said one would normally see a devolution in the beginning and an institutionalisation at the end.

3.2 Method

In this thesis I have used TDS as an analytical tool to divide the educational program 'DNA and Life' into the five different phases described in this theory. The set of criteria, as seen in table 1, have been used to determine the phases. In using these I discovered that the program consists of three different blocks, each block containing a different TDS structure (see figure 6). In the following analysis I will explain my choices and reasoning behind these divisions.

Additionally I have also divided the program into didactic and adidactic situations, and calculated, how much time was spent on each type of situation. A situation was determined as didactic if the teacher was the main driving force behind the situation. This could for example be when the educator asked the questions and the students answered. A didactic situation could also occur if the educator presented a subject and the students asked question. A situation was determined as adidactic if the students were the main driving force behind the situation. This could for instance be when the students carried out a task and the educator only took the part of an observer.

The time distribution was converted into percentages for each class by setting the total time spent, minus pauses, equal to 100%. This was then calculated as an average percentage to create an overall view of the time spent on didactic and adidactic situations.

3.3 Analysis

3.3.1 'DNA and Life' divided into TDS phases

Overall devolution

The educational program begins with an overall introduction to the course of the day and its main theme, biodiversity. I have decided to categorise this as an overall devolution, because the educator gives a general introduction to the theme of the day, biodiversity, its importance and how research in biodiversity is conducted at the National History Museum of Denmark. This creates a fundamental platform of why the students are there and why the work they are about to do is important. In other words the educator tries to prepare the students for the content of the day, and establish an overall didactic contract.

Laboratory work

Devolution

The laboratory work starts with a brief devolution, where the educator explains the method, technical terms and the laboratory manual to the students. This further establishes and fine-tunes the didactical contract regarding the task the students are about to perform. After this the students practice using the pipettes, an exercise I have chosen to classify as a part of the devolution of the laboratory work. The kind of laboratory work the students need to do requires the skill of using a pipette, in order to succeed in preparing samples for the qPCR. According to the didactical contract, it is the educator's responsibility to provide the students with the necessary skills to carry out the task at hand. Since being able to use a pipette is crucial in order to create a qPCR setup that will working correctly, I have classified the pipette exercise as part of the devolution. The devolution, as described in the theory section, shares common features with the action phase, but because the students are not exploring a problem field (see table 1) the pipette exercise is a way of establishing the milieu and thus equip the students with the necessary skills.

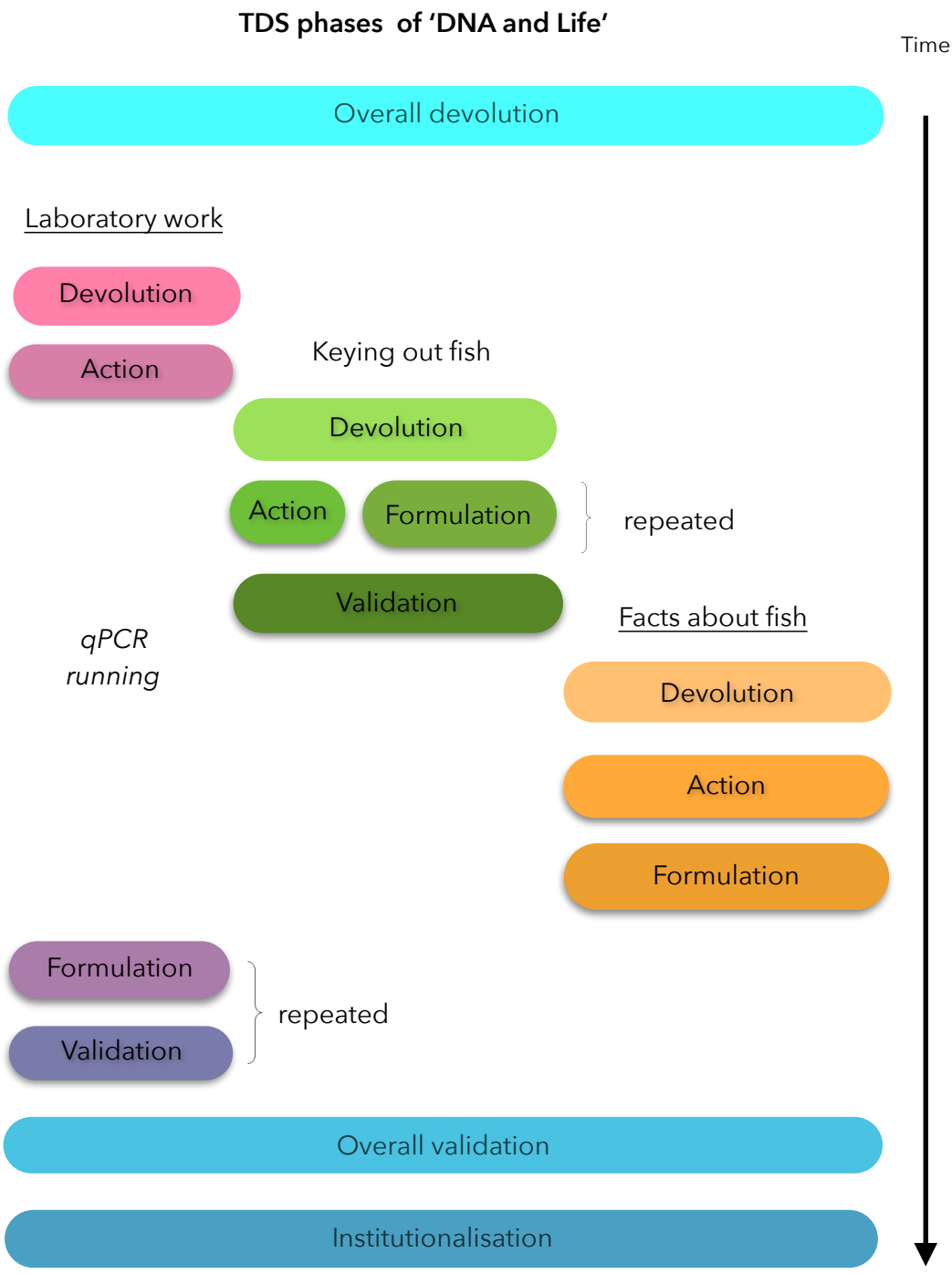

Figure 6. *This figure shows how I have divided the educational program 'DNA and Life" into the different phases of TDS*

Action

When the students begin to prepare their qPCR mix they begin to explore the problem 'What type of organisms is there in our chosen fresh water location'. I observed that the educator took a step back to let the students work within the

milieu established in the devolution, creating what initially appeared to be an adidactic situation. However I did observe students, who asked the educator for guidance, which is a deviation from the action phase since the environment, if planned correctly, should provide the students with enough information to find answers to occurring questions. The questions from the students were often related to the laboratory procedure. Questions they should be able to answer, as they had been asked to read the laboratory manual before preparing the PCR mix. It seems however, that some students need the educators approval of their understanding of the laboratory manual before proceeding, as the questions are of a clarifying nature ('did I understand this correctly?') rather than comprehension ('what does this mean?'). I also observed some students, who did all the laboratory work without asking questions, but with two very different outcomes. Some follow the laboratory manual correctly, creating a correct qPCR setup, while others clearly have skipped certain important steps such as vortexing[3], and thus risking errors in the qPCR setup, that potentially could ruin their setup. Reasons for this will be discussed later in this chapter. In addition one could also argue that the situation here is not adidactic, as the students work is dictated by a manual created by the museum. They therefore do not work on their own, which could be the reason, why I do not see any of the students in my focus groups reflecting upon their action during this phase. Even so this part of the program does meet other criteria for the action phase, such as exploring a problem field and the fact that the students are acting in set milieu. I have therefore chosen to call this a didactic action phase even though it is in contradiction with the original theory. However the theory is created in relation to mathematics and this could be an example of how it does not fit completely, when it comes to biology and laboratory work.

When all students are done preparing their qPCR-tubes for testing, the tubes are put into the qPCR machine, which then runs for approximately two and a half hours. During this time the students eat lunch and carry out the two other tasks; keying out ten different fish and finding facts about them. These two exercises will be analysed

[3] To vortex means to swirl a mass, in this case water. This is important because DNA is heavier than water and therefore sediments. Vortexing moves the sedimented DNA up into the water column, making it possible for the students to obtain it using the pipette.

in later sections.

Formulation and validation

When the qPCR is done, the students start the second phase of the laboratory exercise. As described previously one group after the other are asked to comment and evaluate their graphs. In this part of the program the students explains what they see on the graphs produced by the qPCR (see figure 5). I have chosen to categorise this as a formulation phase, because the students enter into an open discussion about their results, where they need to interpret the graph. A formulation phase can be both didactic as well as adidactic (see table 1), but since the educator is the one asking the questions, I have determined this as a didactic formulation phase. The validation phase comes after the formulation phase and is identified by the fact that the students evaluate the method and their own work in the laboratory. Again I have determined this as a didactic situation as the educator is the one asking the questions. This is as stated done by all groups in turn, which effectively means that each group goes through the formulation and validation phase one by one, and practically goes back and forth between these two phases. The method is therefore evaluated before all students have had a chance to see and formulate hypotheses about their own results. This may pose different problems, which will be considered further in the discussion.

Looking at my data I observed that the first group to go through the formulation and validation phase are the ones, who do much of the work regarding the interpretation of the graphs. This group needs to explain, what the different graphs show and why and how they could be interpreted. As a consequence it is easier for the following groups when asked about their results, as most of the interpreting difficulties has been clarified and explained in the conversation between the educator and the first group. This is shown by that fact, that the students pretty much repeat the first groups' explanation. This does not necessarily mean that they do not understand the graphs or their results, but it could indicate that these students have not gone through the same cognitive challenges as the first group. When this is combined with the fact that the review of the results is done as a didactic situation, then much of the responsibility is removed from the students leaving them what appears to be

disengaged in this process. Because of the nature of the method and because it is new and not thoroughly tested the results and evaluation of the method is very much up for discussion. This results in an open-ended validation of the work done in the laboratory. In other words this exercise lets the students suggestions be as good as the teachers.

Keying out fish

Devolution

This part of the educational program also starts with a devolution. The students are going to start a new task, which then requires a new introduction and a new didactic contract. As with the laboratory work the students need to be equipped to handle the task at hand, which in this case is the identification of ten different alcohol preserved fish. To solve this task the students need to use an identification key for freshwater fish, a tool most high school students are not familiar with. Becoming acquainted with this identification key is therefore an important part of the devolution. I have therefor chosen to categorise the joint keying of the Tench (*Tinca tinca*) as a part of the devolution, as it is a practice round, ensuring that all students understand the usage of the key. This will enable them to carry out the assignment, quite like the pipette exercise in the laboratory work.

Action and formulation

Next I observed a fusion between the action phase and the formulation phase - at least they are very difficult to separate. It might be because the formulation in itself is not that difficult, as it consists of writing down the name of the fish the students have keyed their way to. It therefore naturally follows the action phase, where the students look at the fish and decides which characteristic to go with. The students do this with all the ten fish, and the students therefore go back and forth between the two phases. The educator lets the students work independently on this assignment all the way through, creating an adidactic action phase (as it should be), but also an adidactic formulation phase.

Validation

The validation is very different from the one I see in the laboratory work. Here the educator has the correct answer, and the validation is therefore a clear evaluation of

the students work from the previous phases, as opposed to the laboratory work, where there is no clear answer.

Fish facts

This is the exercise that I see varies the most between the classes I observed. The time spent on this part of the program differs from 43 minutes down to 19 minutes, and as stated in the method students from one school did not carrie out this task. In another observed class only two students carried out the task, as they finished the keying exercise before the other students. In the remaining four classes all students carried out the task, and it took place after the students and the educator have gone through the students' results on the ten keyed fish.

Devolution

First I observe a short devolution, where the educator explains the task to the students and they are provided with the fish their group needs to find facts about. I do not see, as in the previous devolutions, the educator explaining to the students why they need to carry out this task, and the purpose of this assignment therefore becomes unclear. This is reflected in the next phase.

Action

In this phase the student groups independently gather information about their fish, using the information provided in the identification key. Since the task is not clearly defined it quickly becomes very unstructured. The information gathered in this phase is needed, when the students later evaluate the method used in the laboratory. As the educator did not explained this, the students writes everything down as written in the key, and as a consequence a lot superfluous information is gathered, that have no real usage later in the program. This is done independently in the groups.

Formulation

I the next activity the students present the gathered information to the rest of the class. This activity was difficult to place in the TDS structure. I have, however, defined it as an adidactic formulation phase, because the students formulate and clarify their findings from the action phase. The role of the educator is also more of a questioning one rather than an evaluating one. The only thing, which does not really fit this interpretation, is the milieu, since I do not see an open discussion but rather

statements of the facts found by the students. Then again the student, who are not doing the presentation, are allowed to ask question to the presenting group, and thus making it a kind of open discussion or at least a milieu open to questions. Based on this I have categorised the presentations as a formulation phase. I do not see a validation phase connected to this assignment, apart from on a very small scale, when the students evaluate and review their results, leaving it what appears to be unfinished and lacking direction.

Overall validation and the institutionalisation

Towards the end of the program the educator tries to tie together the activities of the entire day. I have chosen to call this an overall validation, because the educator asks the students to evaluate the methods used throughout the day, the laboratory method and the keying, and in that way it leads back to the overall devolution. They are asked to discuss, what they would do if they were the scientists and they needed to examine the biodiversity in Danish freshwater. This type of validation further develops an open-ended milieu. The students are asked to reflect on the days work and use what they have learned in their argumentation. Unfortunately the last subject (fish facts) does not come into play and is left out, when the overall validation takes place and the outcome of the day is discussed.

The institutionalisation phase is not a big part of 'DNA and Life´, but I do observe it as a small part of the program, as the educator spends a few minutes on it at the very end of day. The educator explains how the method has developed from the time the water samples were collected till they arrived at DNALab. For example much has happened regarding improvement of, how water samples are collected. As stated in my theory section it is in the institutionalisation phase, that the official knowledge is presented in relation to the students newly acquired knowledge. It is therefore an important task to make the subject taught relevant for the students outside the classroom. It is in the institutionalisation phase that the main elements of the validation is captured, so the students newly acquired knowledge later can be used as a foundation or starting point for learning (Winsløw 2006). It is therefore important that the institutionalisations phase is given higher priority, so the students can

connect what they learned from their day in DNALab with a broader biological knowledge, and use the knowledge obtained in other situations.

3.3.2 Situations controlled by the educator or the students

When dividing the educational program into the phases of TDS I also looked at how the time was divided between didactic and adidactic situations, or in other words how the time was divided between activities controlled by a educator and activities controlled by the students. By calculating this I can see how much of this educational program the students govern themselves and how much of the time the educator holds the responsibility for what is happening. This was done for all classes, and an average percentage was calculated (see table 2). Due to the inconsistency regarding the laboratory action phase I have chosen to show this percentages in two different ways.

Average percentages of the structure in 'DNA and Life'

Exercise	Overall time spent on the exercise	Didactic situations (the laboratory action phase is adidactic)	Adidactic situations (the laboratory action phase is adidactic)	Didactic situations (the laboratory action phase is didactic)	Adidactic situation (the laboratory action phase is didactic)
Introduction	19 %	19 %	0 %	19 %	0 %
Laboratory work	30 %	20 %	10 %	30 %	0 %
Keying out fish	26 %	13 %	13 %	13 %	13 %
Finding facts about fish	7 %	< 1 %	≈ 7%	< 1 %	≈ 7%
Reviewing results	18 %	18 %	0 %	18 %	0 %
Sum	**100 %**	**≈ 70 %**	**≈ 30 %**	**≈ 80 %**	**≈ 20 %**

Table 2. *This table shows how the educational program 'DNA and Life' was divided between teacher controlled and students controlled time*

In columns two and three the laboratory action phase is considered to be adidactic and in columns four and five the laboratory action phase is considered to be

didactic. No matter how the laboratory action phase is viewed, the division shows that the majority of the day consists of didactic situations, where the teacher leads and governs the situations. In TDS Brousseau does not explicitly write how the time should be distributed between didactic and adidactic situations, but he does say that it is in the adidactic situation the primary learning occur. This distribution could therefore impose different implications for the learning outcome. This will be discussed later in the discussion.

3.4 Discussion

In the following section I will discuss my findings from the analysis, by taking possible issues and pose possible solution.

3.4.1 The laboratory manual

According to the criteria set up by Brousseau (see table 1) an action phase is characterised by being a milieu, where the students can act, explore and reflect within a problem field through an adidactic situation. The milieu needs to be rich enough to provide the students with the answers they need (Brousseau 2006). Confirmation of a correct answer or solution should come from the milieu established by the educator. In the educational program 'DNA and Life' a milieu, like the one just described, appears to be well established, via the devolution and the laboratory manual. Still I observed many students asking the educator for advice or approval in order to be assured that they understood the laboratory manual correctly. Since the students felt the need to ask questions, one could argue that the milieu in this action phase was not well enough established, and that the museum ideally should modify their devolution and the procedure regarding this action phase. But even so I believe that the same need for asking for approval will occur. In other words there is not necessarily something wrong with the devolution, as the students questions might stem from their encounter with an unfamiliar environment. My data for this thesis consists of students who, even though they are in their second or final year in high school, have not had much experience regarding laboratory work. Especially not working with the kind of equipment found in DNALab. In general human activity, in a known environment will be controlled by a set of rules

that has proven successful from previous experience (Rasmussen 1983). In an unfamiliar environment such a set of rules is not available and it is therefore natural to make different attempts until a successful sequence of action is obtained (Rasmussen 1983). In this case however the students are presented with the successful sequence in the manner of a laboratory manual. The students know that the manual consists of the right sequence of actions, but I believe that the questions and need for certainty arise, because they are in an unfamiliar place, both mentally (a type of situation not encountered before) and physically (physically away from their normal surroundings). At this age and at this stage of their education the students have probably not yet obtained the necessary set of abilities in this context to be sure, that their understanding of the written manual is correct (Price and Driscoll 1997). I believe this could be part of the reason for the students questions in the action phase, and also why many of the questions have a clarifying character rather than an understanding related character. I do not observe questions like "what does vortexing mean" or "what is this substance" but rather questions like "do I understand it correctly if…" or "is it not correct if I assume that this means…". It is these types of questions I observe in all the classes followed, and this leads me to believe that a change would not necessarily result in the students not asking questions, as it preferably should be in a typical TDS action phase. It could be challenging for a laboratory exercise, if based on a cookbook-typed manual, to completely avoid this confirmation from the educator. Perhaps if the students spent more time in this type of laboratory and got more familiar with the equipment and procedures used, it could provide the students with a set of rules to navigate in the laboratory without questioning their understanding of the manual. The question is if TDS is a good theory to use when studying laboratory work?

Nevertheless TDS helped me to identify that the action phase in the laboratory exercise is not adidactic as the students work is dictated by a manual written by the museum. If so there is a problem with respect to the criteria set up by Brousseau. The question is if something could be done differently, when a theory that has been developed in a mathematic context is now used in a biological context? The points written in the manual is essential, when it comes to creating a qPCR setup that has the possibility of generating results, and not something one can expect students to

create. This leads me to think that perhaps it is not possible to create a true adidactic action phase when doing cookbook-styled laboratory exercises. The question is what to do then? A suggestion to accommodate this issue is discussed in section 5.

I also see, as stated in the analysis section, that some students forget important steps such as vortexing and centrifuging the provided samples, even though it is clearly written in the laboratory manual. A study by Carlos Reigosa and Marilar Jimenez Aleixandre (2007) shows that when students follow a 'cookbook-recipe' approach in a laboratory, they seem more concerned with accumulating data and getting the job done quickly, rather than learning the concepts essential to knowledge construction. The students' forgetfulness observed in this study might therefore be a result of this need to finish quickly, resulting in some students unintentionally skipping what could be important parts of the laboratory manual. Other studies show that cookbook-typed manuals, do not engage students in creating opportunities to acquire new knowledge (Germann, Haskins et al. 1996) or to stimulate thinking and reflection. The combination of urgency for a quick finish and a step-by-step approach might cause the students to be more prone to make mistakes and/or accidentally skip steps. This could at least explain why some observed students forget important steps in the laboratory, even though the laboratory manual is short and to the point, and the terminology and equipment has been explained during the devolution.

3.4.2 Reviewing the results

When the qPCR is done running the students' samples, they all gather in the laboratory to review the results (see figure 5 for the type of graphs the students can encounter). This is done by reviewing the graphs on the board produced the qPCR machine. The graphs are reviewed by each of the student groups one by one, illustrated by the 'repeated bracket' in figure 6.

As explained in my theory section the formulation phase is where the students discuss their strategy and clarifies their answers to the given question. This phase is then followed by the validation phase, where answers/solutions from the previous phases are discussed and hypotheses are accepted or rejected. In the educational program 'DNA and Life' I observed that the method used is evaluated before all

students have had the chance to view and interpret their results. As a consequence the method is evaluated before all groups have had a chance to examine their own results. This can pose different problems. One consequence could be that the students, who are not discussing their results, are left very inactive, because the review of on average 15 different graphs takes time. During this time the students' who have not yet had a chance to see their own results will have very little input to the discussion going on between the educator and those, who have seen their graphs, and as a consequence they are effectively excluded from parts of the validation process. By missing some of the validation the students can potentially miss what permits him or her to accept the different solutions to the problem (Brousseau 2006). Doing the task is not enough. The feedback through the validation is vital in order to foster the targeted knowledge (Artigue, Haspekian et al. 2014). A study by Ian Abrahams and Michael Reiss (2012) shows that although practical work got students engaged with objects and materials it did not help the students understand the scientific perspectives or help them understand scientific ideas as a way of understanding their observation or data. This does not mean that practical work is a bad idea. It simply means that practical work needs to be followed by a focused and effective discussion, in order for the intended knowledge to be obtained by the student, and that this knowledge does not emerge from the practical work itself. It is therefore important that the phases following the practical work is organised in such a way that the students get the necessary help to build and develop those ideas, which can make sense of the practical work just performed (Millar 2004). An example of this is found in my data material:

Educator:	Which group had the Common carp (*Cyprinus carpio*)?
Isabel:	We did!
Educator:	This is your results then [shows the results on the board]. How many graphs did you expect to see on this chart?
Isabel:	I have no idea what light has to do with, which fish are in the water. We had no idea about samples and ...
Educator:	No okay… [Starts explaining the method]

In this example it is clear that the student has not understood the method or what the different reagents did in the qPCR, and the subsequent discussion and validation is thus crucial, if she is to learn anything from her day's work in DNALab. She actually managed to produce a correct qPCR setup, because the results showed a positive control above the threshold, as well as a negative control and a water sample below the threshold (see figure 5 graph b). But still the laboratory work did not foster the intended knowledge. In this case this student group was the first one to review their results. If a group like the one just described had not been the first to explain their results perhaps they might just repeat others explanations without really understanding the ideas behind the method. Thus they would leave the program without really understanding the method and the scientific ideas behind it.

Another possible problem with reviewing the results in this manner is that the first group reviewing their graph, are the ones that do the work regarding explaining the appearance of the graph. These two or three students might go through different realisation processes than the other students, because they are the first ones to be "put on the spot" explaining what they see on the graph. I observed several groups repeating what groups before them say or even saying that their results are the same as seen in other groups before them. For example:

Educator:	And group number eight, what do you see? (On the graph)
Benjamin:	Well, its the same [as the group before]. Our experiment was made correctly. There is no Northern pike (*Esox lucius*) or DNA material [from the northern pike] in the lake
Educator:	No. At least not in your sample…

Here the student verbalises that their result is exactly the same as the previous group and the explanation, as to what the graph shows, is almost identical to the group before. I cannot say whether or not Benjamin has had a full understanding of what the graphs show, but I wonder if he undergoes the same process as the students before him. The Jourdain effect as explained in my theory section, can be a possible explanation in this case, as it explains teachers recognition of scientific knowledge in a students behaviour or answer even though it is derived from ordinary cause or

meaning. Perhaps the teacher assumes that the students has understood the scientific method, because he uses the correct terminology, but maybe he simply recognise that his graph look the same as the group before, and therefore repeat the answer. As figure 5 shows only three types of results are possible, and when these are explained by previous groups it seems like the rest of the groups are mimicking the answers. At least we need to consider it a possibility, with this type of validation setup. For this reason it might be important for the Natural History Museum to rethink how the results are reviewed, ensuring that all students have equal opportunity when it comes to analysing and understanding the results. Suggestions to how this can be remedied are made in the final discussion, section 5.

In summary, the validation of the method under investigation, therefore poses potential problems. One could risk that students repeat what the groups before them have concluded, because they recognise that their graph looks the same as the ones before, but do not connect it with the scientific ideas. By reviewing the results like this, one could also deprive students from entering the discussion about the the method and therefore hinder them from connecting their work with the scientific idea.

3.4.3 Finding facts about fish

As stated in my analysis this is the exercise that varies the most between the classes I observed. Common to all of them is however the structure as seen in figure 6, where I have observed a devolution, an action and a formulation phase, but no validation. As stated in the analysis section the devolution in this part of the program is not carried out as well as the devolution in the two other exercises, because the educator fails to explain to the students, why they need to carry out this assignment and how it is connected to the two other exercises. An unsuccessful devolution can prove to be problematic in different ways, but the essential part is that it fails to establish the milieu and thus the conditions for learning (Artigue, Haspekian et al. 2014). This is portrayed in the action phase, where as stated in my analysis the students simply write every piece of information from the key down for presentation. Much of this information has no real importance when it comes to the other exercises of the day. This could for example be when the students starts explaining exactly how many

eggs their fish lays or when the fish becomes sexually mature. This is not information that makes any sense in relation to the other two exercises that are part of the program. Thus parts of this exercise seem to have no real aim or relevance. The students do however find and present facts that are of real utility when it comes to the other exercises. This could be where in the water column the fish live, what time during the year they spawn and so on. This type of information could be used to evaluate the method when it comes to evaluating the way the water samples were collected. It could for example be problematic if the students look for at fish, who lives in deep waters, with a water sample collected in shallow water close to land. It could also be interesting when discussing traditional ways of doing biodiversity monitoring, for example keying fish. However as stated in my analysis section this information is sparsely used, leaving this exercise without a real validation phase. The issues just described, combined with the fact that not all classes observed performed this task, leads me to believe that perhaps this task is used as means to fill out the time. This need could occur if the students are done with the keying exercise, but the qPCR machine is not done processing the samples, why they cannot move to the next exercise, which is reviewing the results. Nonetheless I do believe that this task could be an important addition to this program, if a few adjustments where made. This is discussed in chapter II.

3.4.4 Distribution of didactic and adidactic situations

In Brousseaus theory of didactical situations he distinguishes between situations controlled by the teacher (the didactic situation) and the situations controlled by the students (the adidactic situations) (Brousseau 2006). He does not however suggest how the time should be divided between these two types of situations. Still according to Brousseau it is in the students interaction with the milieu that the main learning situation takes place (Brousseau 2006, Winsløw 2006). It is therefore important to create a milieu, in which the students can obtain the intended knowledge through their own action. As shown in table 2, between 70-80% of the students' time spent in DNALab is spent in didactic situations, leaving 20-30% for the adidactic situation. If we accept Brousseau's notion that it is through the adidactic situation the primary learning occurs, this distribution could reduce the learning

outcome for the students. These goals of learning can according to TDS only be achieved if the students are active constructers of knowledge (Sutherland and Balacheff). In this thesis I have not tested the students knowledge before and after their visit to DNALab, so it is of course difficult to know whether or not the learning goals are met. I will however argue that in a educational program like 'DNA and Life', where students are present for an entire day (between six and six and a half hours), the museum needs to add more situations, where the students can act independently in a produced milieu, giving them the possibility to construct and expand their personal knowledge. It is only through this expansion of personal knowledge, that the teacher can later formalise the official knowledge, enabling the student to share their newly obtained knowledge with others (Winsløw 2006). Even though the structure of the educational program 'DNA and Life' follows the phases of TDS (figure 6) (with the exception of the last exercise 'Facts about fish' where a true validation phase is lacking) I believe that more adidactic situations need to be implemented, since the current structure favours the didactic situation. But how could the museum add more adidactic situations? Answers to this question will be further explored in the final discussion chapter. However since TDS is based on the epistemological theory of didactic transposition, it is natural also to examine the educational program using the theoretical notion of didactic transposition.

4. CHAPTER II

Addressing the found problems using didactic transposition

Where the previous chapter was about the structure of the educational program 'DNA and Life' and what the students could learn from it, this chapter is about the scientific knowledge the program is based on and the decisions, that went into creating the program. This will be addressed by using Didactic Transposition theory.

4.1 Theory - Didactic transposition

The didactic transposition theory was first presented in 1985 by the French mathematical didactic Yves Chevallard (Chevallard 1985). It formulates a need not only to consider schools, classrooms, teachers and students, when we study didactics, but also to consider both where the bodies of the taught knowledge are created (Bosch and Gascón 2006) and the process, that determines which part of scientific knowledge that needs to be taught. Science is what scientists do (Achiam 2015), but scientific research is mainly understandable to people within the scientific community and reconstructing the scientists work does not guarantee that learners will reconstruct the knowledge (Bain and Ellenbogen 2002). In order to teach and educate others about science, science research needs to undergo some type of change or reshaping in order for it to be accessible to a public (Sharma and Anderson 2009). Didactic transposition is a theory that describes this process, taking science from its original research context and reshaping and reconstructing it in order to make it fit into an educational context. In order for this to happen the piece of knowledge needs to undergo certain adaptations in order for it to fit into its new 'environment' (Bosch and Gascón 2006). The word transposition describes two things. As mentioned it describes the process of how science research is transformed into something else than its original state, in order for it to be teachable. It also describes how the content is moved from one place to another, more precisely from a scientific environment to an educational one. When talking about didactic transposition we distinguish between two different phases, the external and internal

transposition (see figure 7) (Winsløw 2006, Achiam 2015).

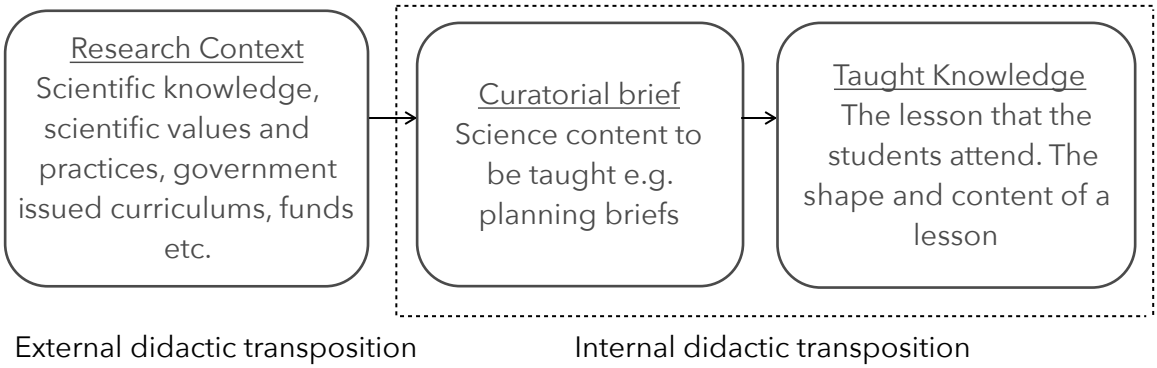

Figure 7. *This figure shows what constitutes external and internal didactic transposition (Achiam 2015)*

The external didactic transposition is the process that takes place outside schools or educational settings. It is the process that affects the transformation and translocation of knowledge. This could for example be the scientific knowledge itself and the values and practices of the specific science (Achiam 2015). It can also refer to government issued curricula, availability of funds etc. The institutions that disseminate science content outside the institution, where the subject is taught or presented, has an influence on the external didactic transposition (Winsløw 2006).

When teachers, educators, museum staff members etc. begin to plan the dissemination of a certain scientific subject, one goes from an external to an internal didactic transposition documented in 'the curatorial brief'. The curatorial brief describes the planning of what is to be taught. This could for example be planning briefs, meeting reports, content documents etc. (Achiam 2015). The outcome of these two phases is the taught knowledge, such as lessons, science programs, exhibitions, etc.

In this thesis, chapter I is connected to parts of the internal transposition since it deals with taught knowledge. This chapter on the other hand partly deals with the external transposition because it is in this chapter the scientific knowledge is under investigation as well as government issued curricula. However it also deals with the the decisions made by the museum, when creating 'DNA and Life', hence it also deals with parts of the internal transposition.

4.1.1 The four different stages in didactic transposition

Chevallard describes four different stages that define the didactic transposition. These stages are scholarly knowledge, knowledge to be taught, taught knowledge and learnt knowledge, see figure 8.

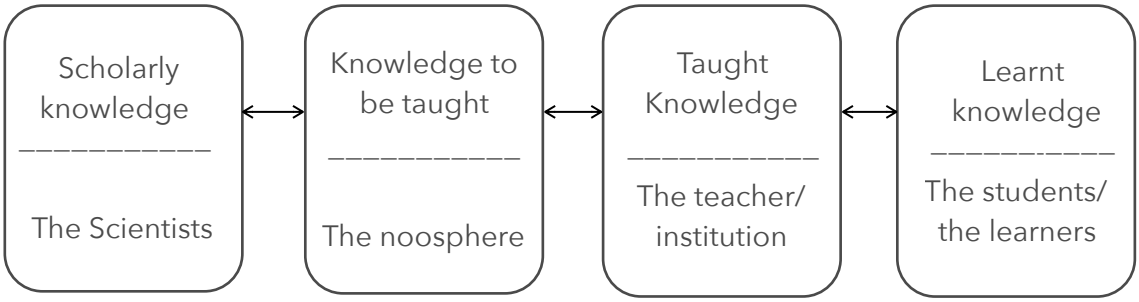

Figure 8. *This figure shows the four different stages in didactic transposition (Chevallard and Bosch 2014). They all influence each other, illustrated with dual pointing arrows*

Scholarly knowledge

Scholarly knowledge is understood as the knowledge, the different practices and the methods used in a scientific community (Achiam 2015). This knowledge is produced and governed by a community of scientists, that all have shared values with social and cultural practices. Scholarly knowledge constitutes all the knowledge that is possible to learn and the knowledge is thus a reference point for educational institutions (Bosch, Chevallard et al. 2006, Bosch and Gascón 2006). Examples of scholarly knowledge are scientific articles and books etc.

Knowledge to be taught

Knowledge to be taught considers everything related to the planning of taught knowledge. This stage of the transposition is managed by what Chevallard calls the noosphere, which means the group of people, who think about teaching. Their main role is to deal with the demands of society on what knowledge that needs to be taught (Chevallard and Bosch 2014) and what is important for people to learn. An example of this could be planning briefs, fund applications, school curricula etc.

Taught knowledge

Taught knowledge refers to what actually goes on in the classroom. How was the lesson put together? How did the teacher teach the subject, what method and which

types of equipment were used and perhaps what type of report the students had to hand in? Taught knowledge is not a reproduction of scholarly knowledge, but it should seek to preserve its main elements (Chevallard and Bosch 2014). An example could be how a lesson in a high school is put together in order to teach the students about different blood types. Was it a talk given by the teacher? In that case what did the talk contains? Did the students do any exercise and in this case what type of exercise?

Learnt knowledge

Learnt knowledge refers to what the students actually learn from the lesson. The teacher most likely has certain learning goals connected to that specific lesson, but are these actually met? For example did the students learn what the teacher intended them to learn about blood types? Did they learn why it is important to know ones blood type? Learnt knowledge is the end of the didactic transposition, but as the students now move forward to learn something else, the transposition begins all over again (Bosch and Gascón 2006).

4.1.2 The reference model

According to Chevallard the minimal study of any didactic problem field must include data and information from each stage in the didactic transposition (Bosch, Chevallard et al. 2006). It is important that we, as researchers of didactics, separate ourselves from the different institutions, that contribute to the transposition process. No matter what didactical problem we look into, it requires a specific viewpoint and perspective in relation to the knowledge and learning in question. We must therefore look at the knowledge and learning in relation to all four stages in the transposition. In order to make sense of all the stages and how they are connected we must create what Chevallard calls an epistemological reference model. We can therefore expand figure 8 to what is portrayed in figure 9.

As figure 9 shows, all four stages in the transposition influence the reference model. As a didactic researcher it is important to emancipate oneself from the institutions under study to avoid using dominant viewpoints of the institutions. Something the reference model can be a tool to achieve. This is also why scholarly knowledge can

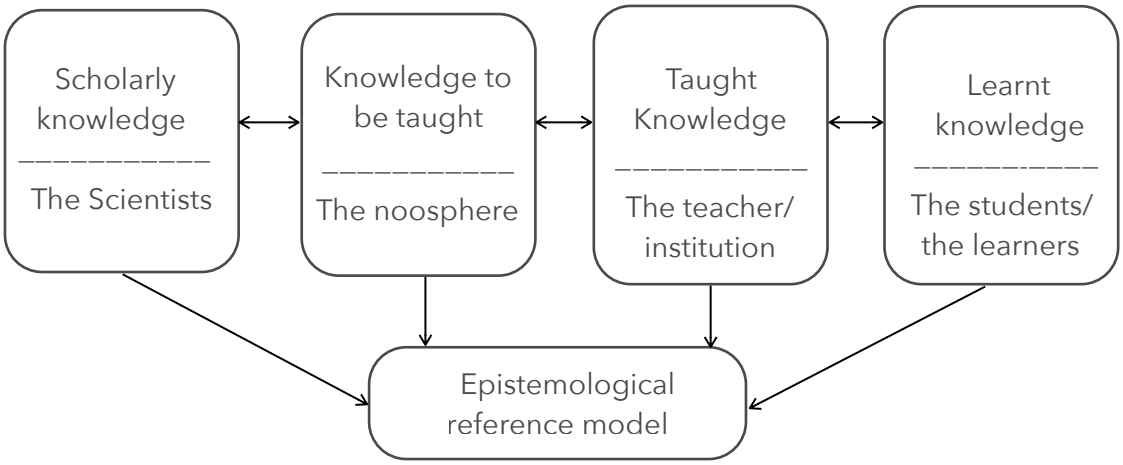

Figure 9. *The four different stages in didactic transposition, now including the reference model (Chevallard and Bosch 2014)*

never serve as our reference model (Ruiz-Munzón, Bosch et al. 2013, Achiam 2014), even though it generally constitutes everything that is possible to learn. By using the reference model we look at all the processes that contribute to the creation of a lesson, an exhibition etc. Therefore knowledge that is available as scholarly knowledge is not always available for the students or the teachers for that matter.

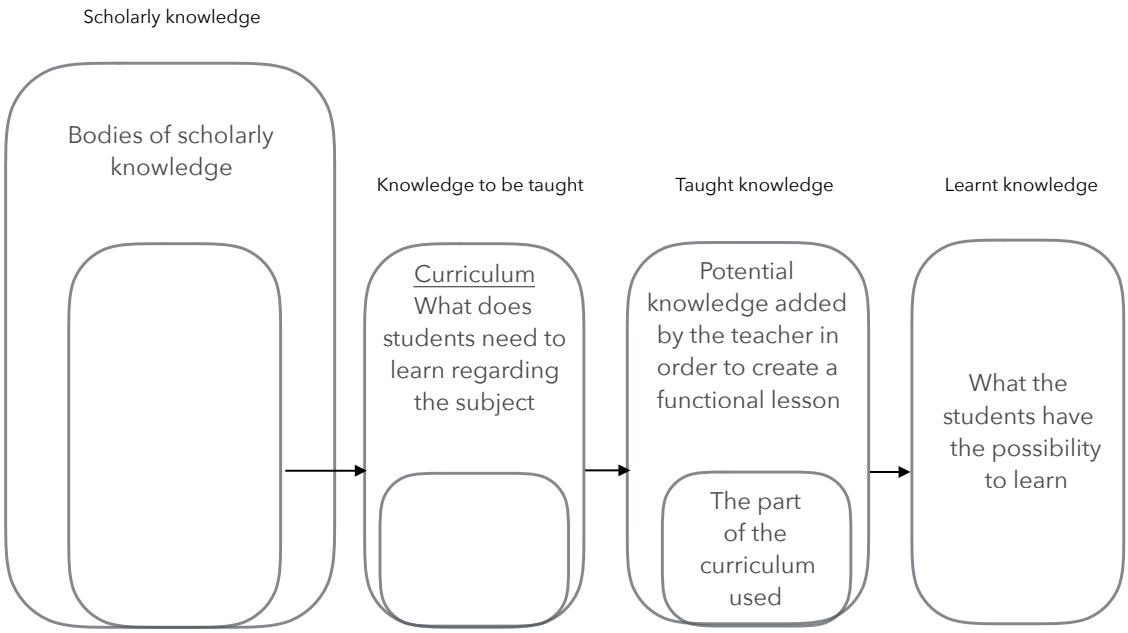

Figure 10. *Shows what can happen to a piece of knowledge, when it undergoes the transformation from scientific to learnt knowledge, as seen through didactic transposition*

So what can happen to a piece of knowledge when it undergoes this transformation? I have tried to illustrate this in figure 10. It is important to notice that the figure shows not only a deconstruction but also reconstruction of a piece of knowledge. A teacher might have to add additional knowledge to a lesson in order for the lesson to be functional. The transposition of knowledge is therefore not necessarily a degradation of knowledge, but a possible expansion too. The information in all these stages needs to be a part of our reference model, but it is not necessarily information we come by right away. That is why our reference model must always change with respect to the didactic analysis (Chevallard and Bosch 2014).

When using didactic transposition as an analytical tool we can, in principle, start wherever we want. In this thesis 'Taught Knowledge' is the point of departure as outlined in chapter I. This is done by asking the question 'What does the students have the possibility to learn"? Which bodies of knowledge are at stake? What processes and restrictions does the original knowledge go through before becoming something that is taught? These are all important question and we can expand figure 9 to what is shown in figure 11.

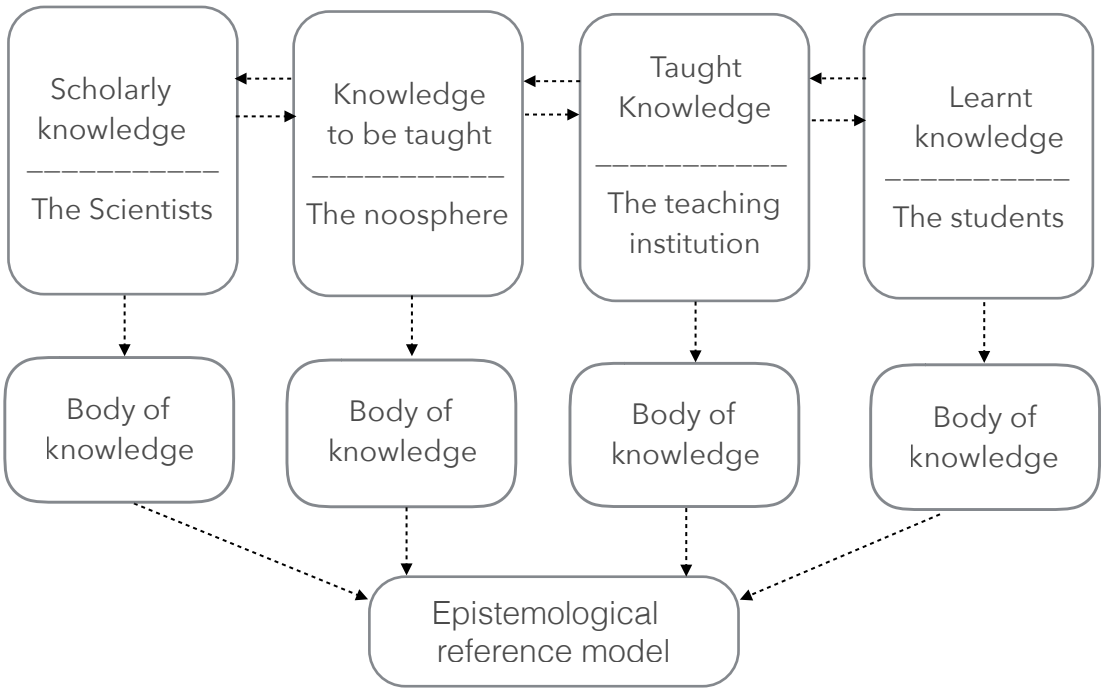

Figure 11. *This figure shows the same as figure 9, but with the expansion of suggested questions one can ask when a reference model needs to produced.*

When creating a reference model one of the first tasks must be to look at what bodies of knowledge that is available in the different stages. When it comes to 'Taught Knowledge (chapter I) this is done by using Brousseau's Theory of Didactic Situations (TDS). Through this work I have found, which bodies of knowledge that is at stake in 'DNA and Life'. The next step is then to look at the other stages of the transposition in order to further understand the educational offer 'DNA and Life' and expand the reference model, which is done in this chapter.

4.2 Method

While my analysis in chapter I, dealt with the last two stages in didactic transposition (see figure 9) the analysis done in this chapter deals with the two first stages: scholarly knowledge and knowledge to be taught.

In order to understand the science behind 'DNA and Life' I have read scientific articles regarding the method used and regarding biodiversity research in freshwater. As a point of departure I read the published article that underlies the program. After this I dug further into the science by searching for relevant keywords using Google Scholar. Additionally I have conducted semi-structured[4] interviews with the project managers and educators from The Natural History Museum. This is done in order to understand the decisions behind the creation of 'DNA and Life'.

4.3 Analysis

4.3.1 Looking at 'DNA and Life' through didactic transposition

In order to move back through the transpositions different stages, and thereby further construct our reference models one first needs to establish what type of scientific knowledge that is at stake. What is the main scientific subject taught in 'DNA and Life'? Looking through my data the word and term biodiversity is mentioned throughout. Andreas Kelager, the project manager on 'DNA and Life', says the following:

[4] A semi-structured interview is a formal interview, with set questions and topics that need to be answered. However it is able to follow topical paths in the conversation that may stray from the guide.

…So, we would like to show them something about biodiversity and Danish biodiversity, because students have a relatively distant and perhaps unrealistic picture of Danish biodiversity. If they know anything about it, they find it boring. They have a much better understanding of biodiversity on the Serengeti or the Borneo rainforests for that matter, and otherwise they do not know very much…

With this in mind I have had a closer look at what comprises biodiversity in a research context to see, how this program fits into that.

Looking through scientific literature I noticed that biodiversity is differentiated into three subgroups: 1)genetic variation, 2)species variation, and 3)ecosystem variation (Gaston 2004). Genetic variation means that within and among populations there is a genetic variability, caused by random mutations[5] in the organism's genome[6]. Species variation refers both to the phenotypic[7] variation within a species, but also the phenotypic variation among species. Ecosystem variation is understood as variation within an ecosystem and between ecosystems. The question is then if these three subgroups can be seen in 'DNA and Life'?

By looking through my data I found that these biodiversity subgroups could be identified in 'DNA and Life', where the laboratory work deals with genetic variation, the keying with species variation and the fish facts with ecosystem variation. In the next sections I have chosen to view them separately because the three subgroups just described fits into different aspects of 'DNA and Life'. Another reason is that the bodies of scholarly knowledge behind these three groups are different from one another; thus the didactic transposition must be different too.

Genetic variation and the laboratory work

If we look back at figure 6 the students' first start working in the laboratory, where they create a qPCR setup in order to test a water sample for selected organisms. As written in section 2.2 the students use a method, that is build upon the principle that

[5] Mutations means a permanent change in a genes chemical structure

[6] The genome is the genetic material of an organism

[7] Phenotype mean an organisms observable characteristics

the genetic code is different amongst different species[8], why it is possible to detect them using specific primers. We could also say that the students use the genetic variation between species to test water samples for different organisms. The first subgroup that sums up biodiversity is therefore very much in play in this program. Following this path I look to the scientific article that this educational program is based upon. Looking at the published paper (Thomsen, Kielgast et al. 2012) I find many similarities between what the students do and what the scientists do. For example both scientists and students collect three 15 mL water samples pr. location (Thomsen, Kielgast et al. 2012). There is however a difference in the collection method that could potentially pose different problems. The scientists, when collecting their water samples, collect them from three different points at the same location. Reading the collection procedure sent to the teachers (see appendix 1) it is not specified that they must collect from different points at the location, only that all three water samples must come from the same location. This could possibly affect the students' results. If all water samples are collected at one single point, and there at that point is very little DNA from the targeted species, we risk all three samples being poor, having little or no DNA in them. This will make it difficult to detect a species, even though the species is present at the freshwater location. If on the other hand the samples were collected from different locations, the risk of getting three poor samples will probably decrease (see figure 12), and as it has been a problem, that the students have not had success in

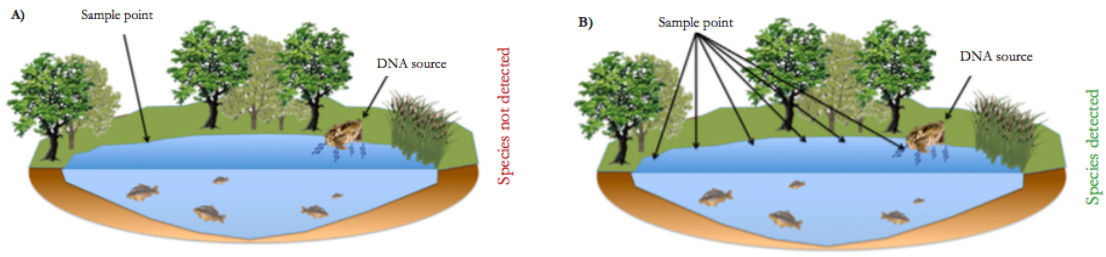

Figure 12 *This figure, borrowed from Herder, Valentini et al. 2013, show how water samples should be collected, to increase the likelihood of finding the organism one is looking for, when using eDNA and qPCR.*

[8] There are also different between individuals in a species, but this is not important here, and will not be discussed further

finding species (personal conversation with the educators on 'DNA and Life') this could be a way of optimising the samplings. Since the data for this thesis was gathered, a new way of collecting water samples has been implemented. This I will return to in my discussion.

Back in DNALab, the students work with preparing the samples to be tested using qPCR. Again there is many similarities between the scientists work and the students work (e.g. they use the same thermal cycles), but one difference between the scientists and the students work, is that the process, where DNA is extracted from the water samples, is carried out before the students arrive. This means that the samples the students receive does not look like the ones they send in. The changes made to the samples are however explained to the students, in the devolution of the assignment. This part of the method was removed on purpose, both because it is time-consuming, but also because the amount of knowledge presented to the students during their day in DNALab is very large. Tina Jørgensen, one of the developers of 'DNA and Life' says:

They (the students) get a lot of information. We must therefore select what we think is relevant…

(personal interview with Tina Jørgensen, 20.02.15)

For this reason that part of the process has been handed over to laboratory technicians hired by the museum.

Another difference I located between the scientists work and the students' work is that the scientists do replicas of their samples when testing an organism. A thing the students do not necessarily do. Looking through scientific research I find that scientist at least make three replicas[9] when testing their samples in order to enlarge the chance of finding the organism they are looking for (Ficetola, Miaud et al. 2008, Thomsen, Kielgast et al. 2012, Thomsen, Kielgast et al. 2012). Unlike the scientists the program does not necessarily make the students do replicas of their samples. It seems like replicas occur, when there is a large number of students in the class, creating a shortage of species to test for, why some students have to test for the

[9] A replica means testing a sample more than once.

same species. I observed several examples of the importance of making replicas. One example is a group that had made a mistake when mixing their reactants for their qPCR setup[10] getting no results. Another group in the same class tested for the same organism, and made no mistake in their qPCR setup and actually found the organism. Another example also illustrates why replicas are important: In a class where two groups both tested their water samples for Northern pike (*Esox lucius*), both groups managed to make a correct qPCR setup, but one group located Northern pike in their water sample, while the other did not. Using this method the students use species-specific primers in order to test for specific species. The students therefore get a tray containing DNA extracted from their water sample, and a primer-probe system for a specific species. In the example given before it seems like there must have been DNA from the Northern pike in one of the Eppendorf tubes with extracted DNA and none in the other. It is therefore important to test more than one sample, since it is possible to "miss" the DNA one is looking for in a sample. This is especially important if there for some reason are low quantities of DNA in the original water samples, due to poor collection protocols, if the sought organism is rare etc. The notion of replicas was discussed in all observed classes, but in one class they did not do replicas at all. When reviewing the results it turned out that those species that, according to other sources (Carl and Møller 2012) existed at the location, were all species where the students have made a mistake in their qPCR setup. This could explain why the students did not find any of the organisms they tested for. It is easy to make mistakes in the laboratory, but using replicas could increase the chance of finding the organisms one looks for. This can be constructed as a strong argument for making replicas and will be discussed later.

Just like the scientists the students test a variety of animals such as fish, amphibians and insects. When reviewing the results the educator compares the students' results with other databases. This is very similar with the scientists work, as they would also compare their own work to that of others. The only problem is the availability quality of databases. The database used regarding the fish comes straight from the

[10] In a correct qPCR setup the positive control needs to be above a set threshold value and the negative control needs to be below it, see figure 5

scientists behind the book 'Atlas of Danish freshwater fish', Peter Rask Møller and Henrik Carl, creating a very reliable comparison in that there is a species list of fish for almost all fresh water location in Denmark. It becomes however slightly different when it comes to the databases used to evaluate the the insects and the amphibians. Here the data is retrieved on an online pages such as www.fugleognatur.dk. The maps retrieved here (see figure 13) are not as accurate as the data provide for the fish and often the students and the educator ends up estimating, whether or not the particular amphibian or insect they have looked for, could have been found in the freshwater source under examination. As a result the comparison is therefore not as convincing as the comparison made regarding the fish. Also if we look at figure 6 the exercises done while the qPCR is running, the keying and information gathering, is both centred around fish, not including amphibians or insects. These are not touched upon besides the fact that the students are looking for them in the laboratory work. This results in an incoherence regarding these two animal groups and it seems like the students have a more difficult time evaluating on these result.

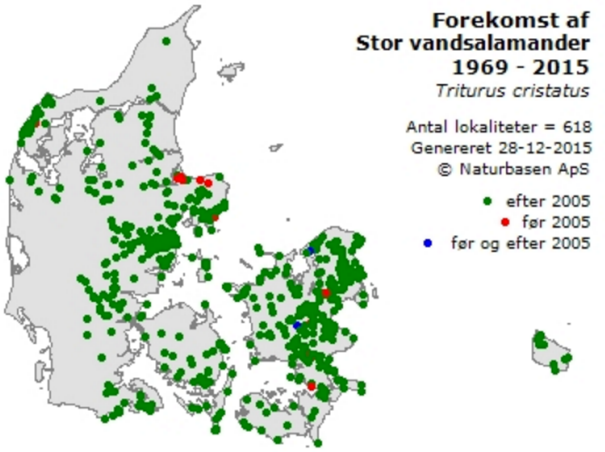

Figure 13. This figure shows a distribution map retrieved from www.fugleognatur.dk on the 28th of December 2015. In this case it shows the distribution of the Northern crested newt (*Triturus cristatus*) in Denmark, and it is these types of maps the students judge their results on when it comes to reviewing the results of amphibians and insects.

Species variation in fish through keying

While waiting for the qPCR to finish its cycles, the students has to key out ten different species of alcohol preserved fish. The research literature is not really dealing with this issue, perhaps for two reasons. Many scientists have a very detailed knowledge of taxonomy regarding the species they work with, and simply recognise

the species by looking at individual fish, because they have seen them so many times. One could however argue that these professionals do key out the fish in that they tacitly recognise features when determining the species, but because this process is implicit it is not described in scientific publications. Another reason could be that scientists indeed do go through the process of keying out fish, in their research, possibly if they work with two similar species, but for some reason do not describe this process in publications. Perhaps the determination of a species using a key is not considered important in relation to the research question and is therefore not included in the article. What is definitely found in scientific literature, when it comes to fish, is a description of the location, where the fish were caught. In 'DNA and Life' all fish are caught in freshwater location in Denmark, but the educators, in all but one observed class, do not mention this to the students. In my data I see examples of students arriving at species of fish, who do not live in Denmark. An example observed in my data is when the students tried to key out the Freshwater bream (*Abramis brama*), a common Danish freshwater fish, some ended up with the fish being a White-eye bream (*Abramis sapa*), a fish not located in Denmark, but common in central Europe. By telling the students where the fish are caught, the educator creates the possibility for the students to use the distribution maps[11] in the key as a way of validating their result on their own. The question is of course whether it occurs to the students to use the distribution maps, if the educator simply says that all fish are caught in Denmark, or perhaps it needs to be devolved further? As stated one class was told before the keying started that all fish were caught in Denmark, but looking at the answers I see no difference between that class and the five others. The group followed in this one class did not use the distribution maps as a guideline during the keying, but perhaps they did guide the other student groups that I did not observe. However the students still suggest fish that does not live in Danish freshwater systems and nobody use the distribution maps in their arguments or answers. Perhaps the milieu has not been well enough established and the students do not connect the information that all the fish are caught in Denmark with the possibility of using the distribution maps in the key.

[11] A distribution map is a map that roughly shows where the species in question is located

Finding facts about fish says something about ecosystem variation

In this part of the program the students have to find information about one of the fish they just keyed out, which at the same time is a species they search for in the laboratory exercise. The students work in groups and must present the information they have found to the rest of the class. This is similar to scientific practice: Scientists also gather information from other sources than their own research when preparing or evaluating experiments. Examples of this could be when creating a review (Casselman and Lewis 1996), using parts of a method put forth by other researchers in ones own experiment (Thomsen, Kielgast et al. 2012) or as it is seen in most scientific publications, where one compare one's results to what others have found. The students' work during this part of 'DNA and Life' does not contribute to the creation of a review, and neither does it contribute to the creation of an experiment, since they have already done the laboratory work. The last opportunity is therefore that the 'Finding facts about fish' exercise is a way for the students to evaluate their work; the method itself and their results. However as presented in chapter I the purpose of the assignment is not devolved properly, and as a result varying details with no connection to the other assignments, are presented by the student groups. When looking at this assignment through Didactic Transposition theory we could say that the transposition work is incomplete. This exercise is therefore, also according to Didactic Transposition, difficult to use further on in this program.

In my analysis I have established that the students indeed work with genetic variation through their work on testing water samples for genetic markers in an attempt to find specific species of fish, insects and amphibians. They also work with species variation as they use a key to detect differences between species in order to key out the fish correctly. Finally they do some work related to ecosystem variation finding facts about some of the fish they are looking for in their DNA work, i.e. finding out how these fish live. This shows some of the variation within an ecosystem, and how different fish have different niches. I have illustrated this conceptualisation of the program, as well as the TDS phases in figure 14 using the TDS phases from figure 6.

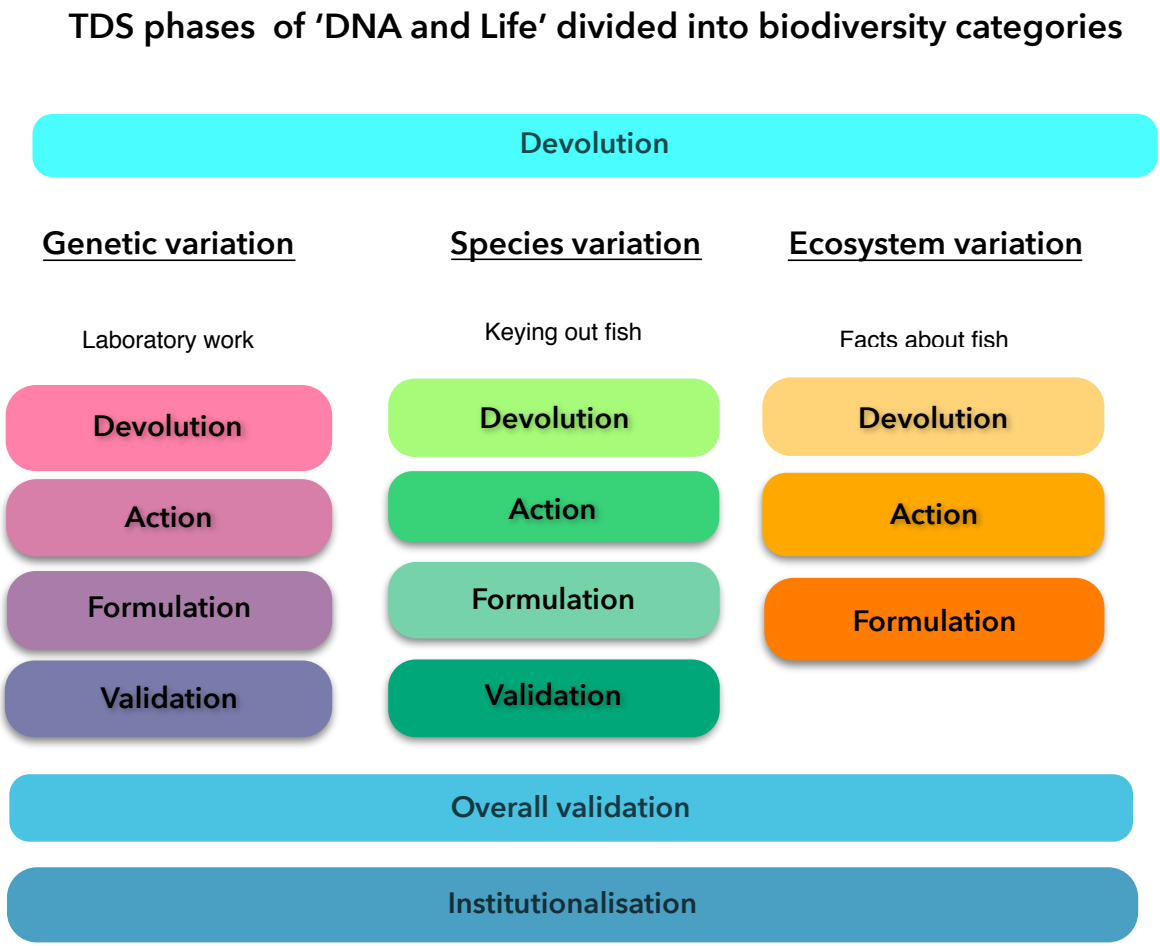

Figure 14. *This figure shows the same as figure 6 but I have now added the three different subjects regarding biodiversity, and added the three tasks comprising from 'DNA and Life', in the right biodiversity category*

4.4 Discussion

In this section I will discuss the issues identified in the analysis connected to this chapter. As shown in the analysis the educational program 'DNA and Life' has a clear focus on biodiversity, even though the three biodiversity subgroups (genetic, species and ecosystem variation) are not all well implemented. I will therefore use the biodiversity subgroups as seen in figure 14, as a way of structuring the following discussion. First I will discuss the genetic variation and the work done in the laboratory. Second I will discuss the exercise where the students key out ten alcohol preserved fish and third I will discuss how the exercise 'Facts about fish' can help to tie the two previous exercises together.

4.4.1 Genetic variation in the laboratory

The collection of water samples

As stated in my analysis the scientists collect samples at different points at the same location, in order to cover a bigger part of the freshwater location and thus increase the possibility of getting DNA from the target organism in their sample. The students are not asked to do the same. Instead water samples are collected at the same point at the freshwater locations. This could possibly affect the results the students get, since not doing replicas lowers the students chance of finding organisms. However when I look at my data the two classes that collected their own samples[12] found either one or two species in their samples. This means that in two out of the three classes that found organisms in their water samples, were samples that had been collected by the students themselves. Or said in another way it was only one sample collected by employees at the museum, where the students found an organism. This does not necessarily mean that the samples collected by the museum were worse collected than the students, as they were collected according to the same manual. The reason the students did not find any organisms, could also be due to students making mistakes in the qPCR setup on the organisms that according to the database was there. Even so I believe that it is still important to ask the students to collect samples at different points at the same location, in order to use this information in the later evaluation of the method. It could be interpreted as a breach of the didactic contract that the educators do not ask the students to collect water samples at different locations and then later they use that same fact to explain the results. If we look at it through the lens of Didactic Transposition, we could say that the transposition here is incomplete.

Making replicas

In the science literature experiments like the one the students perform, scientists conduct replicas when testing their samples, but in the educational program 'DNA and Life' they do not do this kind of testing consistently. For a scientist it can be questionable or even faulty and inadequate, if organisms, like observed here, are not

[12] The four other classes that did not collect their own samples had registered too late to collect their own samples, and therefore examined samples collected by the museum.

subjected to more than one test. The first reason for doing replicas is, as stated in my analysis, to increase the chance of finding the organism one is looking for. Second it reinforces the validity of the result if the organism is located in more than one sample. Third even skilled laboratory scientists can make mistakes in the qPCR setup causing spoiled samples, and the same applies to the students' work. When they look for specific species in the laboratory, it is as previously stated easy to make a mistake in the qPCR setup. For these reasons it makes sense to have more students testing for the same organism, i.e. through replicas. Not necessarily to produce results, even though this seems to hold great importance for the students motivation, but to ensure that they have "all the facts" when it comes to validating the method they just used. A student says:

*"Bummer! We failed [the qPCR setup] on those species that were actually there!" (O*bserved 25.03.15)

Here the student reacts to the comparison of their results to the reviewed database, and how all the samples containing the species, that the database said was present at their location, were somehow spoiled. Not doing replicas could therefore be understood as a break of the didactic contract, as explained in chapter I. The students do not necessarily recognise that they should have made replicas on their own, but they do see that it is an unfortunate turn of events. However most classes observed discuss their way to the use and importance of replicas. As an example two groups make a correct qPCR setup. One group locates the Northern pike in their part of the sample, the other group does not, even though the original sample is the same.

Educator: If we say that your results are correct and your results are correct. What does that tell us about the method?

Catrine: It tells us that it can vary a great deal. So it requires a lot of tests so we can find the most correct result.

By doing replicas, the museum has fulfilled their part of the didactic contract, and at the same time provided the students with the tools to be critical with respect to the

methods function. If we look to the scientific research, critical thinking is a must no matter what type of problem one works with, and that is why it is important that the students learn this. In this case they learn it through their own action and the results thereof. This of course limits the amount of species the students can search for: a problem that will be addressed in the final discussion. Creating a milieu, where the students can think critically about their work and thereby evaluate their own efforts, is important according to Brousseau and TDS, the theory used in Chapter I. We can use Didactic Transposition theory to look to the scientific knowledge in order to understand the science behind the subject taught, in order to create a milieu that provide the students with enough information in order to connect their action with the scientific knowledge. Here a problem located in an educational setting is examined by looking to the scientific knowledge for answers, and the museum should consider using replicas as a fixed part of the educational program 'DNA and Life'. This does not mean that the work the students do must mimic the scientists, but that the science is a way of understanding what happens in an educational context. It is important to emphasise that the work the students' do, is always a transposed version of the scientific knowledge.

The use of different databases when reviewing the results

In my analysis I found the databases used to evaluate amphibians and freshwater insects incomplete. If we look to the scientific community it is impertinent to compare results with those of others in order to support one's results. The same thing could be said for the students although in a slightly different manner. In order to evaluate the method and be convinced about its usability the students compare their results to results generated using other ways of detecting organisms. In 'DNA and Life' two different databases are used. One that is provided by the scientist behind the freshwater fish atlas and another found online to compare amphibians and insects. The data used to compare the fish therefore comes straight from the scientists, who produced it, and the comparative database is therefore large and very accurate, making the comparison trustworthy and reliable. However the information about amphibians and freshwater insects and their location in freshwater in Denmark is perhaps not as well researched as the freshwater fish, but at least these type of

data is not available here. The database is therefore retrieved from the internet and is not as accurate. As a result the students are not able to make as strong a comparison when it comes to the amphibians and insects, and the students therefore make an informed guess by looking at distribution maps as the one shown in figure 13. A solution to this problem will be suggested in the final discussion.

Open-ended exercise vs. closed-ended exercises

During this educational program the students work with two different types of assignments: one where the educator holds the correct answer (close-ended) and one where the educator does not (open-ended). In the exercise where the students key out fish the educator have the correct answers, because she knows beforehand, which species of fish are present in each tray. There is therefore a clear validation of the students work during this exercise. However when it comes to the laboratory exercise, the educator does not however hold the right answers, as the method is still under development. The interpretation of the results are therefore very open-ended, and the students answers may therefore be as valid as those of the educators, as long as they can argue for and against different ideas. This is similar to the way scientists work in biology, as there very rarely is a clearly defined answer and it is therefore necessary that the interpretations are supported by scientific argumentation. The evaluation of the method in 'DNA and Life' is an open-ended interpretation, which might lead to the students learning how to use scientific reasoning and implicitly develop the students knowledge of scientific inquiry (Millar 2004). A study by Berg et al. (2003) shows that an open-inquiry experiment, where students asked questions about practical details and theoretical context, had a higher frequency of reflective questions than the close-ended version, where the outcome was predetermined and the procedure given. The ability to reflect on one's own action is important in scientific work, and in my data I do observe students moving back and forth between possible solutions to different problems or how this method is useable when examining biodiversity. However the same study also shows that students with little interest towards this type of assignment and subject needed more guidance in open-ended experiments. It is therefore important that a milieu created for an open-ended laboratory exercise considers both types of students.

Suggestions to how this could be achieved are discussed in the final discussion section.

Another study by Kempa and Diaz (1990) points out that students showed different affinity towards different ways of learning in the laboratory depending on whether they were characterised as conscientious or sociable. The conscientious students preferred the more formal settings and only enjoyed laboratory work, when it involved explicit instructions, guidance and closure. On the other hand the students characterised as sociable enjoyed open-ended laboratory exercises and had a preference for group discussions. In 'DNA and Life' students are both subjected to an open-ended exercise and closed-ended exercise. These different exercises will according to Kempa and Diaz's study target different students in different ways, and in combining two exercises like these, the educational program 'DNA and Life' can perhaps ensure that the students will find themselves in a milieu suited for their style of learning.

4.4.2 Keying out fish and discovering species variation

The keying out fish exercise is probably the exercise that has undergone the most comprehensive Didactic Transposition, since the students' activities do not resemble any activity found in the research literature. As stated in my analysis it is possible that the scientists key out the species tacitly or that they indeed go through the process of keying, but it is not specified in the scientific research. However what is found in scientific literature is a description of the location, where the organism was located. In all but one observed class, it is not mentioned to the students that all the alcohol-preserved fish are caught in Danish freshwater systems. When reviewing the results I observe some students that suggest fish that according to the distribution map cannot be found in Denmark. If we return to TDS, Brousseau says that the certainty wether an answer is correct must come from the milieu (Brousseau 2006). A way to provide students with an opportunity to evaluate their work would be to inform them of the distribution maps. Distribution maps could be a way for the students to check if their path through the key has resulted in a fish, that could have been caught i Denmark. However in the class observed, where the students had been given the information that all the fish presented were caught in Denmark, they still did not use

the distribution maps, and still suggested fish that do not exist i Denmark. Perhaps the students do not connect the information that all the fish are caught in Denmark with the possibility of using the distribution maps as a way of checking their results. This suggests to me the possibility of using distribution maps needs to be devolved further by the educator. This could be done by verbalising the possibility of using the distribution maps as a kind of preliminary checklist, to see if the species of fish they have keyed lives in Denmark.

4.4.3 Ecosystem variation and tying the two previous exercises together

In the exercise 'Fish Facts' the students find ecological background information about a given fish species, using information in the key. This activity is in many ways similar to scientific practice, but where the scientists gather this information before collecting water samples, the students gather it afterwards. Consider the following example of the European weather loach (*Misgurnus fossilis*).

The European weather loach is a fish that internationally is not threatened (Freyhof 2013), but nationally in Denmark it is considered critically threatened (Holm 2007). Denmark therefore has an obligation regarding the conservation of the European weather loach. However the European weather loach is nocturnal and during the day it digs itself into the substrate, which makes it difficult to find using traditional monitoring methods. The method the students work with is ideal, when it comes to monitoring the status of the European weather loach. In order to collect good water samples the scientists has to be acquainted with its biology in order increase the likelihood of finding the European weather loach if it is present. Examples of these type of information could be its requirement for clean slow flowing water when picking a location, and the necessity of water plants when it comes to breeding (Naturstyrrelsen). To collect water samples that is likely to contain loach DNA, it is necessary to be acquainted with the biology of the fish. As stated the scientists use this information before collecting the water samples, but as the students search for this information after the water samples has been collected, this is clearly not the reason for the students activity. However in my opinion this exercise is still very important. By expanding their knowledge about the fish they are looking for in the

laboratory, they are better able to critically evaluate the method. When this exercise is used, it is used as a way of understanding the method and the graphs it produce. For example if the water samples were collected by the water edge, it could explain why the students did not locate Northern pike in their samples, since the Northern pike is found in deeper waters. As stated in my analysis the information from this exercise is sparsely used, which could be due to the incomplete devolution observed in this exercise, where students are not informed about the purpose of the exercise. By telling the students that the purpose of the exercise is to expand their knowledge of the fish they are looking for, and thus facilitate their evaluation of the method and the sampling procedure, I believe that this exercise could be a key factor in tying the previous exercises together. It would also help the students on which details of the fish' biology to focus on, when it comes to gathering the information. By focusing on these aspects of the assignment I believe, that it will become more useful when reviewing the results and perhaps there will be a foundation for a true validation phase (see figure 6 or 14, where the validation phase is lacking). Furthermore I think that pros and cons regarding th new and the old method of monitoring biodiversity could be shown to the students by tying the laboratory exercise and the keying exercise together.

A study by Robertson-Taylor (1985) showed an increase in students positive attitude towards science, when they were asked to create concept maps[13] prior to a biology laboratory exercise. In other words students had a more positive perception of laboratory work if they were able to work with the concepts used in the laboratory prior to the actual laboratory exercise. The study thus show the need for prior preparation regarding laboratory exercises, increasing the students possibility of making sense of what they are doing when in the laboratory. The museum however has no control over the preparation, in that it is up to the teacher to prepare the students for the course. It can in turn be difficult for teachers to prepare their students based on a written explanation of the educational program online, where they cannot ask clarifying questions. Since it can be difficult to ensure the level of preparation the students do prior to a visit at the museum, it is important that the

[13] A concept map is a map or diagram that illustrates suggested relationships between concepts

work the students do while the qPCT is running, is strongly linked to the methodology used during the laboratory exercise, in order to help the students uncover the advantages and disadvantages of the method.

Another study by Hofstein et al. (1996) shows that students doing laboratory work in chemistry and biology, wanted to be more involved in the process and wanted the exercise to be more cohesive and integrated with the lessons away from the laboratory. I therefore believe that the museum needs to make sure that the work following the laboratory exercise elaborates the scientific ideas behind the method and that it is done in a context the students understand. For this reason I believe that the exercise, where the students find facts about fish, is important because it enables the students to really evaluate their sampling procedure and the method in general. The exercise is therefore warranted and needs to be implemented as a permanent and regular part of the program.

4.4.4 Didactic Transposition Delay (DTD)

The method the students work with in the laboratory exercise was as stated earlier, a method first published by Thomsen, P. F., et al. (2012), in 2012. The method used is therefore fairly new, when it comes to being a method taught and used by high school students. The time the between scientific knowledge is produced and that knowledge entry into taught knowledge is described in Didactic Transposition and is called Didactic Transposition Delay (DTD). In other words DTD refers to the time between the scientific publication, and the introduction into syllabus, textbooks etc. (Quessada and Clément 2007). In the case of 'DNA and Life' the DTD is very short, which could pose different advantages and disadvantages. An advantage could be that students' attitude towards science and experimental work could increase positively, when working with new and current biological subjects. However a study done on the pilot version of 'DNA and Life', conducted as a preliminary test course prior to the implementation of the educational program studied here, showed that this was not the case. If the students failed to get positive results, which is often the case when working with a new not yet well-established method, it left them less positive towards the laboratory work just done (Achiam and Johannesen 2014). In the six classes I observed only three of them actually located organisms through their

work with this new method. In the three classes that did not get a positive result (as seen in figure 5a) I observed what appeared to be disappointment.

Educator:	So! Are the results what you had expected?
Maggie:	I probably thought there was a bit more fish in the lake
Educator:	Yes, you expected to actually find something?
Whole class:	YES!

The students in this class seem a bit discouraged by the fact that they did not find anything at all even though they knew that there were fish in the lake from where the sample was taken. This is also observed in the two other classes that did not locate any organisms (see 65 for another example). However no matter the results, I observed constructive discussions between the students and the educator, as to why the results looked the way they did, in all the classes observed. Also many of the students had good ideas on what parameters that needed to be changed in order for them to increase the possibility of locating organisms. The new method, even though it does not provide the students with results every time, it does provide an open-ended milieu. This evaluative work have the possibility of leading to an increase in positive attitudes towards laboratory work (Berg, Bergendahl et al. 2003, Millar 2004).

Since I collected the data for this thesis, the method of collecting samples has changed, and the students now pump 500 ml of water through a filter, which means they collect the equivalent of ten times as much water as before, increasing the change of getting eDNA in their samples. This has also proved to help the students find organisms in DNALab and Andreas Kelager, project manager on 'DNA and Life' has found that with the new method, the likelihood of a class successfully finding organisms in their samples is almost 100%, compared to a success rate of about 50-60% with the 'old' way of collecting water samples. This mean that almost all classes now find organisms in their water samples. Another change is that when the students found organisms in water samples collected using the old method they found between one and two species. In water samples collected with the new method the students find three to five species, with one class even finding eight species.

Working with a method that has a short DTD, means that changes can happen quite rapidly as seen in this program. The educational program 'DNA and Life' was in this respect and at the time I collected my data, subjected to problems that was out of the museums hands, because the method and research was not at a state, where the collecting method could be improved. It seems like one of the issues seen in my data, has been improved by the development of the method scientifically, and probably also the problems that came with it. However to say anything for certain further observational studies must be conducted, which is outside the scope of this thesis.

5. DISCUSSION

In this thesis I have located different issues using the didactical frameworks of TDS and Didactic transposition. Some issues I have posed solution to by using the framework that helped me find it, but others need to be discussed using both frameworks. This will be done in this section along with at discussion about general implication of this study.

5.1 Issues addressed using both frameworks

5.1.1 Rethinking how the results are reviewed

In chapter I I identified different issues in 'DNA and Life' using TDS as a theoretical tool. One issue identified was that the situation during the action phase in the laboratory exercise could be considered didactic instead of adidactic, as the students work is dictated by a manual written by the museum. Another problem identified was how the method itself was evaluated. The method was evaluated before all results were presented, which means that the method was being evaluated before all students had a chance to see their own results. As a consequence some students seemed excluded from participating in the evaluation and in addition some students seemed to repeat previous groups statements. If we look at this through the lens of TDS, we could also say that the students go through a formulation and validation phase separately in the student groups.

In order to address these two problems I looked at the scientific practice for inspiration. Through this work I found that scientists look at all graphs as a collected results and reviews it as such. If we look at the students process we could say that they are reviewing fragments of the results, because all graphs are reviewed one by one. Instead the students could be provided with all the graphs, and asked to discuss them in groups. Doing this would make the formulation phase adidactic, letting them consider all graphs on their own. This could also potentially let the students go through similar realisation processes as the scientists themselves (Crawford 2000). This suggestion does not make the action phase more didactic, but as previously mentioned I am not certain that this is possible when working with a cookbook-styled laboratory exercise. I therefore suggest an adidactic formulation

phase instead, in order to incorporate a genuine adidactic situation, which could provide the students with the necessary tools in order to understand the method and the science behind it.

Another potential issue that emerged through my analysis using TDS is the relative distribution of teacher controlled situations and student controlled situations (didactic and adidactic situations, see table 2). According to Brousseau it is through the independent work (the adidactic situations) that the students learn (Brousseau 2006), but the current structure prioritises the didactic situations. However the situations described in the preceding sections offers a perfect opportunity to add another adidactic situation, in making the students review all the results in groups before discussing them with the educator and the rest of the class. If we look at this from a TDS perspective the students would now have an adidactic formulation phase followed by a didactic validation phase. According to TDS, the formulation phase can be either didactic or adidactic (Table 1), and it is therefore in line with TDS, to make the formulation phase adidactic. The change suggested here is created from using Didactic Transposition, looking to the science for inspiration on how to add more adidactic situations. Looking at scientific articles it is clear that scientists do not validate a method by a single graph, as the possibility of getting that result by chance is too great (statistically insignificant), and the chance of not seeing the bigger picture too high. By letting the students look at all graphs before they validate the method would provide them with some of the same opportunity by giving them all the information available before they form opinions about the method. With this suggestion one could also avoid the inactivity I observed in some students, when the results are reviewed and perhaps the validation would also be more dynamic when all students have had a chance to interpret the results. This change could also accommodate another issue that emerged in my analysis. If all students groups discuss the results before they listen to other groups interpretation one could perhaps lower the tendency of student groups simply repeating what other groups said.

Another issue that this recommendation could possibly address is the need to help different students in different ways when it comes to open-ended assignments as

discussed in chapter II. When the students work within an established milieu through an adidactic situation, they should be able to do so without seeking advice from the teacher or educator(Brousseau 2006). However as presented in chapter I, this is not always the case. If an assignment proves to be to difficult for some students, the teacher can devolve the assignment again, but must be careful not to devolve it so much that the students does not learn the intended knowledge (the Topaz effect, see chapter I). By making the formulation phase adidactic one could make it possible for all students to navigate in an open-ended assignment, providing the students who need it, with additional devolution, but at the same time letting the students, who thrive in this type of assignment, navigate it without interference. Open-ended exercises also resembles the scientists work, in the way that no scientists ever work with questions that already have an answer, why the nature of scientific inquiry could be made more clear to students through open-ended exercises (Crawford 2015).

5.1.2 How to do more replicas and keeping in line with the main thread

In chapter II using Didactic Transposition I found that the students do not consistently do replicas of their samples when using this method of finding organisms in freshwater. I also found that the classes observed, which did not find any organisms in their samples, were a bit discouraged when it came to evaluating their own efforts. In general it seems that finding an organism (see figure 5 graph a) counted as a positive result, to the students. Getting what I would call a positive result, where the whole qPCR setup was done correctly, but not finding the organism (see figure 5 graph b), did not seem to count for much according to the students. This could be due to the way the assignment is staged. In the introduction the students are assigned a role as the researcher, who needs to test a collected water sample for different fish, amphibians and insects. When the results are reviewed and it turns out that they did not find any organisms and the method therefore did not generate “anything”, they get disappointed. The students disappointment could also be enhanced by the them believing that new methods have a certainty for success, even though that is rarely the case when working with a newly established method. A method like the one the students work with is not as certain as older and more

thoroughly tested ones. However the students could increase the likelihood of finding organisms if they did replicas. Something that scientists do in their work with this method (Ficetola, Miaud et al. 2008, Thomsen, Kielgast et al. 2012). This will of course reduce the number of different species that the students are able to test for, since two or three groups have to test for the same organism. But by reducing the number of species the students test for, it could potentially eradicate another problem. In 'DNA and Life' the students search for fish, amphibians and insects. However the insects and amphibians is only part of the program to the degree that the students look for them in the laboratory. Fish on the other hand is a reoccurring theme through all three exercises (see figure 6 or 14). My suggestion would therefore be to look only for fish in the laboratory, letting two or three student groups look for the same fish. The work the students do when they key out the alcohol preserved fish and especially when they find facts about fish, potentially provides them with the tools to evaluate the method they used in the laboratory, but only when it comes to fish. The same tools are not given to the students when it comes to amphibians and insects, why they do not have the same opportunity to evaluate the method based on these animal groups. If the museum finds it necessary to keep the amphibians and insects as a part of the laboratory work, I would suggest that they include these two animal groups in the two other exercises as well. Nonetheless I would like to stress the importance of doing replicas. Doing replicas will increase the chance of getting results (figure 5, graph a or b) even if one group makes a mistake in their qPCR setup. But even more important than getting results, it could teach the students about the scientific importance of double-checking results in order to strengthen them. So even though the new sampling procedure has changed, increasing the possibility of finding organisms, I will still recommend letting the students do replicas, because it provides an insight into the method and general scientific work in a laboratory. This issue was located through Didactic Transposition, but could also be looked at via TDS. If we consider the educator's responsibility of creating a milieu, that portrays the method in an accurate scientific way, then not doing replicas could be interpreted as a breach of the didactic contract.

5.2 The reference model as a result

In chapter II section 4.1.2 I described what is called a reference model, and that all four steps in Didactic Transposition affect the reference model (see figure 9). In this thesis chapter I deals with the last two stages in Didactic Transposition, Taught Knowledge and Learnt Knowledge, where as chapter II deals with the first to stages, Scholarly Knowledge and Knowledge to be taught. TDS can therefore be a theory used within Didactic Transposition as a means of understanding the stage Taught

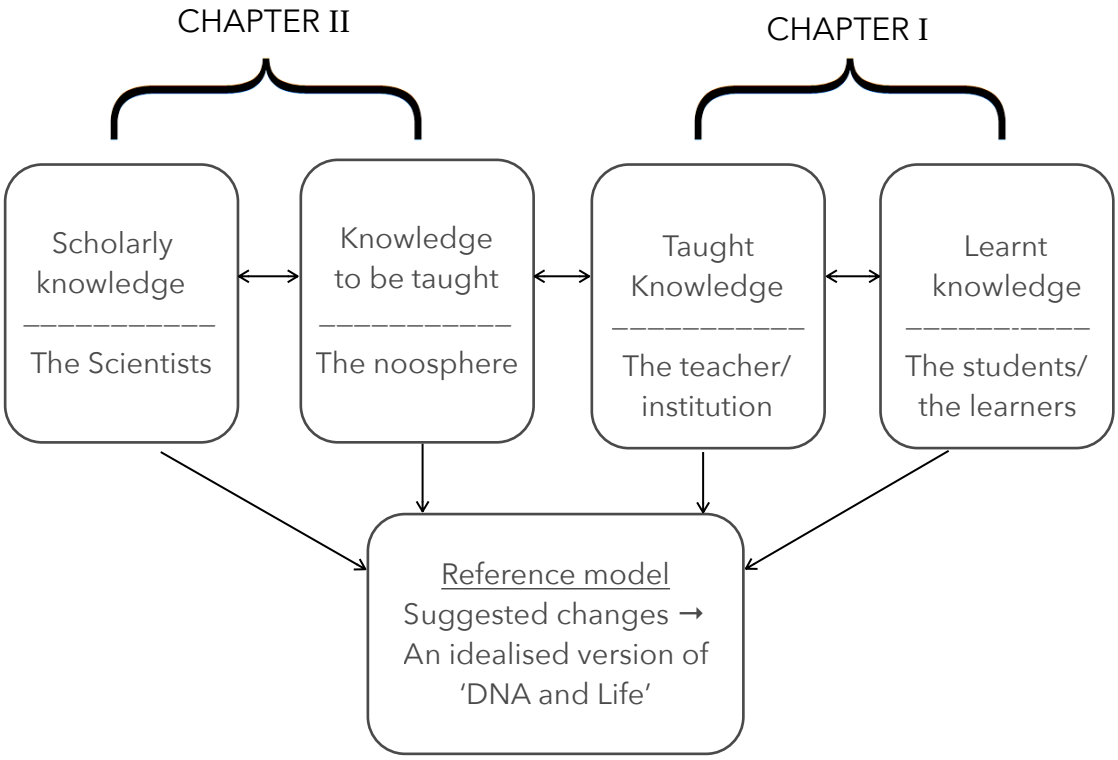

Figure 15. *This figure shows which chapter deals with what stage in the didactic transposition. It also shows how the two different chapters feeds into the reference model, and how the reference model could function as a result*

Knowledge (see figure 15). My analysis in chapter I and II, as well as my discussion in section 5.1, therefore constitutes my reference model. The reference model thus serves as a theoretical idealised version of the educational program under investigation, since all 4 stages of the transposition feeds into the suggestions made for altering parts of the program (Kjølbæk 2015). This effectively means, that the reference model here serves as a result, in that data collected in the four stages are the basis of the evaluation of this program as well as the basis for the suggested

changes (Achiam, Lindow et al. 2016). One could also say that it serves a dual purpose, as it in addition has a theoretical function, where it ensures that all institutions that influences 'DNA and Life' are looked at equally. It is through the making of the reference model, I am able to come with suggested answers to my initial research question: what effect does working with a new method have on students working in a laboratory? This is discussed in the next to sections.

In the next sections I will use my analysis and creation of a reference model to comment on laboratory work in general and also use it to evaluate the usage of a newly developed method in a teaching context.

5.3 Cookbook-styled laboratory work

Laboratory work is a great way to vary the learning environment and let the students manipulate scientific objects. However as other studies show (Hofstein and Lunetta 1982, Hofstein and Lunetta 2004), we must be careful not to assume that laboratory work itself automatically teach students about science and scientific ideas. This thesis is build upon data from the educational program 'DNA and Life'. A program where laboratory work is a central component. In my data I observe several students, who had difficulties when it came to evaluating the results from the qPCR. Some students, it seems, had done all the laboratory work without really understanding the scientific ideas and concepts behind it (see previous quote, page 44). This is not uncommon as other studies have shown that cookbook-styled exercises, were only effective in getting the students to do what the teacher intended, but not providing them with the knowledge of scientific ideas (Abrahams, Millar et al. 2008, Abrahams and Reiss 2012). In my data I observed that, none of the student groups I followed questioned anything about the method or what they were doing, when they were in the laboratory preparing their samples for testing, which further supports the idea that the action phase, when doing cookbook-styled laboratory work, is not adidactic. It was the discussion about the results obtained and the subsequently back tracking to the method itself, which seemed to spark scientific thoughts with the students and start a discussion about the scientific ideas behind the method. It was through the evaluation of the method that the students began to be critical about their own work and efforts in the laboratory and where the limitations of the method were discussed.

In other words this is where I observed metacognitive activities and where the students started to consider the manipulation of the scientific ideas behind the experiment, not only the manipulation of the materials. The manipulation of ideas is a process that is important when it comes to promote learning from laboratory experiments (Hofstein and Lunetta 2004). The work done following a laboratory experiment therefore seems crucial, when it comes to understanding scientific ideas in the laboratory. If we look at cookbook-styled laboratory exercisers through the lens of TDS we could say that the action phase is not adidactic as the students follow a prewritten manual. According to Brousseau it is through adidactic situations students essentially learn and I therefore believe it important to make another phase adidactic when using cookbook-styled manuals. The fact that my data suggest that it is not in the action phase/laboratory work, that students conduct scientific ideas does not make it redundant, as it could be the foundation the scientific ideas are build upon. It is however necessary to incorporate some type of assignment or exercise, where the students are the prime actors in order to provide the students with the best opportunity to make sense of their work in the laboratory and the scientific ideas behind it. In other words cookbook styled tasks are not adidactic and another adidactic situation needs to be added in order to provide the students with the best opportunities to learn the scientific ideas behind the experiment. In this thesis this is suggested as an adidactic formulation phase, where the students review all results in groups before discussing them in a plenary and didactic validation.

5.4 Teaching a newly developed method

In 2012 the Natural History Museum of Denmark sent a application to Lundbeckfonden in order to get the fundings to create the educational program 'DNA and Life', the same year as the method was published as a scientific paper. A question one could ask oneself is whether, or to what extent engaging, a brand new method could improve students' attitudes towards science. The results of the pilot project showed that students' attitudes towards science were not measurably changed by their participation in the program (Achiam and Johannesen 2014) and the data comprising this thesis show a similar tendency. In the six classes I observed

three of them did not locate any organisms using the new eDNA method. The students in these classes seemed discouraged by the fact that the method did not provide them with any "real" results. Even so in all classes I observed, students participated in evaluating the method, and came up with ideas regarding improvements to optimise the method and possible ways to ensure results. I also observed students that were able to be self-critical, when it came to evaluating not only the method, but also their own performance in the laboratory. However this did not appear to emerge from the method being new, but rather from the open-ended questions provided by the educator. It seems to be the open-ended way of evaluating the day's work that sparked a great deal of critical thinking by the students and not the fact that the method was new. Staging open-ended evaluations can be done whether or not the students work with a new method. If we look at this through Didactic Transposition theory, we could say that in staging an open-ended evaluation of the students work, we closely simulates the scientific process. It is therefore not surprising that it is here we see the students argue and reason as scientists. The evaluation of a new method could also be staged using a more close-ended approach, but this most likely would not yield the same critical discussions as observed in this educational program. In teaching a new method still under evaluation, this open-ended evaluation perhaps comes more naturally than when teaching a method that has been tried-and-tested for many years. But ultimately I believe that the students learning outcome and ability to take a critical stand, when it comes to the method used, does not emerge from the newly developed method, but rather emerges from the staging of the exercise. Studies have shown that open-inquiry based work provides students with more positive perception of science and laboratory work (Berg, Bergendahl et al. 2003) and that inquiry based work in a laboratory could yield higher test scores (Blanchard, Southerland et al. 2010). I wonder if open-ended evaluation of the laboratory work could provide the same? Studies have shown the need for intervention and negotiation of ideas as a necessity for students understanding of science (Driver 1995, Barron, Kim et al. 1998). The laboratory work that comprises the data in this thesis is not particularly inquiry-based, since the students work is outlined by the manual. The evaluation of the results is however staged as open-ended in such a way that the students can reflect

on the method and get feedback on their ideas from their peers and the educator. It lets the students engage personally in the method in that they evaluate not only the method, but their own performance both when collecting the water samples in the field and working in the laboratory. Engaging personally in the scientific work have proven to increase the students attitudes towards science (Osborne 2007). However it was not all students that participated in this evaluating work. This could mean that not all students have understood the method, the results it provide or the scientific ideas behind it. However it could also have to do with the way the results are reviewed, where the method is evaluated before all students have had a chance to see their own results. Those students that predominately participate in offering explanations to the results and how the method functions are the students that have had the chance to see and validate their results. I therefore believe that it is even more important that the way the results are reviewed is changed in order to ensure that all students have an equal opportunity to come with their personal evaluation of the work done in DNALab.

6. CONCLUSION

The aim of this thesis was to examine how students worked in a laboratory and if teaching a new method would increase students enthusiasm towards science? This was done by analysing the educational program 'DNA and Life' offered by The Natural History Museum of Denmark. The analysis was done by combining two different theories in one theoretical framework. TDS was used as a part of Didactic Transposition in order to analyse the structure and design of the program. The outcome of this was used as a point of departure for the rest of the analysis, which was done using Didactic Transposition theory. These two theories posed solutions to the identified problems separately, however some solutions were suggested by combining both theories.

In chapter I I used TDS as an analytical tool to examine the program. Here I identified differences between TDS' description of the action phase and the actual action phase as practiced in the laboratory. The action phase is according to TDS adidactic, and students should therefore be able to navigate in the milieu without help from the teacher. However during the laboratory work I observed students asking if they understood the laboratory manual correctly. This is most likely due to the students lack of experience working in a laboratory, and not due to a badly designed manual, as I found the manual to be short and to the point. As the questions seemed to arise from the students inexperience with laboratory work, I do not believe that it is possible to completely avoid these types of questions. This means, as discussed, that TDS could be a theory that is difficult to use when it comes to cookbook-styled laboratory exercises. You could however argue that TDS was also the theory that showed, that the action phase, when doing cookbook-styled laboratory exercises, is not controlled by the students (an adidactic situation), since the students follow a manual created by a teacher or educator. According to Brousseau it is through the adidactic situation that we essentially learn and I therefore believe it is important to add a genuine adidactic situation in order to let the students connect the work done in the laboratory with scientific ideas. But as the laboratory work as mentioned above could not fully meet the criteria for the adidactic action phase, it is essential to make one of the other existing phases adidactic. By using Didactic Transposition (chapter

II) I identified how and where to transform one of the other phases found.

When reviewing the results one group after the other the students go through a didactic formulation and validation phase (see figure 6). This way of looking at the graphs appeared to result in unengaged students and students repeating other groups interpretations. Going back through Didactic Transposition I found that scientists always use all graphs when interpreting their results. With this as an inspiration I suggest that students are presented with all the graphs produced and that they discuss them in groups with no interference from the educator. This would create a genuine adidactic situation, and students would have the opportunity to form their own opinions before the results are reviewed in the class and the method evaluated. This would if we look through the lens of TDS, be called an adidactic formulation phase.

Another issues was that many of the samples did not result in a positive test outcome, i.e. the students did not find organisms in their samples. This appeared to cause discouragement among the students, if the entire class did not find any of the organisms they looked for. Scientific knowledge shows that, when scientists use this method, they all do replicas of their samples in order to increase the chance of getting results, but also because if the organism is found in more than just one sample it increases the strength of the result. I therefore recommend that the educational program 'DNA and Life' include replicas as a permanent part of the laboratory work. By not doing so the museum breaks the didactic contract, as they neglect to provide as many opportunities as possible in order for the students to find the organisms they are looking for. This change would decrease the number of species the students are able to test for, but as two out of the three exercises are about fish (keying fish and finding facts about fish) The National History Museum of Denmark could consider only looking for freshwater fish in the laboratory, excluding amphibians and insects from the program. However if the museum believes it important to include insects and amphibians as a part of the program I would recommend to make these organisms a part of the two other exercises as well. Otherwise the students will not be equipped with the knowledge to evaluate the method using these organisms.

Laboratory work is a central part of biology. It is therefore important that students studying biology gets an understanding of how laboratory work is conducted. Nevertheless we must not assume that students understand the science from the laboratory work itself. It is therefore important to incorporate adidactic exercises based on the laboratory work, which lets the students explore and understand the scientific ideas behind the laboratory work.

The educational program 'DNA and Life' teaches students about biodiversity using a newly developed molecular method. In recent years there has been much focus on teaching authentic and cutting-edge science, but the question is if it increase students enthusiasm towards science. In the data comprising this thesis I observed students working with cutting-edge science through their participation in 'DNA and Life'. Through the work I observed students, who discussed ideas regarding improvements to optimise the method and who participated in evaluating the method. I also observed students that were able to be critical, when it came to evaluating how and when to use the method and also be critical, when it came to their own performance in the laboratory. This type of discussion shows much similarity to the way scientists argue in the scientific literature. Even so I am not convinced that the discussions emerged from the method being new. I am more inclined to believe, that it was the open-ended evaluation in this educational program that engaged the students and got them to argue scientifically and not the fact that the method was new. Staging open-ended evaluations can be done whether or not the students work with a new method, and I will recommend creating this type of environment when doing laboratory exercises in order to involve and excite students when it comes laboratory work.

The work in this thesis indicates that if students are to achieve the optimal learning outcome from cookbook-styled laboratory exercises, the exercise needs to be followed by exercises where students, without interference from an educator or teacher, discuss and evaluate the work done in the laboratory. The results in this thesis also indicates that an open-ended evaluation of the laboratory exercise and not the fact that the method used was new, engaged students in laboratory work and got them to argue like scientists.

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Figure 2 from:

http://www.bbc.co.uk/schools/gcsebitesize/science/add_edexcel/cells/dnarev1.shtml

9. APPENDIX

Appendix 1

DNAlab
Statens Naturhistoriske Museum

STATENS NATURHISTORISKE MUSEUM
KØBENHAVNS UNIVERSITET

Velkommen til projektet DNA & LIV på Statens Naturhistoriske Museum!

I dette projekt skal du og dine elever bidrage til en monitering af biologisk og økologisk interessante dyrearter i danske ferskvandssystemer. Metoden vi skal anvende er udviklet af forskere på Statens Naturhistoriske Museum. Dine elever skal i forbindelse med et besøg i DNAlab på Statens Naturhistoriske Museum foretage qPCR-analyser (”quantitative polymerase chain reaction”) af indsamlede vandprøver i et forsøg på at påvise DNA-fragmenter fra de organismer, vi ønsker at monitere. Man kalder sådanne vandopløste DNA-fragmenter for miljø-DNA eller eDNA (”environmental DNA”).

Da vi i DNA & LIV-projektet ønsker at få undersøgt så mange danske ferskvandssystemer – søer, skovsøer, vandhuller, moser – som muligt, vil vi meget gerne have din og/eller dine elevers hjælp til at indsamle en vandprøve fra en ferskvandslokalitet i jeres lokalområde. Det kan fx være en af de lokaliteter, I typisk besøger i forbindelse med feltarbejde, eller det kan være en lokalitet, som er biologisk, lokalgeografisk eller lokalhistorisk interessant, overset eller omdiskuteret.

Vandprøven kan indsamles i forbindelse med en ekskursion, eller du kan enten selv indsamle prøverne eller få nogle af dine elever til at gøre det. **Vandprøver MÅ KUN indsamles i perioden juni-august**. Efter indsamling skal prøven sendes til Statens Naturhistoriske Museum, hvor vi opbevarer den (på frys) og præparerer den, så den er klar til, at klassen kommer på besøg i DNAlab (prøven har ingen udløbsdato, når først den er afsendt til museet).

På næste side finder I en vejledning til indsamling og forsendelse af prøven. **Læs hele siden grundigt!**

Såvel indsamling som forsendelse er meget enkelt at gå til, og i den tilsendte kuvert finder I alt det udstyr, I behøver for at indsamle og sende prøven.

God fornøjelse – og tak fordi I er med til at gøre DNA & LIV til et landsdækkende projekt!

Det tilsendte indsamlingskit består af:

- 3 poser, der hver indeholder 1 stk. 50 ml centrifugerør med 33 ml ethanol 96 % og 1 stk. 2,0 ml mikrocentrifugerør indeholdende 2 ml 3M natriumacetat pH 5.2
- 1 x 15 ml centrifugerør (til indsamling af vandprøver)
- frankeret svarkuvert til forsendelse af de indsamlede prøver

Indsamlingsprocedure:

1) Tilsæt 2 ml natriumacetat fra et mikrocentrifugerør til de 50 ml ethanol i centrifugerøret.
2) Fyld 15 ml søvand i 15 ml centrifugerøret. *Sørg for, at der ikke kommer sediment og større partikler med i prøven.*
3) Tilsæt disse 15 ml vand til 50 ml centrifugerør (indeholder i forvejen 33 ml ethanol + 2 ml NaOac).
4) Sæt låg på 50 ml centrifugerøret og vend røret flere gange.
5) Læg røret i en lille lynlåspose.
6) Gentag ovenstående procedure med de to andre 50 ml centrifugerør. ***Bemærk, at alle tre prøver skal være fra samme lokalitet, men ikke nødvendigvis samme sted på lokaliteten.***
7) Udfyld mærkaten på den store lynlåspose, og læg de tre små poser med vandprøver i den store lynlåspose.
8) Mærkaten skal udfyldes med følgende oplysninger:
    - Dato for indsamling af vandprøve
    - Lokalitetens navn
    - Lokalitetens GPS-koordinater (WGS84, decimalgrader) for indsamlingsstedet fx ved hjælp af Kraks online kort eller Google Maps.
    - Gymnasium og klasse
    - Kontaktperson (navn, tlf. og e-mail)
    - Dato for aftalt besøg i DNAlab
9) Læg den store lynlåspose i svarkuverten (15 ml røret og 2 ml rørene kan blot kasseres).
10) Smid kuverten i en postkasse.
11) OBS! Husk fotodokumentation af lokaliteten, og send billederne til dnalab@snm.ku.dk.

VIGTIGT:

- Der kan indsamles vand fra en hvilken som helst offentligt beliggende sø, dam eller vandhul i Danmark.
- **Vandprøver MÅ KUN indsamles i sommermånederne (juni, juli, august), da koncentrationen af eDNA i vandet er størst i denne periode.**

- Indsaml ikke vand fra forskellige søer, for DNA'er i de tre vandprøver bliver "puljet" til én prøve. Ønsker man at indsamle fra 2-3 søer skal man benytte ekstra indsamlingskits (1 pr sø).

Sørg for at tage prøven i vandfasen og ikke for tæt på sedimentet. De tre vandprøver kan enten indsamles det samme sted eller tre forskellige steder i søen.

- Hvis kuverten ikke sendes samme dag, skal den holdes på køl (køleskab).
- For at sikre at prøverne ikke ligger uden køl weekenden over, må prøver **ikke** sendes en torsdag, en fredag eller en lørdag.
- Når prøverne er afsendt, skal der samme dag gives besked både til dnalab@snm.ku.dk og til bioanalytiker Pernille Selmer Olsen (pvsolsen@snm.ku.dk). Så tager vi hånd om jeres prøver.
- Skulle der ifm. prøvetagningen opstå spørgsmål, så kontakt bioanalytiker Pernille Selmer (23 82 80 91).

Appendix 2

DNAlab
Statens Naturhistoriske Museum

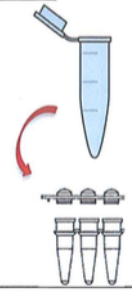
Miljø-DNA Protokol

Gruppe _____

Art _____

Real Time PCR opsætning

To trin



A. Lav et **PCR Mix** med de nødvendige reagenser til en PCR reaktion

B. Fordel PCR Mix i tre **PCR rør** og tilsæt prøve og kontroller

---

A) PCR Mix blandes i et Eppendorf rør.

Reagenser	Volumen
TaqMan	40 µl
ddH_2O	36 µl
Primer forward	4 µl
Primer revers	4 µl
Probe	4 µl

1. Skriv *PCR Mix* på låget af et tomt Eppendorf rør med en sprittusch.
2. I skemaet til venstre står, hvilke reagenser du skal bruge. Omryst hvert af de fire reagenser: **TaqMan, primer F, primer R** og **probe** vha vortex'eren (ca. 10 sek). H_2O behøves ikke at blive vortexet.
3. Centrifugér reagenserne 10-20 sek. Afbalancér centrifugen ved at sætte de fire rør overfor hinanden to og to.
4. Brug pipetterne til at blande reagenserne i *PCR Mix*-røret i de mængder og den rækkefølge, som er angivet i skemaet.
5. Vent til alle grupper er færdige.

B) Real Time PCR opsætning i tre PCR rør (en strip)

Rør	1	2	3
Indhold	**Positiv kontrol**	**Negativ kontrol**	**DNA fra Sø**
PCR Mix	22 µl	22 µl	22 µl
DNA positiv kontrol	1 µl		
ddH2O	2 µl	3 µl	
Sø-prøve			3 µl
I alt volumen	**25 µl**	**25 µl**	**25 µl**

1. Notér gruppens nummer på snippen af PCR-rørene. Skriv ikke andre steder på strippen.
2. Vortex *PCR Mix,* DNA positiv kontrol og sø-prøven
3. Centrifugér rørene. Brug et tomt rør til afbalancering.
4. Tilsæt først PCR Mix, dernæst positiv kontrol, sø-prøve og ddH_2O i de angivne volumener i hvert PCR-rør. Husk at skifte pipettespids.
5. Bank let på PCR-rørene med en finger for at blande indholdet og centrifugér dem sammen med et andet holds prøver som modvægt.
6. Sæt PCR-rørene i Realtime-PCR maskinen.

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Fiskebestemmelses øvelse

Bakke nr.	Art

Noter

Resultater af real-time PCR

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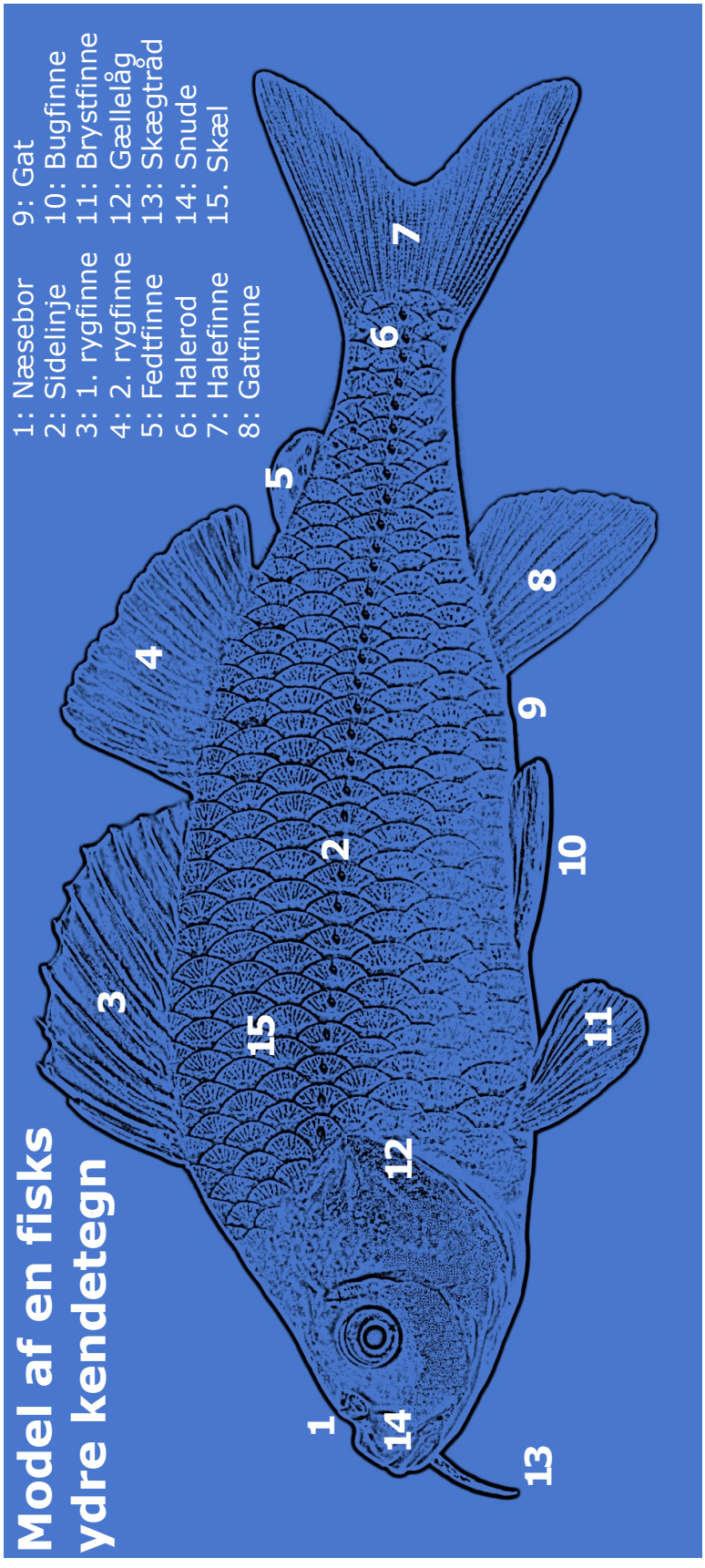
Hvorvidt arten er fundet via Miljø-DNA og traditionel metode.

Organisme Gruppe	Dansk navn	Latinsk navn	Positiv kontrol	Negativ kontrol	Sø (eDNA)	Database
Fisk	Dyndsmerling	*Misgurnus fossilis*				
Fisk	Europæisk ål	*Anguilla anguilla*				
Fisk	Gedde	*Esox lucius*				
Fisk	Karpe	*Cyrpinus carpio*				
Fisk	Karusse	*Carassius carassius*				
Fisk	Pigsmerling	*Cobitis taenia*				
Fisk	Skrubbe	*Platichthys flesus*				
Fisk	Trepigget hundestejle	*Gasterosteus aculeatus*				
Insekt	Bred vandkalv	*Dytiscus latissimus*				
Insekt	Lys skivevandkalv	*Graphoderus bilineatus*				
Insekt	Stor kærguldsmed	*Leucorrhinia pectoralis*				
Padde	Grønbroget tudse	Bufo viridis				
Padde	Løgfrø	*Pelobates fuscus*				
Padde	Løvfrø	*Hyla arborea*				
Padde	Spidssnudet frø	*Rana arvalis*				
Padde	Stor vandsalamander	*Triturus cristatus*				
Pattedyr	Odder	*Lutra lutra*				

Noter

Appendix 3


Model af en fisks ydre kendetegn
1: Næsebor
2: Sidelinje
3: 1. rygfinne
4: 2. rygfinne
5: Fedtfinne
6: Halerod
7: Halefinne
8: Gatfinne
9: Gat
10: Bugfinne
11: Brystfinne
12: Gællelåg
13: Skægtråd
14: Snude
15. Skæl