Degree Project in Technology and Learning

Second cycle, 30 credits

Analysis of earthquake forecasting using machine learning with simulated data

and

How can a visit to a science center influence students’ perception of science?

Can a neural network predict the location, magnitude and time of an earthquake in a simulated situation, and, a qualitative study of high school students’ change in perception of science after workshops at a science center

JARL WALLHEDEN

TRITA – ITM-EX 2024:269

Stockholm, Sweden 2024

www.kth.se

Examensarbete inom teknik och lärande TRITA–ITM-EX 2024:269

Analysis of earthquake forecasting using machine learning with simulated data
and
How can a visit to a science center influence students' perception of science?

Jarl Wallheden

KTH Civilingenjör och Lärare

Godkänt 2024-11-20	Examinator Anna Karin Högfeldt	Handledare Torbjörn Bäck Louise Björlin Svozil Susanne Engström

Master of Science and Education Thesis TRITA–ITM-EX 2024:269

Analysis of earthquake forecasting using machine learning with simulated data
and
How can a visit to a science center influence students' perception of science?

Jarl Wallheden

KTH Civil Engineering and Education

Approved 2024-11-20	Examiner Anna Karin Högfeldt	Supervisor Torbjörn Bäck Louise Björlin Svozil Susanne Engström

Analysis of earthquake forecasting using machine learning with simulated data
and
How can a visit to a science center influence students' perception of science?

Can a neural network predict the location, magnitude and time of an earthquake in a simulated situation
and
A qualitative study of high school students' change in perception of science after workshops at a science center

Jarl Wallheden

September 2024

1 Author's Note

First I'd like to thank my advisors Torbjörn Bäck, Louise Björlin Svozil and Susanne Engström who helped and advised me for far longer than intended.

I'd also like to thank my good friends Anton Svensson, Anton Höglund Mayer, Anton Myllykoski, Anton Sundberg, Anton Sundberg, Anton Hallin, Anton Bringlof, Anton Lenstrup and Anton Wallén. And special thank you to Matilda who helped me tremendously when motivation was low.

2 Abstract

This is a study in two parts, a technical and a pedagogical. The technical part is about forecasting of simulated earthquakes through the means of artificial intelligence (AI) and the pedagogical part examines the effect a visit to a science center changes the way high school students conceptualize science.

This technical study tries to answer whether or not a small machine learning algorithm could forecast the size and location of a simulated earthquake based on a simplified model in which radon gas is emitted from the epicenter as a function of time before the earthquake. To achieve this, the simulation included a network of radon detectors distributed in the regions surrounding the epicenter. This model combined with the radon transmission model generated a simulated time-dependent radon signal in each direction. This data was then fed to a neural network and since the data was simulated, a large dataset could be used for training the network.

The results show that with the simplified model used, a basic artificial neural network could with an error of $< 5\%$ forecast the relative position, magnitude and time of an earthquake one day before the earthquake and 10 days before with an error of $\sim 5\%$. Since the nature of real radon emission and transport is not known in relation to seismic events, this result is just a demonstration showing that a neural network, given a step, linear or exponential correlation between radon and seismic activity, can forecast the position, time and magnitude of an earthquake.

Science centers have recently gained a lot of popularity in Sweden with the aspiration to invoke curiosity for science in students while also offering an alternative learning environment. An alternative that have been argued as something positive in many aspects to learning (Sjöberg 2011, Ersen & Muhlis 2015, DeWitt & Hohenstein 2010) but how does it affect the way students conceptualize science? This study examines 27 high school students' conceptions of science before and after a visit to a science center by interviewing them in groups before and after.

The results indicate that students' scientific literacy increased, as conceptions regarding stereotypes and that science is something distant were less common in the interviews conducted after the visit. Suggesting that their understanding of scientific research increased to a point where the most common stereotypes were not needed in order to describe their thoughts. An extension of this is feeling like science is something real and closer to the students. The students' interests and motivation did not change notably, many students were however more secure in their perception that doing research is not for them. A concept that managers decide what scientists do appeared during the first set of interviews but was almost nonexistent afterwards, despite the fact that the science center did not challenge this concept.

It's clear that science centers affect the students' perception of science to something more along reality and is therefore a good tool for teachers to use as alternative learning environments.

3 Sammanfattning

Detta är en studie i två delar, en teknisk och en pedagogisk. Den tekniska delen handlar om att prognostisera simulerade jordbävningar med hjälp av artificiell intelligens (AI) och den pedagogiska delen undersöker hur ett besök på ett science center påverkar gymnasieelevers föreställningar kring forskning.

Denna tekniska studie försöker svara på om ett mindre neuralt nätverk med en simpel inlärningsalgoritm skulle kunna förutsäga storleken och platsen för en simulerad jordbävning. Detta baserat på en förenklad modell där radongas skickas ut från en jordbävnings mitt, beroende av tiden innan jordbävningen. För att uppnå detta inkluderade simuleringen ett nätverk av radondetektorer placerade i regionerna kring epicentret. Denna modell, i kombination med radontransportsmodellen, genererade en simulerad tidsberoende radonsignal i varje riktning som fångades upp av detektorerna. Denna data matades sedan till ett neuralt nätverk. Eftersom datan simulerades kunde en stor datauppsättning användas för att träna nätverket.

Resultatet visade att med den förenklade modellen kan ett grundläggande artificiellt neuralt nätverk förutsäga positionen, magnituden och tiden med ett fel på $<5\%$ för en jordbävning dagen före jordbävningen, 10 dagar innan hamnar felet på $\sim 5\%$. Eftersom den verkliga radonstrålning och transport-modellen inte är känd i korrelation till seismisk aktivitet är detta resultat enbart en demonstration som visar att ett neuralt nätverk kan, givet ett stegvis, linjärt eller exponentiellt samband mellan radon och seismisk aktivitet, förutsäga position, tid och magnitud av en jordbävning.

Vetenskapscentra har på senare tid fått stor popularitet i Sverige. Detta med strävan att väcka nyfikenhet för vetenskap hos elever och samtidigt erbjuda dem en alternativ lärmiljö. Ett alternativ som har argumenterats som något positivt i många aspekter till lärande (Sjöberg 2011, Ersen & Muhlis 2015, DeWitt & Hohenstein 2010) men hur påverkar det hur elever erfar vetenskap? Denna kvalitativa studie undersöker 27 gymnasieelevers föreställningar om naturvetenskap före och efter ett besök på ett vetenskapscenter.

Resultaten tyder på att elevernas vetenskapliga förståelse ökade, föreställningar om stereotyper och att vetenskap är något som inte berör dem var mindre vanligt efter besöket. Detta antyder att deras förståelse för vetenskaplig forskning ökade till en punkt där de vanligaste stereotyperna inte behövdes för att beskriva deras tankar. En förlängning av detta är att eleverna känner att vetenskap är något verkligt och närmare eleverna. Elevernas intressen och motivation förändrades inte nämnvärt, många elever var dock säkrare i sin uppfattning att forskning inte är något för dem. Den ursprungliga idén om att chefer bestämmer vad forskare ska göra dök upp under den första uppsättningen intervjuer men var nästan obefintlig i den uppföljande, trots att vetenskapscentrat inte hade som mål att ifrågasätta denna tanke.

Det är tydligt att vetenskapscenter påverkar elevernas uppfattning om naturvetenskap till något mer verklighetsförankrat och är därför ett bra verktyg för lärare att använda som alternativa lärmiljöer.

Contents

4 Preface

This thesis began with the technical part and the aspiration to connect that idea with the pedagogical part. As the thesis and it's research questions developed, the connection between the parts became weaker and were therefore split into two quite separate parts, both with similar foundations. Using the technical part as a foundation, the pedagogical part quickly became related to science and science education. First the idea was to arrange a field trip to the research institute to both study the effects on students of being in an official research environment and to promote the idea of continuing with further studies, this was later changed to a visit to a science center.

With time the different research questions grew apart further in such way that it was decided to keep them separate. This shows the difficulty in combining scientific research and at the same time analyzing students perception of it. To keep a clear direction for both research questions throughout the entire thesis it has been divided into two parts in such a way that it appears as if there are two theses back to back, instead of mixing the technical parts with the pedagogical ones. They share a common introduction in the beginning and a shared conclusion towards the end.

5 Introduction

This thesis is divided into two parts, a technical part and a pedagogical one.

The first techincal part is related to the large EU-funded research project artEmis which is trying to find a correlation between groundwater radiation levels and seismic activity with the long-term goal of forecasting earthquakes (ArtEmis 2021).

The study uses a simplified model for radon transport correlated to an earthquake and a set of distributed radon sensors surrounding the epicenter. Data collected from these simulations are then fed to a neural network as training data with the goal of having the network to be able to find patterns in the data and then be able to forecast when the earthquake is going to happen, where the epicenter is and the magnitude of the incoming earthquake.

A serious concern with doing science that could possibly affect millions of lives, like an early warning system (EWS) for earthquakes would, is how those affected get informed about the research. If the research does not reach those who would use it, it's useless. If false or incorrect information spreads to the public, it may place distrust in science. For example, if the consensus is that the new EWS is perfect and is the solution for all earthquakes world wide, when in reality it can only work in very specific conditions, this could lead to people ignoring previous signs and only using the new EWS (Dahmani & Bohbot 2020; Karlberg 2015). This could cause distrust and repulsion of new technology. This also applies to scientists as well, even though they have full confidence in their new invention a human should always monitor what's happening before making statements to the public. A famous example of why is the Russian missile controller Stanislav Petrov's decision to not fire a nuclear warheads against the US when their EWS indicated that the US had fired nuclear weapons towards Russia, correctly believing it to be a false alarm (Bennetts 2017).

The second part of this study is therefore how students conceptualize science. Do they think science is standing in lab-coats and working on medicine, which is the norm when describing a scientist (Chambers 1983). What do they believe scientists research about? Who do they think decides that and is there such a thing as “bad” science, if so, what is ”good” and how do they differ? All these things are related to doing science and thus form an image of how students conceptualize it. To answer this a class of upper secondary school students currently taught by myself were interviewed in groups of four where they answered questions like above and were then attending a science-center tour. During their visit they got to practice small scale research and also have some fun. The class were then interviewed again some time after the visit, the reason being to see if any differences could be traced from the visit.

The interviews were then analyzed with phenomenology such that the conceptions and phenomenas highlighted were used as a basis for describing how they conceptualize science. This then leaves us at the research questions:

5.1 Research Questions

5.1.1 Technical Question

Is it possible to train a neural network to accurately forecast an earthquake using simulated data and a simplified model for radon transport?

5.1.2 Pedagogical Question

How do high school students describe the concept of science before and after participating in lectures, laboratories and workshops at a science center?

6 Technical Introduction

Earthquakes have been a problem for ages. We know of historical events such as the destruction of the lighthouse of Alexandria, colossus of Rhodes. Many countries are affected to this day, recent examples include the tsunami in Indonesia 2004, earthquake outside Fukushima in Japan 2011 and of course recently the earthquake in Turkey and Syria 2023. Not only did these earthquakes take a lot of lives and destroy historical artifacts in the timespan of days. The economic and structural aftermath could take years to stabilize and leave thousands of people homeless. Just the tsunami of 2004 in Indonesia is estimated to have killed over 227,000 people, with over $14 Billion in damages (Goff & Dudley 2021). To be able to reliably forecast these major seismic events and warn the surrounding countries would help tremendously.

Since there's no way to prevent an earthquake from happening we must rely on our intellect to defend us from destruction, or simply learn to live with it. In Greece, ruins have been found rebuilt on faults (cliffs created by earthquakes), suggesting that buildings or temples were purposely built in these earthquake-ridden landscapes despite the inevitable destruction from them. This isn't necessarily as counter productive as it may sound, the cracks created in the bedrock can become natural springs of clear healthy water, making these temples holy (Stewart & Piccardi 2017). We will probably never know the true reason but it's clear that people historically saw earthquakes as something natural and something they had to live with.

In this day and age we can not simply accept that countless lives should be lost to, what we believe, preventable causes. Although many cultures have had that thought throughout the years, it's only in the last 250 years or so that we've started to actually understand it. As John Michell proclaimed in 1757 that earthquakes originate from the earth's interior when massive rocks tumble around (Bevis & Michell 2012, 22), although not completely right, it's definitely a well put statement. Almost a hundred years later, in 1844, the first modern seismometer was created (Forbes 2013) and this new instrument detected the shaking of the ground. The bedrock isn't completely rigid, it stretches and compresses under massive pressure, creating transverse waves. The seismometer then detects these small movements, and prints them out on a piece of paper, or in modern times, saves the data using computers.

Seismic activity, earth's inner movements, is the reason for earthquakes. Under the outermost layer of the earth, tectonic plates move around, very slowly, about the speed of fingernails growing (NOAA 2023). When these plates eventually collide an earthquake occurs. While the understanding of seismic activity is not complete we do know where the tectonic plates are and where they meet.

Now we have a more advanced seismometer, measuring the waves in three dimensions: East-west, north-south and up-down, making triangulating the epicenter easier. This new version can also distinguish when two different waves reach the seismometer, the pressure wave and the shear wave. The p-wave, short for pressure wave, is the wave created from changes in pressure. These arrive first and are thus the first waves detected by the seismometer, suggesting that an earthquake is imminent. The p-waves travel around twice the speed of the s-wave, the wave that shocks the ground. S-wave or shear wave is the wave that stretches and compresses the earth, in short, the earthquake. The time between the waves is the window of opportunity to signal an alarm. This time is however very short, the 2004 Sumatra–Andaman earthquake had its epicenter about 160 km from the shore of Indonesia (Goff & Dudley 2021), giving about 20 seconds of time to sound the alarm. This is barely enough time to get out from a first story apartment, clearly not enough time.

Seismometers are still used today to measure seismic activities, however they are not used directly for forecasting earthquakes as they only record what's going on in real time, and when an earthquake appears we'll already know. This data can however be used to create models of earthquakes and this indirectly help to forecast seismic events in the future.

Today we have different Early Warning System's (EWS) all over the world, such as Shake Alert (Shake Alert 2023) that have sensors that can send information that an earthquake has occurred a couple of minutes before the shock hits. These work because the earthquake "moves" at the speed of sound through the earth while the signal from the sensors travel almost instantly (Shake Alert 2023). However, a few minutes' advantage is not enough to evacuate a city, nor enough to prepare for an incoming tsunami if the earthquake happens at sea. If we can increase this time to hours or days ahead of an earthquake we could potentially save thousands of lives.

There have since been many attempts to predict or forecast earthquakes, such as analyzing the ratio of speeds for the p-wave and s-wave or animal behavior, as it seemed animals would reach for higher ground before a tsunami would come (Mott 2005). Most common is however to look at the trends of earthquakes, how often they appear, where and how large they are. Analyzing patterns might give some sort of probability of an event happening. As an example, if records show that a magnitude 6 earthquake happens every 10 years in an area, if nothing has happened in 13 years it's quite probable that it will happen soon. Although the probabilistic approach is promising, the predictions can be too vague for them to work as a useful forecast (USGS 2024).

In the autumn of 2022 scientists from several international universities started the project ArtEmis (Awareness and resilience through European multi sensor system) with the objective of trying to find if there's a link between radon-concentration in the groundwater and earthquakes. The project is coordinated by professor Ayse Nyberg at KTH. (ArtEmis 2021). Although there are 15 major tectonic plates, the ArtEmis project will focus on where the African plate meets the Eurasian plate, around the Mediterranean sea.

Greece experiences on average $\tilde{3}$30 earthquakes a year with magnitude 4 or higher, making it the most earthquake dense country in Europe (EarthquakeList 2024). This is also why it was chosen to test this new theory within the artEmis project. By placing about 200 radon sensors in different groundwater-wells around the Mediterranean sea in Greece, Italy and France the project will collect the groundwater's radon-concentration of that area.

The main objective in the artEmis project is to investigate if the combined radon data acquired from the network of about 200 sensors could give precursor information for forecasting major seismic events such as earthquakes. These sensors will not only collect data on radon concentration in the groundwater but also temperature, time, CO2-levels and atmospheric pressure. The idea is to build a machine learning algorithm to review and analyse the data automatically. The artEmis data will be used in conjunction with existing seismic data to train the machine learning model on possible radon-seismic correlations (ArtEmis 2021).

This idea of using radon as a precursor is based on many previous observations, most notably on the observation made by G. Igarashi. et al. (1995) of the radon-concentration anomaly and the Kobe Earthquake in early 1995. In the paper G. Igarashi. et al, showed that the groundwater radon-concentration 30 km away from the epicenter had risen ten-fold in the year leading up to the earthquake to drastically fall 9 days before the disaster. The author pointed out that there is likely a correlation between groundwater radon-concentration and earthquakes but did not elaborate on the mechanics involved.

Other scientists have also noticed such correlations. Y. Yasuoka et al. (Yasuoka 2005) measured the radon-concentration of the air and groundwater in the aftershock region of the Kobe earthquake. This study showed that the radon-concentration deviated with over two standard-deviations from the mean just before the earthquake.

Most notably J. Planinić et al. (Planinić 2005) noted that all earthquakes with magnitude 3 or more in a radius of less than 200 km from the measuring site had a radon-concentration anomaly of at least two standard deviations. They also calculated the mean time after until the earthquake, after a radon deviation of 2 standard deviations, to be 37 with standard deviation of 3.3 days. However they only had 26 earthquakes to compare and study, to confidently proclaim that there's a correlation between radon-concentration and earthquakes more research is needed.

Showing that there is a correlation and understanding the nature of such correlation will take time, resources and knowledge and is something much larger than that of a master's thesis. What this thesis aims to do is to show that if there's a correlation between groundwater radon-concentration and earthquakes, we can use that information to reliably forecast them.

By creating a very simple simulation of an earthquake on a computer and simulating correlated data we can make use of a neural network (NN) to help us find the correlation. If an NN can find and extrapolate information from the data we created with any form of correlation it should be able to do that with real data too where the correlation is unknown.

A Neural Network (shortened NN) is a computer algorithm which "learns" by reinforced learning, similar to Skinner's theory about pedagogic, meaning it rewards good behaviour and punishes bad behaviour (2014). The algorithm is given a dataset and transforms this into so-called neurons, this is the input of the network. A neuron is a float type constant with typical values ranging from -1 to 1. These are then connected via weights and biases to new neurons, the so-called hidden layers, which one can imagine as the "brain" of the network.

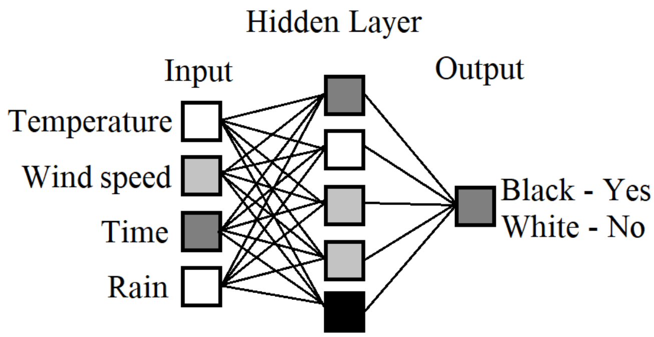


Figure 1: An illustration of a neural network of size (4,5,1).

The process is repeated until we reach the output neurons, which decide what the network would do.

For example: A neural network is designed for trying to figure out if a person needs a jacket when they go outside. It has 4 inputs, the temperature outside, the wind speed, if it's raining or not and what time of the day it is. These inputs are of different types and are therefore normalized to be float-type numbers between 0 and 1 instead. The normalized span does not alter the networks performance, since the biases and weights can change in accordance. The span is thus determined by the users preference. Temperature can be on a scale from -40 C and +40 C, where the value 0 represent -40 and so on. This can put limitations on the network, since when the temperature exceeds 40 degrees it will no longer work. This is only a matter of scaling and in some cases it could be necessary to avoid normalizing. The output is a single neuron saying yes or no, see Fig 1. It receives the weather information and feeds it through the algorithm, it then decides that perhaps it's 70% sure you need a jacket. However we, the user, are 100% sure we need a jacket so we tell the NN: "With this information you should be 100% sure!". The network will take this information you told it and learn, so the next time this type of weather it will be a bit more certain. After many many times telling it what to think it will finally do what we want.

Neural networks have almost been in practical existence longer than home computers, the chess bot Deep Blue from the 1980s vs the first affordable home PC from 1977 (Campbell 2002; Petkauskas 2023), and are widely used today in many different fields, such as facial recognition in your mobile phone, self-driving cars and of course chess.

7 Technical Method

7.1 Radon based prediction

While the ArtEmis project is running its toll over a span of several years their method of detecting earthquakes will still be used in this project. The fundamentals will stay the same.

Radon is a radioactive element with a relatively short halftime and also the only radioactive gas. It is probably most known for being measured in old houses when checking the quality of the air. Radon is created from the decay of larger radioactive nuclei and since radon too is radioactive it will eventually decay into other elements, such as polonium or bismuth. When an element decays it releases energy, in the form of either smaller particles such as photons, electrons, alpha particles, or a combination of them. This energy can quite easily be detected directly under the right conditions, without the need to send a sample to a lab to figure out as one would with some of the chemical elements. This makes radon perfect for quick determination of its concentration. However placing a sensor in a well and leaving it there is not ideal conditions. Therefore the artEmis project is developing special sensors able to withstand the elements and still retrieve high quality data.

To understand if there's a source for radon we first need to know where it comes from. This is done with decay-ladders. A heavier radioactive nuclei decays into smaller lighter nuclei over some time, if these are stable we reach the bottom of the ladder, if these also are radioactive they too will decay into lighter nuclei until the bottom is reached. Radon comes from three such ladders, uranium-235, uranium-238 and thorium-232. All these have their half-life, time needed for half of the mass to decay away, of at least 700 million years, compared to radon-222, the most stable of Radon's isotopes, 3.8 days. By measuring the amount of U-235, U-238, Th-232, in the ground we can calculate the point of equilibrium for Radon, the point in which the amount of radon decayed away will replenish from the other sources. By studying this we can derive how much radon there should be in the soil. When this is the only element in the decay chain which increases, we know that radon must have been transported to the detector.

Seismic activity leads to sudden collapses of tension, from which earthquakes originate. These collapses of tension cause massive amounts of pressure that could theoretically push radon up from the depth, through the soil and up in the groundwater. The exact nature of how radon is transported from underground seismic activity is unknown. In reality it will likely depend on the regional geology, and it might be an indirect process with underground stress transporting quickly towards the surface regions followed by a slower radon transport/diffusion in soil and water. In the current study, using simulated data, the radon transport is modelled in a simplified way by assuming a radon source at the epicenter, modelled as a function of time followed by a very simple transport equation. By strategically placing sensitive radon-detectors in areas close to seismic activity, such as around the Mediterranean sea, we can detect this increase of radon and prepare for an imminent earthquake.

7.2 AI and simulations

Since no large amounts of data exist for radon levels in groundwater while an earthquake happens, it needs to be simulated. In this study the simulated data will be used to train a neural network to forecast earthquake activity, such as its estimated time of arrival, it's magnitude and where its epicenter will be.

The process of making the simulation will start off as simple as possible, first creating a 3-dimensional grid 2000 km wide, 1000 km high and 30 km deep, about the size of the Mediterranean. Then placing sensors randomly spread across the grid instead of finding a way to optimize their location, selecting a single-point to act as the epicenter instead of a long ridge and creating the ground to be completely homogenic. The earthquake was then given three characteristics, its location, time until it rupture and its magnitude. Since it's unclear exactly how radon is transported from the depths making it hard to simulate, the decision was made to use the earthquake as an radon-emitter. Three functions for the amount of radon emitted from the earthquake were created, a step-function, an linear function and an exponential function. These functions work such that the amount of radon emitted is normal until the tension collapses in which the amount increases according to whatever function was tested. This has no basis in reality but is a mere experiment to simulate data.

The radon emitted has some travel time to reach the nearest sensor, traveling at a constant speed in a linear trajectory, the radon still decreases along its path. Both by decaying along the way and also by diffusion, the soil traps some of the radon along the way. When the radon reaches the sensor it will detect it and store the concentration-data of that day. 40 days after the tension collapses the simulated earthquake happens and the simulation is over. The data collected is a list for each sensor containing all their measured values, Table.1 shows an example of 3 sensors capturing data for 4 days.

[Bq/L]	Day 1	Day 2	Day 3	Day 4
Sensor 1	20.1	19.8	20.0	21.3
Sensor 2	20.2	21.3	23.3	25.1
Sensor 3	21.0	21.3	21.5	22.1

Table 1: Example of sensor values in Bq/L

This data is then fed to neural networks, to train and compare them. If this happens we know that the network is capable of learning to predict very, very basic scenarios. We can then change the simulation to appear more random, adding different types of radon transport functions as well as noise in the data to see if the network still manages to learn.

7.2.1 Creating the neural network

The neural network was created on the basis of a backpropagating function. In simpler terms one can say we're creating a function and testing it towards known questions and answers and then changing the function depending on how correct it answers. The key part of an artificial intelligence is that it changes itself without guidance from a human. This involves math ranging from advanced to very advanced depending on how the network is constructed and its means to learn.

Any network has an input and an output often represented as values between -1 and 1. The input is our data, the output is what the function believes to be the answer. Having 20 sensors collecting data each day for 40 days gives us 800 inputs, each stored in what's called a neuron or cell. All these neurons are connected to new neurons in a "middle" or "hidden" layer. A network of shape [4, 5, 1] can be seen in Fig 1.

In order to go from one layer of neurons, such as the input layer to the next layer and so on, threads must be made between them. These threads, often called weights, represent how strong the connection is between two neurons. The value of the next neuron is the sum of all previous neurons multiplied with their corresponding weights to that neuron. This can easily be written as the matrix multiplication:

$$\vec{y} = A\vec{x}$$

Where $\vec{y}$ represents the next layer, $\vec{x}$ the previous and A is the matrix containing all the weights.

To be able to have neurons that only matter when its value gets big enough, or that its value is always close to one, we add a bias to each neuron too. The formula is updated to:

$$\bar{y} = A\bar{x} + \bar{B}. \tag{1}$$

However since there's no way to control the growth of this equation, both B and A could become arbitrarily large. We need to implement scaling factors. The most common one is the sigmoid-function, a function that takes any value and scales it to fit between zero and one. For example, if the top neuron in the next layer gets the value 1.5 the sigmoid function squishes it down to 0.81. With this in hand we now have the equation:

$$\bar{y} = f[A\bar{x} + \bar{B}], \tag{2}$$

where the function f is the sigmoid-function. This step is repeated for each layer until $\bar{y}$ is the output in which an answer has been given to us.

Now for the back propagation where the network learns. The answer given to us is compared with what the real answer is to create an error-function, the indication of how well the network is doing. This function is crucial to be able to improve the network but is quite easy to understand. We want the answer of the network to be the same as the real answer so by taking the sum of the differences and normalizing them we get a value from zero to one of how well the network answered where one represent it being wrong in all aspects and zero

Figure 2: Mean and Median - error as a function of learning rate

being a perfect match between the given answer and the real answer. We want to minimize this equation. We have the equation:

$$E = |\overrightarrow{Real_{Answer}} - \overrightarrow{Given_{Answer}}|$$

The only way to minimize this equation is to change the given answer by tweaking each bias and weight of the network to better fit the desired answer. To do this we look at the derivative of E in each aspect of each weight and bias and then change them a portion of that value, the portion is called learning rate and is a nondeterministic variable that normally lies between 0.1 and 10. A small analysis were made to figure out the optimal learning rate, see fig 4 and fig 5. A network with 800 input neurons, 40 hidden neurons and 4 output neurons will have 44 biases and 32160 weights to change. This is then repeated for each data set and given that larger networks have exponentially more calculations, it requires a lot of computing power to train large networks. This in itself is a whole study in which multivariable calculus is recommended to grasp the basics. Due to this a deeper explanation of the math will not be given.

By running smaller networks with different learning rates and comparing their mean and median error of 1000 data sets an estimation of the optimal learning rate was found. It was clear that the learning rate affected the error of the network. Figure 5 shows that the optimal learning rate lies around 0.5 to 2.5, however the trend between 2 and 3 is increasing. The step size were 0.5 so an even narrower search were made between 0 to 2 with the step size of 0.05.

Figure 6 shows that most values between 0.3 and 2 work, the value 1.7 were chosen for the remainder of the study. It's entirely possible to have a

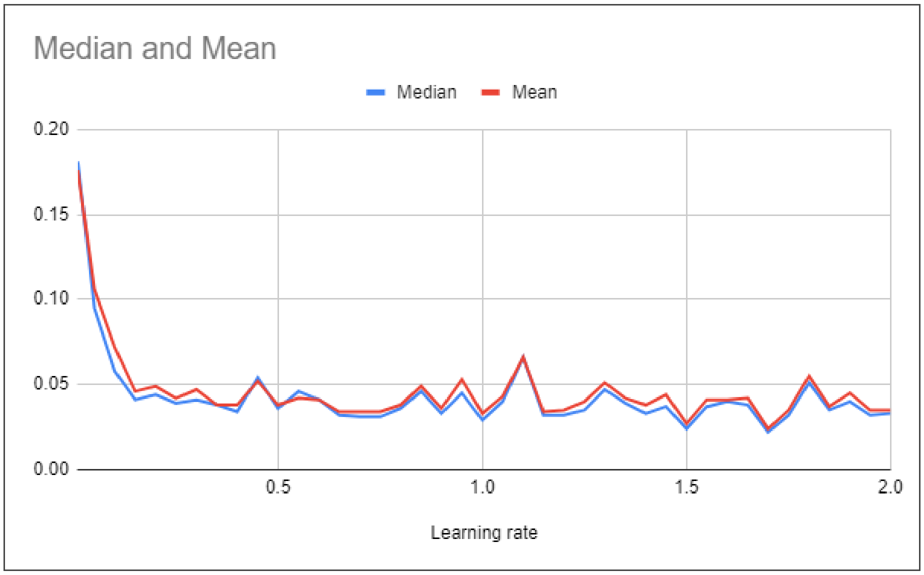


Figure 3: Mean and Median - error as a function of learning rate

dynamic learning rate, changing from data set to data set. To figure out the optimal dynamic learning rate is however outside scope of this study so instead a simplified version, where the learning rate was decreasing with 1% every 100 generation was used.

7.2.2 The parameters

In order for the simulation to at least resemble the real world, parameters and information of it needs to be taken into consideration. When constructing the simulation a grid roughly half the size of the Mediterranean sea was set to be the world. The map of 2000 km x 1000 km was chosen because of its simple values and possibility to compare to real world results. In this grid 200 sensors were placed at random, the choice of 200 comes from the artEmis project plan to place somewhere between 100 and 300 sensors in the Mediterranean coast, where 200 seems to be the final bid (ArtEmis 2021). Each sensor measured radon levels once a day and saved the value for 40 days. According to (J. Planinic, et.al) the time between the radon anomaly detected and the earthquake was 37 $\pm$ 3.3 days, thus a value of 40 days should be enough for the network to forecast what's about to happen.

The initial amount of radon emitted from the source was calculated backwards from the Kobe earthquake (Igarashi et.al 1995) where a magnitude 7 earthquake seemed to imply a radon increase of 20 Bq/L (Igarashi et.al 1995). The value of $5000 \cdot (10^{M-7})$ was chosen, where M is the magnitude of the simulated earthquake.

The only parameter left to choose is the speed of the radon away from the

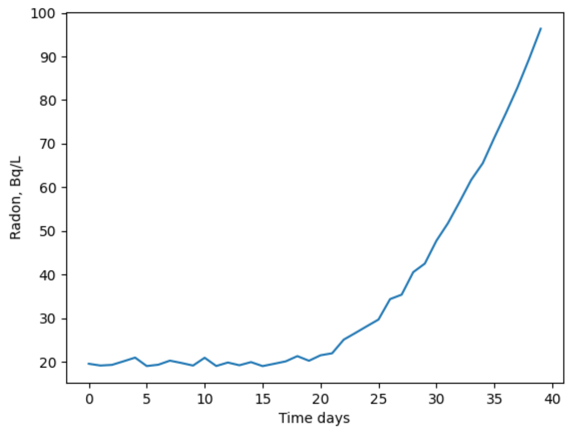


Figure 4: Example of radon levels for a sensor with the radon-earthquake correlation being exponential

source as well as the diffusion constant for the soil. The speed was chosen to be 1000 m/day, about 0.01 m/s, this is completely arbitrary. A higher speed gives the radon bigger reach since less radon will decay away, a lower gives clearer resolution. In the end the velocity was simply chosen by feeling.

7.2.3 The Simulation

The training data was generated from a python program using the radon transport method described above to deliver radon to a set of randomly distributed sensors. This means that the effectiveness of the AI is directly linked to how the simulation is created. If the data collected is of a certain type, say the distance to the epicenter, the AI can "learn" from that data instead of the values of radon collected by the sensors. In order to distance the simulation from the data collected a lot of randomness was introduced. This was made to make systematic errors disappear and to force the AI to learn how to sort out good data from the noise.

In order to make the best possible simulation several versions were made, each differ in some way.

Version 1

The first version of the simulation was made by guessing reasonable values of the parameters. The size of the map was chosen to be about the size of the Mediterranean sea outside of Greece, the time radon levels were increased before the earthquake was 200 days and the amount of radon emitted from the source to be a constant 10,000,000 Bq/l. The simulation randomly placed 200 sensors all over the map, these sensors collected one datapoint. The last value before the earthquake started.

This version showed promise in finding the placement of the epicenter, however the size of the earthquake and how many days until it's about to happen did not show any results whatsoever. Due to the fault in size and time the method needed adjustments.

Version 2

By decreasing the amount of radon at the source and adjusting the speed of the radon from the source fewer sensors measured anomalies. This resulted in a bit more precision for the AI's suggested location. To improve the time and magnitude the sensors were made to save the last 40 data points. If the network can see the discrepancy of what time each sensor detects the radon anomaly it might be better at predicting how long until the earthquake happens.

To better visualize the simulation, a map was created see figure 7. This includes a map over a fictional world. On the map 200 sensors are represented as small dots, which vary from black to white depending on the radon level for that sensor, white representing high levels and black low. There's also a red cross representing where the earthquake is about to happen. The output of the AI is represented under the map and also as a red circle with a black dot in the middle. While all points are stationary the AI's red circle might change its position to hopefully forecast where the earthquake will appear.

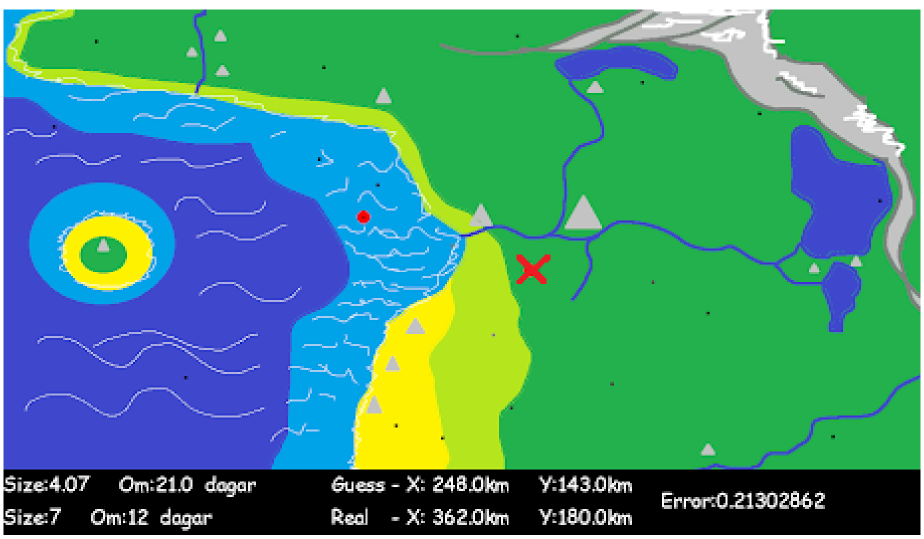


Figure 5: Screenshot over the program window, here with 20 sensors

However with 200 sensors each saving 40 points of data, the AI needs to read 8000 values each simulated day and calculate over 400,000 derivatives to train from. This is not a problem, in fact it's probably for the better of the AI, however it takes a very, very long time to train an AI with so much information. About one earthquake-simulation every ten seconds only leads to about 400 per hour, which may be much less than needed to fully train a network. Solving the optimization problem was difficult since it's also a matter of hardware and

not only code. The code had some obvious flaws and some optimization led it to process about 500 generations per hour. Another optimization was needed.
Version 3

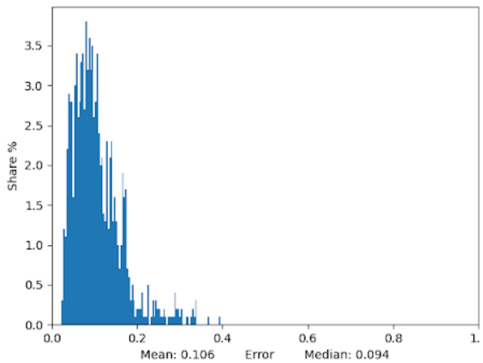
The best way of improving the learning-rate of the network was to make the network smaller. This made training faster with the same computational power. However, making it smaller might “rob” us of important data. If no sensors are close enough to the earthquake no data is processed and the network can’t figure out what’s happening. To solve this additional problem, we shrink the entire map.

By creating a new variable “scale” we can change the size of the map and amount of sensors in the area with one value. With the scalar 10 for example the amount of sensors are divided by 10, the width and height of the map is divided by root(10), in order to maintain the correct sensor-density. With scalar 10 we get 20 sensors resulting in just over 30000 calculations, less than 10% of the original calculations.

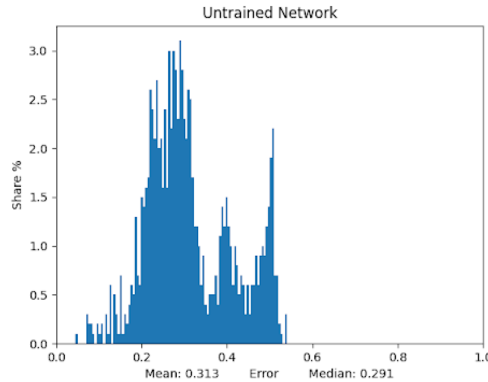
7.2.4 Comparison

In order to be able to compare different shapes of networks a standardized method was created. It consisted of each network having 4000 generations of training and then testing itself towards 1000 more. This means that the network has learned from 160000 points of data and is then tested towards 40000. No comparison is made from the learning data, so only the last 1000 generations are compared in the aspects of difference in distance, time and magnitude from the real values of the earthquake.

For example here is the distance error distribution for a trained network (fig 6.a) and untrained network (fig 6.b). We can clearly see that the trained network have shifted towards a lower error compared to the untrained one. The trained network reaches a lower low-point as well as a lower high-point, with an error that’s centered around 0.1 while the untrained network doesn’t seem to have a center at all with several peaks and wide spread. More of this comparison will be made in the result section.



(a) Trained network



(b) Untrained network

Figure 6: Comparison between a trained network and a network without any training

8 Technical result

8.1 Error

A network's greatness is measured by its normalized error, where a low error-score suggests a greater network. Since the network has three different factors to predict, three different errors can be obtained. Also there is the combined error where the errors from all the factors are squared, combined and normalized again. The error in short is the absolute value of the difference between the desired output and the network's output which then is normalized to a value between zero and one, where one is terrible and zero is perfect.

Radial, or distance, error is the normalized distance from the network's estimated epicenter and the actual one. Given that the program works in a confined space, an error of one would suggest as far away from the actual epicenter as possible. The function for error is given by:

$$error_{distance} = \frac{|r_E - r_N|}{R}$$

Where r_E is the epicenter position, r_N is the predicted position and R is the maximum distance away from the point the network could have guessed, set to 23 km. For example, if the epicenter occurs at a position and the networks predicted position is 5 km away the error becomes become 0.271 or 21.7%.

Magnitude error is the difference between the actual magnitude and the estimated magnitude. It's important to note that although magnitude is logarithmic, meaning a magnitude 8 earthquake is ten times stronger than a magnitude 7 earthquake, the error has still been seen as linear.

$$error_{magnitude} = \frac{|M_E - M_N|}{M}$$

Where M_E is the magnitude of the earthquake, M_N is the predicted magnitude and M is the maximum magnitude, given to be 10. A predicted earthquake of 5 from the actual magnitude 7 gives the network an error of 0.2.

Time error is the normalized linear difference between the predicted amount of days left and the actual amount of days left to the earthquake, counted from the first day radon levels is increased.

$$error_{time} = \frac{|t_E - t_N|}{T}$$

Where t_E is the time left until earthquake, t_N is the predicted time left and T is the total time, 40 days. A predicted time left of 15 days from the actual time 13 gives the network an error of 0.05. An error of zero means that it precisely predicts how many days until the earthquake hits. An error of one means that on the day of the earthquake the network suggests that it will happen in 40 days.

The combined error is given by the vector length of all three errors.

$$error = \frac{\sqrt{error_{magnitude}^2 + error_{time}^2 + error_{distance}^2}}{\sqrt{3}}$$

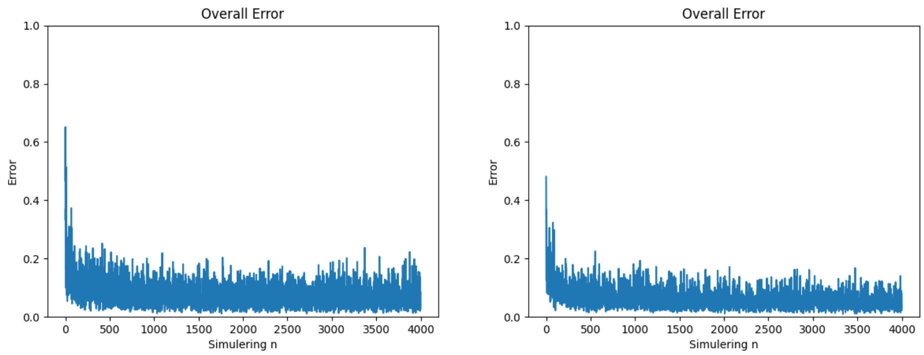
8.2 Comparison

To begin, smaller networks were tested to find mistakes and possibly find improvements before putting a large network to the test. First out was a network of size 160-40-4, meaning a small and fast network with only one hidden layer, 4 sensors all collecting 40 data points and the four outputs. Figure 7.a Shows how well it learned overall. We see a very sharp decline in the beginning but after just a few generations improvements stop, leaving a trail of noise and no clear decline. This suggest that the network is too small to learn all the necessary data.

A larger network were then tested, now with 10 sensors used and another layer added. The network became of size 400-40-20-4. From figure 7.b we see that this network performed with similar accuracy as the smaller network however with more data and thus more information to analyze. The network had similar problems with divergence. Even after 4000 simulations the network still wasn't accurate and performed about as well as it did after 500 simulations. A probable reason for this divergence is a learning rate set to high . A larger network were then first tested with a constant learning rate as previously, and then with an ever decreasing learning rate.

A network of size 400-70-40-20-4 with a constant learning rate of 1.7 had the learning curve seen in Figure 8.a.

The network learns quickly in the beginning but does not seem to converge as the number of simulations exceeds 1000. This could be because the networks' learning rate is too high for the relatively small network.Therefore, the learning rate was lowered it by 1% every 100 simulations with the goal of keeping the

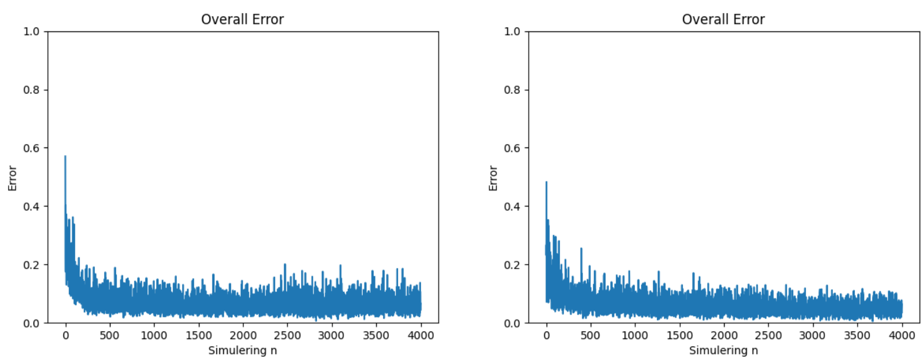


(a) Learning curve of network 160-40-4 (b) Learning curve of network 400-40-20-4

Figure 7: Learning curves of two different networks

fast learning in the beginning but by time smoothing out the divergent tail of the error. The new error graph can be seen in figure 8.b.

The tail of the learning curve is much less noisy. With these findings in mind the largest network of the study were trained. The network, of size 800-70-40-20-4 started with a learning rate of 1.7 with a decrease of 1% for each 100 simulations.



(a) Learning Curve of network 400-70-40-20-4 without dynamic learning rate (b) Learning Curve of network 400-70-40-20-4 with dynamic learning rate

Figure 8: Learning curve difference between fixing the learning rate and have it be dynamic

Figure 9 shows that the large networks learning curve follows the same structure as the previous ones (e.i., sharp decline in the beginning which flattens out after a while). However I'd argue that the network improves throughout the entire learning trial. A brief overlook comparison between the smallest network (Figure 7.a) and the large network (Figure 9) tells that the larger network per-

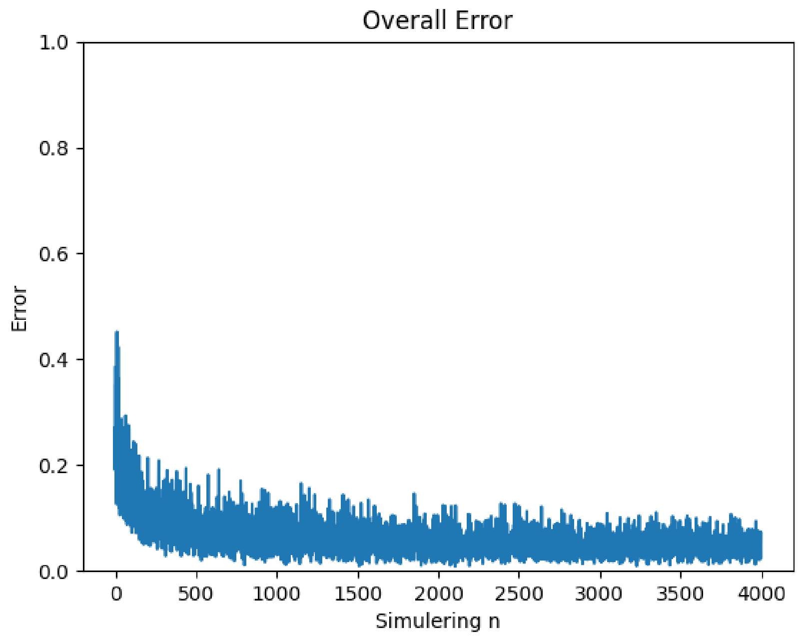


Figure 9: Learning Curve of network 800-70-40-20-4 with dynamic learning rate

form much better. Since the overall error is comprised by three different errors it could be of interest to look at them separately.

In figure 10 we see the learning curves for the network's distance, magnitude and time forecast, taken as an average of the neighboring 5 values to minimize noise. Also note that the y-scale has been decreased to visually separate the lines and make the graph easier to read. The independent graphs for each of them can be found in Appendix 2.

From simulation 1500 and forwards the different errors become apparent. The error in time is less than that of distance but larger than that of the magnitude, suggesting that the network is better adapted for forecasting the magnitude and/or the time of impact than it is for pinpointing the epicenter.

To evaluate the network's capacity, we need to look at the error's histogram over the 1000 simulations the network tested itself without guidance/learning. Figure 11 show us a histogram of the overall error for each of the 1000 simulations, showing a mean of 0.047 and a median of 0.045.

To put this in perspective we need to compare it towards the parameters given. Given an error or 4.5% of an 40 day simulation be about one to two days off, either early or late. The magnitude could differ by up to 0.4 in the case of an incoming M9 earthquake and about 0.3 in the case of a smaller magnitude 6

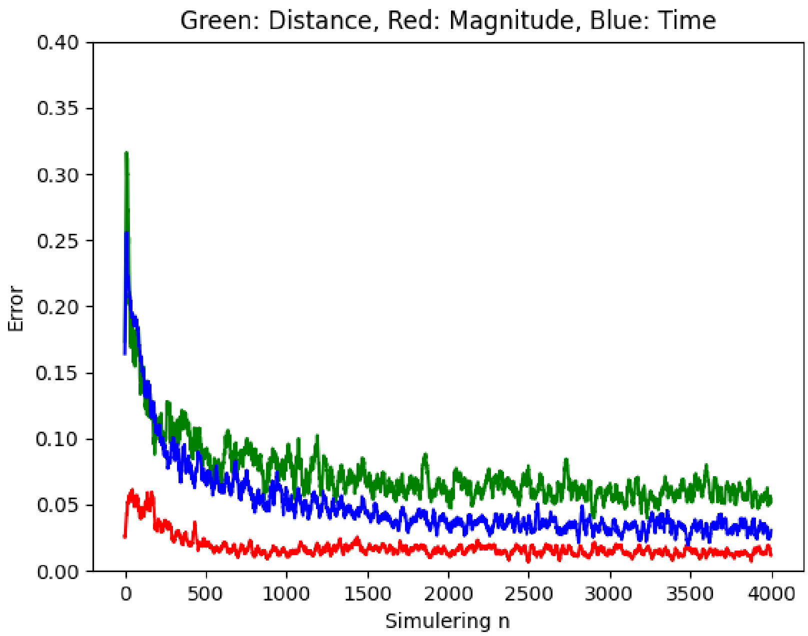


Figure 10: All Learning Curves of network 800-70-40-20-4

earthquake. The fault in distance could be in the 10 km range.

This is however the mean error of the entire network, as seen in figure 10 some errors are more prominent than others. The error in distance is larger than that of the magnitude. However the difference is at most twice as large. Suggesting that the fault in distance should not exceed 20 km.

There is however many assumptions to take into consideration here. These results were given on the premise that there is a strong correlation between earthquakes and groundwater radon concentration as well as an extremely simplified model of how this correlation behaves.

The AI showed promise in determining the characteristics of the earthquakes, with minimal error. However, this was after many iterations of creating a simulation which the network could learn from.

The results show that the AI generally improves over each simulation, indicated by the fact that the error decreases. However, the error does not converge to a specific number. Rather it squeezes the divergent graph to fit between two numbers. The maximum error decreases, leaving the graph to appear convergent.

By comparing the network's performance before and after giving it simulated data we can clearly see in figure 12 that the network improves. Notice the change in mean and median error for the entire network across 1000 simulations.

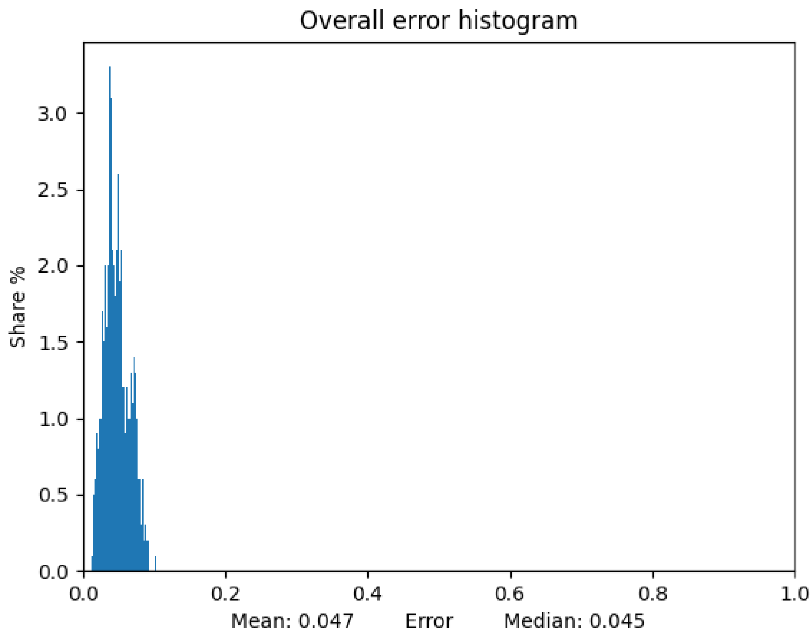
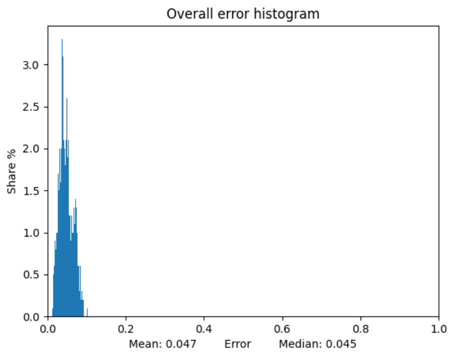


Figure 11: Histogram of the overall error on the day of the earthquake

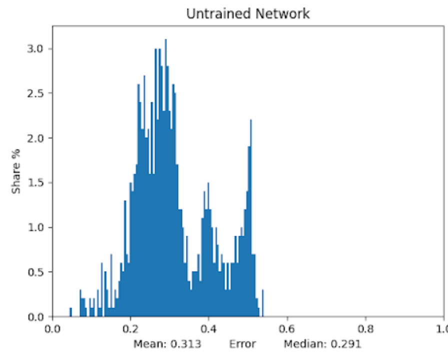
From figure 10 one can see that the distance error begins with a clear downwards trend, reaching convergence around 2500 generations in. This is interesting since time error converge later, around 3000 generations in, with a lower average error. Why this happens will be discussed further in chapter 9. Also note how the magnitude error converge after only 500 generations.

Based on the values used in the simulation, this network would always forecast the epicenter within a 20 km radius of the true epicenter, and, in many cases, within 10 km. It is however important to point out that these values are somewhat arbitrary. Since the accuracy of the simulation can not be confirmed we must take these results with a grain of salt. What we've shown here is rather that a network can, to some degree, forecast where an epicenter will appear based solely on simulated data. This suggest that real data might also be applicable to be interpreted by a network to forecast a real earthquake.

To have a perfect network on the day of the earthquake does not mean much, it will be too late to evacuate. To see if the network could forecast with some time in advance three networks were tested on 1000 simulations and evaluated both 10 days before the earthquake and on the day of the earthquake. See table 2 containing the mean and median for 3 networks of same size trained on three different types of radon transport functions, showing both 10 and 1 days before the earthquake. We see that the network still performs well even 10 days ahead,



(a) Overall error for the final, trained network



(b) Overall error for an untrained network

Figure 12: Comparison between a trained and untrained network

Function	1 day Mean	1 day Median	10 day Mean	10 day Median
Step	0.042	0.037	0.037	0.036
Linear	0.047	0.045	0.031	0.028
Exponential	0.059	0.057	0.045	0.044

Table 2: Table over mean and median error values for different times and different radon transport functions

no matter the radon transport function.

And for the large network seen in Fig. 13. the histogram 10 days ahead of the earthquake is very similar to that on the day of the earthquake. Showing a mean and median error of 0.049, we can deduce that the network performs just as well 10 days ahead, further strengthening our claim of using AI as an precursor for seismic activity.

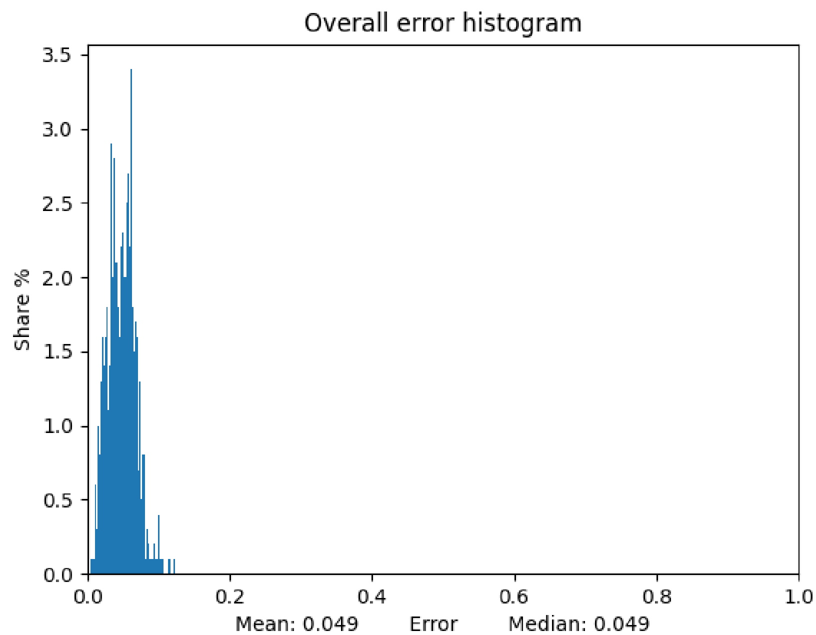


Figure 13: Histogram of the overall error 10 days ahead of the earthquake

9 Technical discussion

Leading up to testing the network, smaller networks were tested to make sure everything was working. In the end 20 sensors were chosen as the maximum, although just 10% of the amount planned in the real life application. There's two ways about this. If the program with 20 sensors can find a pattern so can the network with 200 sensors. While the smaller network wouldn't provide any clear pattern this does not necessarily apply for the larger network. Starting small, and progressively testing larger networks is a promising way to find what work and what doesn't, as well as saving a lot of time.

One key component of the network, the learning rate, was based on the performance of smaller networks with different learning rates. While the optimal value was estimated around 1.3 for the smaller networks it's hard to tell if this also applies to the larger, main network. It's entirely possible to further optimize the network by tweaking this constant. This is, however, in itself a whole new study.

While this result may seem quite far from the expected values we must remind ourselves that the numbers in radius, time and magnitude are arbitrary, and it's the point that the network was able to improve its guesses by expanding the network and feeding it simulated data. The question isn't how well it works, it is if it's possible to train a network on the simulated data, and this we can with certainty conclude.

The error obtained from the magnitude has a very sharp decline in the beginning and then almost lies flat throughout the simulation. This is expected since the magnitude was set to a specific range of numbers, 6 to 9, and convergence happens very fast towards constants in neural networks.

One could argue that this is the reason for time error being smaller than the distance error. The network has 40 different times to learn, since the simulation only runs for 40 days and we have one data point each day. However the epicenter of the earthquake had over 2 million different possible placements in the simulations.

It's important to keep in mind that although there are many more possibilities for placement, most of them can be seen as one. Having the epicenter 20000 m (away) from the sensor will roughly give the same levels of radon as an epicenter 20010 m away. This leaves the amount of different earthquakes locations to much lower than 2 million.

If there are two or more places in the simulation where not enough data is created to distinguish different scenarios from each other, the network will receive conflicting answers. By many generations, the AI's default outcome will then just be the best case scenario on average, predicting a location that's somewhere closest to all these null-data points. This is why we don't see an error greater than 0.5. To never exceed that number the AI just needs to be stationary in the middle, not guessing towards the edges.

One way to counter this would be to use more sensors, thus creating more data spread around the map. This was not tested due to the immense computing power needed for it.

Due to lack of computing power and time a proper network-analysis was not conducted. The effect this had on the final outcome is however minimal and the result could be achieved without it. However, for a network to properly achieve its full potential several networks need to be run at the same time, and with a selection of those, use the best as the final version. This is due to the initial randomization. If luck would have it, the network could perform really well almost instantly, but it's just as likely to be very far away from the desired shape. Some networks can also end up in a local minimum point, this means that the network can't improve from there. This is why using many networks at the same time is a good idea, it minimizes the odds for that. This study did not train multiple networks at the same time due to the increasing computational power needed, however with further optimization such as multi threaded code, this would be possible and could give an even better network with greater accuracy.

9.1 Future technical research

In the next few years, the artEmis project will continue with both detector development, radon measurements in ground water, data analysis, and an ambitious analysis of different AI methods for the forecasting of earthquakes. With a vast amount of real measured radon/seismic data, it is likely that large-scale computer networks will have to be used for the forecasting models.

By expanding the idea of how radon travels through bedrock one could improve the accuracy of the simulation. This could be in the form of creating different areas on the map that contain different types of bedrock and sediments, changing the speed and diffusion of radon in those areas.

With great networks comes great responsibility, it's very interesting to see how far a network could be pushed to accurately forecast the earthquakes many factors. Future research should look into how to optimize networks used in this type of study.

If it turns out to be a correlation between radon and seismic activity it would be interesting to see if this is the only correlation. Perhaps radon isn't the only correlated gas, and perhaps some other gas has a stronger correlation. While radon is relatively easy to detect because of its radiation, making wide spread data collection quite simple, it could be interesting to research other common gases. This is an interesting idea that's not studied in the artEmis project.

This study has made many assumptions in its model for seismic activity. Building on this it could be of value to know if it's even possible to simulate an earthquake with classical physics. If the characteristics of an earthquake are such that quantum physics is needed, modeling an earthquake could prove impossible, at least as a tool for simulating the effects.

Another stone left un-turned is how the geological rock formation affects the correlation. Perhaps sandstone, limestone and other common rocks in Greece are great for radon transport while rocks found Australia are not so great for the detection of radon correlated with seismic activity. If a long term goal is to develop an EWS for earthquakes this would obviously be of great importance. This is currently being studied in the artEmis project.

This method of forecasting earthquakes is based on the correlation between radon and seismic activity. Could this seismic activity indicate volcanic activity? Although there's only about 80 eruptions a year from volcanoes, some of which happens continuously, it's still an important question. Just because they're rare doesn't mean we should ignore them.

10 Pedagogical Introduction

In recent times science centers have gained popularity in Nordic countries (Sjöberg 2011) indicating that science and especially natural science is of great interest to the public youth. Does science centers help students develop their scientific literacy, and as an extension their idea of what science is?

Noted by Illeris (2007) an important factor for students' learning is motivation. This motivation can come both from social factors and other exterior motives, but notably intrinsic motivation are more strongly associated with a higher quality of learning (Deci & Ryan, 1994). This could suggest that students already interested in the specific subjects taught at science centers will learn more from them.

Since the Swedish school system aim to invoke curiosity and invoke a life full of learning (Skolverket 2011) and since science centers are often used to do just that, it's no surprise that there's already over 300 science centers around Sweden targeted towards different age groups (Svenska Science Centers). They aim to invoke curiosity, interest and a desire for deeper understanding of science and of course strives for a positive experience. Taking my students to a science center could therefore serve many uses, both for work and for this thesis.

DeWitt & Hohenstein (2010) noted that students in science centers talked to their classmates with more cooperative intentions and used more cognitive engagement than in the classroom. This shows that it's not only the labs that make students learn more but also the social aspect of the visit which well ties in with Vygotskijs (2010) idea of working together in the zone of proximal development (ZPD) where students are met with problems they're able to solve but not unaided, needing to cooperate with someone in the same ZPD.

According to Louise Archer et.al (2010) younger students, age 11 and below, have a high interest and positive attitude towards science which then drastically falls around the age of 14. While no reason for this is given it's clear that the perception or concept of science must have been changed into something negative. The reasons for this could be many. Additionally Lindahl (2007) points out that most interests and career paths are formed around that age, which they still follow years later. She also points out that getting students interested in science when they're not becomes increasingly harder with time, so for science to remain interesting it must give the students positive experiences throughout their prepubescent years (Lindahl 2007). Creating these positive experiences could result in a positive conceptualization of science, altering the way teens perceive science.

While science centers aims to create a positive experience for students it's not the only attributing factor for the students' conception about science. One factor could be experiencing the stigma that only intelligent people can do science (Kihwele 2014) and those who aren't shouldn't even try.

Many researchers have worked on students' conceptions of science before. The Draw-A-Scientist test (Chambers 1983) showed quite clearly the stereotype of scientist being a older man bound to his laboratory wearing a white coat and doing something dangerous. Chambers (1983) also points out that these stereotypes have not always been the same. Before the 1900s the different types of scientists portrayed in comedic ways were greater. These stereotypes are common to this day, TV-series such as Stargate SG-1 (1999), Rick and Morty (2013) and movies like Interstellar (2014) all depict scientists as highly intelligent with the ability to solve the most difficult problems in no time, often in lab coats doing something practical instead of reading and documenting progress. Matthew C. Nisbet et al (2002) showed that science presented in a negative light on television created doubt surrounding science as a whole, leaving room for conspiracies. This was something Jaron Harambam and Stef Aupers also noted in movies where a conspiracy-theorist is the protagonist (Harambam Aupers 2015). These experiences are very common, leaving little room for students to find alternative perceptions about science.

According to Ersen & Muhlis (2015) 6'th grade students who regularly visit science centers improve their scientific process skills. This suggests that SC can alter the way students work with science and further how they think and perceive science. It's a stretch to then claim that even a single visit would alter the way students perceive science. However, it leaves the possibility especially considering the scientific method.

The natural sciences programs in Sweden include other subjects than physics which also contributes to their perception. Subjects like religion, literature and social sciences all brings up some form of science and it's implications. Religion brings up the impossibility to prove or disprove god's existence, literature and social sciences brings up how the world is perceived through the lens of different scholars. Most, if not all, science centers are focused around the world of natural sciences meaning they don't intend to challenge students thoughts in other subjects.

It's generally very difficult to explain ones thoughts precisely, to understand what someone is thinking is even harder. This causes problems when studying what students learn from experiences, but there are several ways to work around this problem. Thematic analysis (Braun Clarke 2006), for example, study the themes surrounding a certain topic by asking different question about it. This is followed by analysing the answers and picking out the most common subjects which appeared in the interview and then matching them with either existing themes or creating new one to fit. An continuation of this is phenomenographic analysis (Marton 1981), which analyses which phenomena appear in the discussions. These phenomena can then be categorized and compared.

We're left with the following research question:

- How can a visit to a science center influence students' perception of science?

11 Pedagogical method

To be able to answer if and how students' perception and conceptualization of science change after a visit to a science center, the study was divided into four parts.

- Preparations
- Science center visit
- Follow up
- Phenomenographic analysis

Preparation work is the work done before the visit, the *science center* is the visit to the science center and *follow up work* is the work done after. This all ends with the *thematic analysis* used to compare the interviews before and after.

While quantifying perception is a tremendously difficult thing, understanding the answers students give in contradiction to what they understand is a study of its own. One can perceive to have an understanding about something without the ability to explain it to others. Therefore it was decided to only look at the themes of their perception and, even narrower, examine how the themes changed after a visit to a science center.

To examine what part of students' perception changed, this study was conducted as the following. 27 students aged 17 to 18 years old in Stockholm, Sweden, were interviewed in groups of 3-4 students and asked five questions about science and the scientific method. These were questions such as "What is the scientific method?" and "What is bad science?". The full list can be seen in Appendix 1. They were then brought to a science center where they would conduct two experiments. A Corresponding interview was conducted after the visit with the same questions and the same groups of students.

It's important to note here that the students interviewed were taught by myself in the course *Physics 1a*. Studying my own students made the selection process very fast and were useful for finding a time at the science center as I could attend and assist as a teacher. To avoid conflicts of interest between their grade in the course and the answers in the interviews, all parts of the study were made voluntary. One student abstained from the entire study and one abstained from interviews. The remaining students were well informed that the answers given in the interview would not affect their final grade of the course and that they could drop out at any time.

The tool used for analyzing the students' answers is called phenomenographic analysis, this method is based on finding phenomena in the answers given instead of comparing them word for word, making any two answers where each sentence is completely different seem more aligned with each other (Marton 1981). They could of course be less aligned if the conceptions brought forth in the sentence differ. Note here that a phenomena is seen almost the same as a conception, not as in the phenomenon of UFOs. Every question was analyzed for each group providing a sort of mind map of the topics, not concepts, of the interview. This way, an overview of potential concepts can be seen before deciding them, making the process of combining the concepts easier. The mind maps of all the groups' answers were then combined to make five mind maps of the topics for each question before and after, ten in total. These topics were then reduced down to the concepts these topics were related to. The result of this study is thus the difference in conceptualization before and after the visit to the Science Center.

11.1 Preparations

In order to detect change, data needs to be collected before the field trip and then again after. To do this, several interviews were conducted with the 27 students. These interviews were done in groups of 4 (one with 3), with a time limit of 20 minutes. During this time five main questions were asked, along with occasional follow up questions. The questions can be found in Appendix 1. The interviews were done during the student's physics class such that students not interviewed had class as usual.

The questions aimed to create a small discussion between the students and thus let all the students formulate their own answer and compare it to their fellow classmates'. The interviews were recorded with the permission from the students and then transcribed to make analyzing easier. All the students' information were kept confidential (Björndal 2009).

In order to maintain a civilized discussion during the interview, meaning to keep the students on topic and not get dragged away on tangents, a medium level of structure was used. According to Björndal (2009) any interview can be placed on a scale of structure, where high structure implies standardized questions and rigid alternatives to answer, while low structure suggests open communication, much like a normal discussion. Somewhere in between these definitions we have open standardized questions with open answers as well as someone to guide the interviewees from question to question and to ask follow up questions.

The pros of having a guide in the interview are several. Most importantly it gives the flexibility to change the questions as the interview progresses (Björndal 2009). Due to the nature of conducting group interviews the probability of the students swaying the question into another was very high, and something to accept. Stopping the discussion just to later ask the same question they were already answering may make the students think that they answered the question wrong and might look at the interviewer for confirmation of what to answer (Björndal 2009). By, instead, savoring their free thoughts and observing the way they try to explain it to the others in the group one might find the connections they are trying to make. By adding follow-up questions almost any question can get a comprehensive answer.

The reason for the interviews to be in groups was partly to keep a manageable amount of data while still having the data to be of quality. Had it instead been 27 one on one interviews the transcription process and analysis would have taken far too long. The other part is that students learn from their social environment in mainly two ways, "more knowledgeable others" MKO, and “zone of proximal development” ZPD. These are two concepts developed by Lev Vygotskij (2010) where MKO usually depicts a student learning from a parent or teacher and ZPD means that there is a region of obtainable knowledge from either problems or others, such that the problems aren’t far to difficult for the student to solve while not being something the student already knows. This also applies to conversations. Trying to reason and learn with someone with about the same amount of knowledge can increase the knowledge for both parties, but when the knowledge differs greatly no new knowledge is obtained by either parties. Einstein probably wouldn’t learn much from a toddler in regards to physics, as he probably would with Schrodinger. The aspiration was to let the students learn from each other how to describe their thoughts and together form a coherent picture.

While the discussion is open and the answers too, it’s important to remain true to the original question. Since several questions were held, compared, reheld again after the field trip and then compared again, it was important to have the same questions to be able to compare them. To maintain this the interview is somewhat standardized. This has the advantage of giving quite exact answers to the question, which is good since it’s easier to compare. However, some details about the subject might not be answered by the interviewee since it’s not in the question, leaving room for the students to have knowledge but not be able to show it (Björndal 2009).

The questions were then created in such manor that made it easy for students to answer descriptively of what they know, giving room for concepts and perceptions. While it’s important to ask the questions for which you seek an answer you must also remember to ask them in a non-confronting manner (Björndal 2009). This might seem obvious but some questions seem to have a right answer from the get go and any answer beside this right answer is taboo. An example of this could be the question: “Is science important?”. “Of course it is!” One might say, but for others that perhaps don’t like the trajectory of the technological advancements might disagree. To avoid confrontation or shame of not knowing or agreeing they will just simply answer the desired answer (Björndal 2009). Questions of that nature have therefore been avoided.

During the same time the interviews were created and taking place, the labs were also being created. Ventenskapens Hus kindly offered two pre-made labs to use in this study. One was used as normal with the intention to let the students have fun doing science. The other lab was modified to better fit the topic in their physics course and to match the goals of the study. This goal was of course changed too and it’s purpose became to accurately depict how real life science can be done. The two labs became the Temperature-lab and the Radon-lab and the purpose of the visit in aspect to the study is the Radon-lab. For the physics course both labs were relevant.

The Radon-lab had elements of advanced physics, real life implications, stereotype breaking ideas and of course learning. All of these had a purpose to expose student to what natural science and the scientific method actually looks like.

To avoid a situation where the students come to the laboratory and don’t have a clue what they're supposed to do, two preparation-lessons were held in the week prior to the visit. The lessons' focus was to give students the basic understanding needed to understand and/or to enjoy the lab and help them achieve the goal of the lab (Rennie & McClafferty 1995). The basics in radioactivity, decay, energy and spectroscopy was taught.

11.2 Science center visit

When all the interviews were conducted and the preparation lesson had been held the students were brought to the science center, Vetenskapens Hus, on the fourth of April 2023. There were no clear hypothesis of how students' perception would be changed by the visit. However, with many new experiences, dressing in lab coats, working with radioactive material, working with very precise and expensive equipment, some change was expected.

The visit was divided into three parts.

- Laboratory about radon (90 minutes)
- Break (15 minutes)
- Laboratory about temperature (90 minutes)

The labs were chosen for two reasons. The radon-lab was created to give the student an insight of how research on radioactive material could be conducted, similar to the practical work on the artEmis project, which the students had heard about. The temperature lab was chosen for it's simplicity while also being a standard lab at the science center, meaning it has been thought out and tested to make it as good as possible. The reasoning behind having just two labs was because students needed to be divided into at least two groups.

The students were divided into two groups á 14-15 students each and went through the schedule from different directions. Group 1 started with the radon-lab while group 2 started with the temperature-laboration, and had the break at the same time. The science center's laborations is held by staff working there, while me and my accompanying teacher were only there to keep the class in check. There were two staff teachers, one for each lab, for simplicity's sake we shall call them Alice and Bob. Alice held the temperature and pressure lab while Bob took care of the radon lab.

11.2.1 The radon-lab

The group was divided into sets of two, where the set with 15 students had one group of three. They were then seated around four tables, two groups per table, with a computer in front of them.

Bob began with a presentation of nuclear decay and basic particle physics, the reason why some nuclei are unstable as well as what their half-life is. After Bob had explained the fundamentals of radioactivity he presented the object in the middle of the classroom, a gamma detector.

After this Bob took out a radioactive substance, of which he did not disclose to the students. The detector picked up a lot of gamma radiation with a specific energy, this substance was Cesium 137 a substance which decays into a stable element, so no further reactions happen. However when the detector was supplied with Uranium 238 a lot of spikes appeared. This is because of uranium's decay chain, not only is the uranium sending out gamma rays but also the elements which it decays to, some of which send out more than one type of gamma ray, thus several different levels of energy.

This presentation had the aim to give students insights of how radioactive materials appears different and therefore can be detected quite easily.

Now it was time for the students to open their computers and do some work! Bob had provided them with two different decay chains and the students' mission was to figure out what element was under the detector by just looking at the graph of energies and trying to match them with known energies emitted from substances. For example the students could look at the graph and choose from a list in the graphing program to point out where different element's gamma energies should have spiked. If the element and the graph shared a spike in the same place, odds are in your favor of that substance being in the chain. The different chains were from Thorium 234 and Uranium 238.

The reason for this part of the lab was to show how science was and in many ways still is being done, which is to gather information and trying to solve a problem based on the theories read beforehand. By experiencing science done in such a real way, the intention was to leave a mark on the students and therefore change the way they perceive science.

To make the lab relevant for their every day life Bob placed a radon-can, a can used to measure the radon level at a location, under the detector and measured the amount of radon in it. These cans had been shown to the students during the preparation lesson and placed in three locations, the school, the cellar of the science center as well as my own cellar. The results were not very interesting showing that the schools radon levels were well below the threshold of danger (4 +- 4, vs 250 Bq/m3).

11.2.2 Break

During the break coffee, soft drinks and fika were offered to students and accompanying teachers. This was held in the hallway where benches and tables are located.

11.2.3 The temperature-lab

Alice had the other group and the theme there was about temperature and pressure. The students were placed in groups of 4 and seated around 4 tables. Then Alice had a brief lecture of what temperature is and how black body radiation ties in with that. This was to provide the students with some basic understanding of how a thermal camera works, as well as other closely related concepts. After a demonstration of how a window blocks infrared light but not a plastic bag the students got different questions where they could play around with thermal cameras to find the answer.

11.2.4 Exit

After the visit to the Science Center the students could also visit the science center and research institution AlbaNova where the artEmis project were being worked upon. This was however not mandatory and therefore up to the students to decide for themselves, none of the students went there.

11.3 Follow up

Following, additional interviews were held in the same way as before. The time between the first and last interview were about a month. The questions were the same and the students were still asked to discuss with each other what they thought to be the answer. To avoid "cliffhangers" a lesson was also made to explain the lab for all those who did not understand it, and to further cement that those who understood, understood correctly.

The two interviews were then compared using thematic analysis to determine if the visit had changed the students' conceptualization of science.

11.4 Phenomenographic analysis

11.4.1 General Phenomenographic analysis

To be able to compare the initial interviews with the ones done after the field trip a phenomenographic analysis was made. The principal follows that of the thematic analysis but in the end searches for concepts/phenomena instead of themes. Phenomenographic analysis aims to pinpoint what the student perceive or conceptualize within a certain topic (Marton 1981) while thematic analysis is saying that although it's hard to pinpoint the exact feeling/understanding a student has of something it's quite easy to recognize themes in what they describe (Braun Clarke 2006). Since the interview did not rely on any expected conceptions, nor search for any specific change in the students' perception the analysis was conducted inductively.

Thematic analysis follows recursive steps to define, refine and combine themes found in the interview (Braun Clarke 2006). These steps were used as a basis for the phenomenological analysis but searching for concepts and phenomena instead.

1. Familiarizing yourself with your data
2. Generating initial codes
3. Searching for themes
4. Reviewing themes

5. Defining and naming themes
6. Producing the report

11.4.2 My process of analyzing

The dataset was the 13 interviews done before and after the visit to the science center, all with the same questions. It was natural to familiarize myself with the data as time went by, transcribing all of the data. This also made making initial codes easy. These codes where then used to find different conceptions. For example:

Question: What does a scientist do when they get a result?

Transcript	Code	Speaker
You can't publish the result without consulting another person. You can't just give it to a hospital and say "here use this", because that could have both negative and positive consequences. So you need several people to decide since it's published globally.*	Implies the importance of peer-review to avoid unforeseen consequences	Student 1

* The interview was conducted in Swedish but has been translated to English

The concepts were created by searching for similarities between interviews. These were later refined by analyzing if the concepts had sufficient data to back it up. Concepts deemed to be vague or uncommon during the interview were removed, as in thematic analysis (Braun Clarke 2006). It is worth noting that all interviews before and after are analyzed as one, such that all collective codes and concepts are represented when comparing. This means that in theory one group could be solely responsible for a concept if their interview was completely centered around it.

12 Pedagogical result

12.0.1 Conceptions

There were five concepts at the end of the interviews, it can already be noted that no new concept appeared after the visit such that all of the concepts were present from the beginning. The concepts are:

1. Science is distant - The students lack insight to the world of science.

2. There is a boss - Someone else is in command and decides what the scientist work with.

3. Science proves something - Science strives to find proof in all imaginable subjects.

4. Stereotypical scientist - Typical stereotypes such as working in lab coats mixing chemicals or trying to make a new medicine.

5. The Good, the bad and the ugly - There is ethical, unethical and incompetent science. Ethics can apply to both the process of doing science as well as it's purpose.

All of these conceptions are distinct with only conception one and four being similar, they differ quite clearly though. Conception 1 focuses on what's unknown or vague while conception 4 focuses on misconceptions and stereotypes. To navigate how the concepts changed they have been split up, both by type of concept as well as if it's before or after the visit.

12.1 Conception 1 - Science is distant

The first conception, *Science is distant*, showcase the students lack of interest or insight into the world of science. It could be of choice or by chance as the students have very different interests.

12.1.1 Before

The clearest example of this phenomena is when the students are asked a direct question.

> "What is the scientific method?" - Interviewer
> "I have no idea" - Student 1
> "Scientific method? A pure guess is when you use proof?" - Student 2

We see here two different ways to interpret this first conception. One with total lack of insight into the scientific fields or the show the inability to describe it, the other answering something vague but related to their perception of science. While this statement is partly the correct answer, this might be more of a guess from the student. This becomes clear after a while when the same student says:

> ”Honestly, I’m pretty clueless about this” - Student 2.

This in response to trying to explain the previous answer, further emphasising the lack of insight.

Due to the nature of the interview many conceptions could appear in a single quote. The following quotes could also fit within the conception of stereotypes.

> ”I imagine that many people spend their whole lives coming up with a single conclusion. So... damn long.” - Student 16

> ”I imagine it’s when the money has run out. It is probably a little like, until it is not possible to do more research.” - Student 17

They clearly state that it’s their conception, ”*I imagine*”, and then describe two common stereotypes. Words like ”probably” and ”i imagine” are words used to avoid saying that they don’t know, or perhaps, attempt to describe. It’s also noteworthy that student 17 does not elaborate on what it means when ”is not possible to do more research”, another indicator that the student lacks insight. The stereotypes will be analysed further in *Conception 4*.

There were also those who just lacked the interest for natural sciences as student 18 points out.

> ”Maybe. I will not research more in physics, unfortunately.” - Student 18

This when asked if they’re were to ever do science themselves, the *unfortunately* is probably a response to the fact the interviewer were doing science in physics and the student wanted to show some empathy.

Sometimes a stereotype can be what’s keeping students from interacting with science. In the following quote we see how a student has the interest but the stereotype of working alone is keeping the student away from the journey.

> ”It is very fun to find out more about the world. But I don’t know if I could do it myself.” - Student 6

Also note how the student also lacks understanding of what doing science is, to learn about the world does not necessarily mean to do science. Reading a book about birds or a book about quantum physics is a good way to learn about the world, without doing any science.

12.1.2 After

This conception was less prominent after the science center visit. There was however one aspect that appeared first now, namely the idea of time. The lack of insight were more prominent in other aspects than before, and less in those seen before. The students’ interest were about the same but less vague after, those who liked it said they liked it and those who didn’t said that too.

The new sign of *distance* can be seen in this quote.

> "It's maybe something that... there's been quite a bit of research around it already. It might take a little less time if you know a lot of things in advance and don't need to test as much in this big span. But if it's something completely new, then maybe you need to do a little more research if you don't know what might happen. What already exists, you have no foresight into areas." - Student 7
>
> "Do you mean that research done today is shorter than what was done a hundred years ago?" - Interviewer
>
> "Most of the time, yes, I'd say that." - Student 7

This is an interesting take that science would be faster today than before since no example is given. The argument is well described but still consists of many uncertainties and factual errors, there are many examples of science being quick long ago and being slow now. The idea that new research would be quicker because of previous research giving insight is also a leap of faith, take the Higgs boson for example, a particle theorised in 1960s but was first shown fifty years later. While the student add that it's only most of the time, it's clear that the student lacks insight to whats happening in the scientific community.

The last quote appear well thought at first but also show a total lack of insight into science.

> "I could explore but not do research. Things should happen. It should not just be sit still and look at a computer." - Student 27

It should be noted here that explore and research have very similar sounding names in Swedish but essentially means the exact same thing as it's translations, some arguments came to light discussing the difference of exploring a subject, research and exploring a forest. This shows some lack of insight, to not be able to differentiate between doing natural science and hiking, the only similarities are their names in Swedish.

That was however the only clear example of misunderstandings about science, lack of insight still appeared in answers such as "*I don't know*" and lack of interest were about the same as before, perhaps a bit less vague.

12.2 Conception 2 - The boss

This is the phenomena of someone being in charge, and above the scientist. This boss decides what the scientist work on, what resources are available, the schedule and the allocated time for the work. When a result has been achieved the boss is a crucial part of publishing the results.

Before the visit this was a very direct conception, afterwards, no direct answers was given.

12.2.1 Before

There was one quote that perfectly encapsulate how the concept of hierarchy was described.

> "I just think it depends on what they got from the job for or from their boss. So I think they go from that but I guess it's mostly tests on the computer, right now anyway, it's not very practical anymore, most of it is already done. Or most of it isn't, but most of what we know about is done, there is the greatest chance of finding something new through computer simulation." - Student 12

The most common way to talk about this phenomena was to put it in context with something else or to state that the boss exist and then describe something else. It was often used to set a basis for their explanation of something. We see in the previous quote that the boss decides what the scientist do, but it has no further importance with how the scientist work, the latter part of the quote has nothing to do with it.

Another common occurrence with the idea of a boss is when it's discussed how long a scientist work. While many answered "until they're done" or "as long as they live", many also talked about money and that the boss was the one who funds the work.

> "I imagine that many people spend their whole lives coming up with a single conclusion. So... damn long." - Student 16

> "I imagine it's when the money has run out. It is probably a little like, until it is not possible to do more research." - Student 17

This quote show both the idea of time and money. The idea of a boss does not need to be in the literal way of a single person who hired the scientist, but it can be an organisation or a company, all of which falls under the idea of a boss. What's interesting is how many students said contradictory things about how the research is published. Many stated that the paper should be peer reviewed and at the same time stating that the scientist should show the boss first, often with the idea to take patent.

Here we see two quotes talking about what to do with the results found. Note how the first quote has a quite nuanced take on what to do with the results found but then ends the statement contradicting and saying it doesn't apply if it's under *hierarchy*. The student doesn't elaborate further on what kind of hierarchy but the idea of a boss is clearly present.

> "But maybe you just look further, how can you develop this a little more. Although it may feel perfect at the moment, there may be much more to build on. You also write a long paper and check with other researchers, if it's not like hierarchy or something like that." - Student 17

and

> "What I would have said is that you take a patent so that no one else can steal your part." - Student 9

Here the focus is not on publishing it, at least not first it's about taking patent so no one can steal the work. This seems to stem from the idea of working for a company with the intent to make money. This was also a common point during the interviews before the visit.

12.2.2 After

The answers surrounding this topic after the visit were few. Some brushed it off, not laying any weight on it while others acknowledged that they probably had some influence.

> "You should probably take it up with your boss. To say you've done it. Then you probably have to talk to someone officially. So that you can show what you have figured out." - Student 3

12.3 Conception 3 - Science is finding proofs

This is the idea that all science do is finding proofs, getting facts and giving the future scientist something to work with.

Before the visit this idea was generally very direct, students had a firm idea that science was to prove something. There were few elaborations on what that meant or how to create proofs. After the visit this was a bit more nuanced.

12.3.1 Before

These first quotes perfectly encapsulate the common ideas the student have about proof.

> "Question everything" - Student 9
> "If you want something objectively proven" - Student 10
> "If I've understood it correctly, you have a theory you test until you've proven it true or false" - Student 9
> ".../ It's just if you want something proven" - Student 11

We see how Student 10 point out that the scientific method gives objective proofs, a very direct approach. It's interesting how the student still think there's a difference between a proof and an objective proof. We also see how the students perceive science to be black or white, it's true or false, and that's what the science show.

This show that the students lack some understanding of what the goal of research is. Here they assume it's always as easy to prove something false as it is to prove something true.

One answer were quite interesting diverging from the idea of creating proofs and instead proclaimed that science can't prove anything since it must leave room for improvements.

> "It [the scientific method] must leave room for counterarguments, we must be able to correct and formulate better reasoning" - Student 5

This might be true within physics where our understanding of the world is constantly changing. But with axiom based subjects, like mathematics, definite proofs can be found. This may very well be a communication issue, since the statement is very close to what science looks like.

> "Scientific method is way to.. To understand an idea" - Student 14
> "You need scientific proof to, what is it called? Back up your claim" - Student 15

Here the student differentiate between proof and scientific proof by saying that scientific proof is what you need to make an argument for something. This is correct in many aspects, which show that the student has a quite clear understanding about the importance of proof. However there's no mention of "regular" proof, most likely a wording issue, suggesting that scientific proof is the only proof.

Here we again see the pattern of proof equals truth. While the quote might seem to suggest that there has been no foul play doing the science, the context and Swedish translation show the idea of science telling the truth.

> "That it is, that it is true. It's fact and it's been tested and that you have the outcome you want." - Student 15

This quote is in relation to making medicine and what's most important with doing science, having truthful results means that a medicine works in the way it's described. However, the most interesting part of this quote is the last part, "you have the outcome you want".

To suggest that one of the most important things about science is getting the result the scientist want, is a very interesting take. This show how students conceptualize science to only find the right answer. The idea of learning what works and what doesn't, isn't seen as equally important. This highlights how students can lack insight in many different aspects. The idea of testing many times to see if something works is a fully correct observation of science, but very few scientist would say that the most important thing about their research is getting the result they want. This idea is most prominent within conspiracy theories where the goals are not to do science but to secure a predetermined result.

This was not the most common answer to what's important, some students used a different wording and landed in a more reasonable statement.

> "When it comes to products that are released, I would assume that it is first and foremost that the product works." - student 10

Talking about products, often of medical type, the idea of proof is somewhat distorted into "works". The similarities are big, generally it was seen as proof for something abstract, a working product for something more concrete.

12.3.2 After

After the visit the idea of proof changed slightly, away from concrete ideas about truth towards a more nuanced thought of consistency and protocol.

We see a difference in what proof means in this first quote.

> "Well, to prove things in a reliable way, based on facts and also to give room for improvements." - Student 20
> "Do you agree? Would you like to add anything to that?" - Interviewer
> "You get the results from many experiments with similar starting conditions, so you know how to relate to the results" - Student 22

To prove something in a reliable way shows that they understand the difference between objective proofs, such as in math, and theoretical proofs given in physics. Saying that proofs are based on facts and that results are given by multiple tests are two correct ideas. Since the idea of proving something reliably begs the question what reliably enough is, leaving room for improvements is therefore not a contradiction. It's noteworthy how a student point out that results needs context, a point brought up again in conception 5, about how looking at proofs from different angels can alter it's meaning. We also see how a vague answer still portrays the reality of finding proofs.

> "It depends on what part they are in. If they are trying to prove something, they might be running tests on the computer, I'd think. If they have proven something, they have written a report about what they have proven and what they have done. There is a lot of documentation and simulations. But then you can also walk around and... Yes, I'm not sure. But just go around and research." - Student 9

Note how the student begins with a clear idea that the process of science is divided into at least two parts, a finding proof phase and a documentation phase. This still show that proof is what research is about, maintaining the same idea as before the visit.

A new branch of the purpose of science is seen after the visit, it doesn't need to be centered around proof, it's the context that decides. They still believe that a rigorous proof is needed in areas where negative consequences are at hand, but in other fields it's not as important.

> "Do you have to use the scientific method?" - Interviewer
> "Yes, if you want to get accepted in the academic community you need to use it. But there's other fields where you don't, such as religion don't use scientific methods. That's another thing" - Student 5
> "Anyone wanna add to that?" - Interviewer
> "No" - Student 6
> "So it's just science or religion" - Interviewer

> "No, it's also in every day conversations and such. You don't need to analyse with scientific methods. So much depends on the context, which people you talk to or what kind of people there is around you" - Student 6
> "Lots of that and also what the goal is. If it's a study about medicine it's really important to use scientific methods so the people who use it to save people know it's reliable" - Student 5

The students differentiate between doing science and having a discussion. This show that the students must have some understanding in the scientific process. As student 5 says, it's important to know a medicine is reliable, with the implication that the opposite would bring concern over unforeseen consequences. This show that it's not a proof that's needed, it's a reassurance of a product's function. We see this argument brought up several times.

> "If it is so or not. Because if you are too quick to say 'Yes, this will work'. Or 'yes, this won't work'. But we... Then there could be the risk that it could... What if you're wrong? And if you are wrong, it can end quite badly. Depending on what it is about, of course." - student 1

Further we see a complete turn regarding one point brought up before the visit. Finding proof does not seem to be the most important thing anymore, neither is finding the truth.

> "Yeah, that's obvious, but there is no such thing as 'the most important thing' about research. The most important thing is... That you might make progress in research. That you don't get the answer results immediately, but that you figure out [something] and then use that to..." - student 27

The student is cut off by another student. The importance of progress was prominent throughout all interviews, a clear shift in thought.

12.4 Conception 4 - The Stereotypical Scientist

It's been documented before (draw a scientist) that most students picture a scientist in lab coats with goggles. This is very similar, the conception of a typical scientist doing typical science.

12.4.1 Before

A common stereotype seen almost exclusively before the visit was the idea of a boss making all of the decisions, creating a budget and is the first person to read the final report. This was often said in passing, with the focus being on something else. This is clear in the following quote.

> "I just think it depends on what they got from the job for or from their boss. So I think they go from that but I guess it's mostly tests

on the computer, right now anyway, it's not very practical anymore, most of it is already done. Or most of it isn't, but most of what we know about is done, there is the greatest chance of finding something new through computer simulation." - Student 12

The student purpose the idea of a boss as a foundation to their thoughts about if tests are on a computer or practical. Therefore there are two stereotypes coming to light here, the boss who decides and running tests on a computer. It's noteworthy how many stereotypes assume working with medicine in lab coats mixing chemicals, but this student suggest that it's mostly work on a computer. This stereotype become more prominent after the visit. The idea that most of the practical work has been done also shows a lack of insight into science, something to be expected when talking about science using stereotypes.

The idea of working in a lab was by far the most common stereotype before the visit. This quote represent a lot of what was said, working with medicine, lab coats and doing that every day.

> "Or it could be that you're mixing ibuprofen in a fucking lab, or that you work with something like uranium and have to change into the worst outfit every day." - Student 24
> "Precisely." - Student 25
> "And sometimes it may require that there's, I don't know, so it may have to have a lab for what you are going to research. It depends on the subject." - Student 24

The student also brings up the idea of needing a lab for what is being studied directly after pointing out twice that the scientist is already in a lab. This hints towards the idea that a normal lab is for mixing chemicals and there's other subjects, like radioactivity, that need a special type of lab.

Another stereotype was brought up in discussions regarding the length of doing science.

> "I imagine that many people spend their whole lives coming up with a single conclusion. So... damn long." - Student 16

This idea in different variations were very common. Working an entire lifetime for a single result, working until the funding stops or working until the desired result is found were all given as the time span.

To work a lifetime were sometimes seen as just working, finding many results and doing it for the love of doing science. Otherwise the idea of working until a result is found was the dominant answer, no matter if it takes a year, a week or just a day. These answers were not seen as stereotypes as they quite accurately depicts reality, even if they're stereotypes that accidentally represent the truth. The idea of finding a single result however is seen much more as a stereotype as is common in popular fictional works.

12.4.2 After

We still see the idea of working with computers more after the visit, likely a result of working with computers at the SC. This quote comes to light again.

> "I could explore but not research. Things should happen. It should not just be sit still and look at a computer." - Student 27

We also see the idea of publishing and writing appear. This quote mentioning how the paper is long and other common additions to this was to show it to the boss.

> "Publish it. Usually in some form, some paper, some long report on the whole method and how you arrived at the answer and what the answer is." - Student 5

Further a quote that shows both these stereotypes, working on a computer and then writing a paper on what has been proven. It's clear that the student also lack fundamental ideas of doing science, saying that scientist can "just go around and to research".

> "It depends on what part they are in. If they are trying to prove something, they might be running tests on the computer, I'd think. If they have proven something, they have written a report about what they have proven and what they have done. There is a lot of documentation and simulations. But then you can also walk around and... Yes, I'm not sure. But just go around and research." - Student 9

Generally the stereotypes were fewer and often better descriptions of the truth than before. A vague stereotype can be seen in the way the following student places science in boxes, and that they're used in a specific order.

> "We can place it in different boxes. So first you do research, check if it works, find flaws. Then you maybe do the test again. And then you continue with new methods, until you have the answer." - Student 1
> "It's a guess but it feels like finding flaws is the last thing you do after you've done all the tests many times. So you can evaluate more exact..." - Student 2
> "Technically it's a part of it" - Student 1

Despite these often used steps, it's the way they're presented that makes this a stereotype. First do research and the test the research, this holds to the common movie-plot stereotype of a scientist working to find an answer to a problem, and in a dramatic way test this new solution and see if it works.

Lastly a stereotype was found indicating that science today is easier than it was previously thanks to advancements in computer science and all the previous results and proofs given. This is of course true in some aspects, however as technology advance so will it's tasks, in order to conform to new science.

> ”For example, the machines used to perform it today are much more advanced than they were in the past.” - Student 7

> ”It used to be a lot by hand, now you have computers that can do things for them. So it’s not as much you have to work with in your head and therefore it can shorten [the time] a bit. It is easier to collect and compare information if you have everything in tables on different [computer] files.” - Student 5

Student 5 points out that there’s less working with ones head and more work for computers. An interesting follow up would have been to ask what scientist do with the brainpower left over, were scientists smarter before?

12.5 Conception 5 - The Good, the bad and the ugly

Here the process is talked about in such way that it only made way for three different ways of doing science. The ethical and competent way, the unethical way and sometimes the incompetent way. Ethical suggest that the science is done in a correct manner, both as a process and from an moral/ethical ground. Unethical is just a correct process wise, but the reasoning is perhaps unethical or immoral. Incompetence is when the process fails, doing the calculations wrong or not following safety procedure.

12.5.1 Before

The most common example of unethical science is work done on humans against their will. This was as common before as it was after the visit, likely due to the fact that this was not a topic brought up on any lessons before, during or after the visit.

> ”Another bad research I would say It’s when you do research on, you use humans to learn more. I mean people who are alive, so you hurt them to be able to learn about how the human body works. Maybe you dissect a living human and that is grotesque” - Student 13

Immoral science was often brought up together with words such as power, war and money. Creating weapons for war was seen as immoral science since the end goal of the product was seen as such. The difference between unethical and immoral is distinct and well depicted in the following quote.

> ”Bad research can also be, for example, an atomic bomb. It was research, but it was something that wasn’t really for a good cause but was for war or for personal gain.” - Student 2

Here the immoral practises appear, to create something that could be used for unethical achievements but could also be used to benefit humans. Examples of using bombs to destroy asteroids appeared with the asterisks of the unlikelihood of that idea. It did however start the conversation of where the line is drawn between good and bad research, a common subject, both before and after. The idea of working on something for a specific goal, be it weaponry to defend, insect repellent to increase crop production or dynamite for mining was frequently given as example of ideas that had something good in mind but was then transformed into something of unethical or immoral character. These examples showcase good research as a foundation, which later on when other scientists improved or changed the product changed into something bad. This show that the students have a clear idea of how to differentiate ethics and morals.

The idea of incompetent research was vague before the visit, there was clear examples though.

> "But then I also think about research that can be destructive. As another type of research, Archaeology. What's his name? Some archaeologist used dynamite to excavate... was his name Schliemann or something like that. He used dynamite to excavate Troy." - Student 5

This example was one of the few that described a situation where it truly was incompetent science. Schliemann did find ancient Troy, at the expense of more present day Troy. Most other examples brought up miscalculations in numbers, accidentally using the wrong substance while mixing chemicals and such. This makes it clear that there's at least an existing thought that research can be of bad nature. This is also briefly brought up discussing what to do with the results found. Showcasing the importance of science and the power it has.

> "That you really do the right thing. That you really do the right thing when you publish it or showing it to the public and releasing it to the public. This also applies to medicine and anything like that that can harm people, if it is not one hundred percent clear." - Student 15

Another way to look at incompetent science is by looking at the improvable. This was quite common, most students agreed that religion could not be made a scientific theory. Not explicitly talking about incompetent research, but it's implied that it's a stupid idea to try to prove a religion.

> "Do you need to use the scientific method?" - Interviewer
> "[No] Religion for example, that's not scientifically proven" - Student 9
> "Yeah, It's not because it's a philosophy" - Student 12
> "That's also a part, people need something to believe in, a guide to become better people" - Student 9
> "The things we cant explain with science. What happens after death, religion and so on" - Student 11

12.5.2 After

The idea of ethics and immorality are still present and mostly unchanged.

> "Whereas atomic bombs are not used very often, perhaps against blowing up. But there is a little more to... Yes." - Student 1
> "Yes, I agree with what you are saying. It can..." - Student 3
> "Atomic bombs can be used in a good way. If it's going to blow up an asteroid heading towards us, sure. But... I think... So... The possibility of doing it may be a little lower than you think." - Student 1

There was one thing brought up after the visit that hadn't been brought up before, regarding immorality in commercials. Some students, when discussing immoral research, brought forth the argument against some food companies which have interests that differ from citizens. The students suggested that these companies had profits as their main priority instead of public health, willingly deceiving costumers with commercials about certain products to make them appear healthier or cheaper than they are. Discussion about the ethics of studying costumers habits and preferences and how they could be manipulated was toughed on briefly.

The only time deception is talked about directly is within this quote.

> "It's when you try to make the result look like something it's not. That you have some hypothesis and then try to design some investigation that sheds some angled light on it." - Student 6

It's interesting how only one student pointed out fake information and deception in a time where fact checking and "fake news" are as far reaching as ever. The student realizes that the entire process needs to be made according to the wanted outcome, it's not only the results that matter.

13 Pedagogical Discussion

There are many factors that could have altered the students' perceptions during the time from the first interview to the second, leaving room for many interpretations of the results. These objections and different interpretations could lay a foundation, to further research these topics, leaving less room for speculations and interpretations. Some ideas to clarify and solidify results can be seen in chapter 13.1 "Future pedagogical research".

Although I've interviewed different people with the goal of understanding their ideas before, I've not done it at this scale. The interviews were time consuming, both for myself and the students, and improvements for them could be identified not long after they were done. Since the study is based on the interviews it's likely that a more thought out interview would help in identifying the concepts brought forth.

Another important fact to consider is that the students interviewed were also members of my own class. Acting as both teacher and researcher at the same time while making sure that my students understand the difference is hard. Students motivated by good grades could be scared to say something that in their head sounds wrong and that could negatively impact their final grade. While it has been clarified that answers given at the interviews would not affect their grade in any way, it could still affect them subconsciously. While no direct mention of this is given in the interviews it's good to always keep this in the back of your head.

The pre-interviews showed that the students seem to affirm the belief that a scientist usually works in a white lab coat with a microscope, medicine or space, similar to the Draw-A-Scientist study from 1983 (Chambers 1983). It's interesting how the perception of a scientist hasn't changed much in the last 40 years, compared to relevant things as technology and medicine. One student noted that some scientists work their entire lives to find a single result.

> "I imagine that many people spend their whole lives coming up with a single conclusion. So... damn long." - Student 16

A very common stereotype in movies such as Interstellar (2014) which is very rare if not unheard of in the real world, showing an example of taking stereotypes as the truth. It's at least reassuring that this misconception was not as present after the visit, hopefully suggesting that they've been rendered obsolete.

Another development can be seen in the way students seem more confident in what science is and what scientists do. *Science is distant* is a far less prominent concept after the visit, which can be the reason stereotypes decrease as well. If a student know what they're talking about there should be less need for stereotypes to describe their thoughts. There were exceptions of this, one quote show that the idea of what science is still is distant for some is:

> "I could explore but not do research. Things should happen. It should not just be sit still and look at a computer." - Student 27

This show a lack of understanding of what science can be about, but it's not completely unexpected. During the lab, computers were the only source of information and data to the students leaving them with little choice but to use them. These computers were quite old and did not operate quickly and combining that with the gamma detector needing time to collect data, a lot of time was spent waiting. It is however very interesting that the student want something to happen and not just sit by a computer. Is it just the practice of science that is perceived to have this overwhelmingly amount of staring at a computer? Many jobs requires computers for many different tasks. This could simply mean that the student is longing for practical, not theoretical, work. It's entirely possible for the student to see that as doing science and simply means that they're not interested in that, avoiding being seen as negative they add a compromise which, is this case, comes out completely wrong. If changes in students' perception of science came from the lab equipment, surely they'd work just as fine in a laboratory in their school. It would be interesting to see if it's the exercises themselves or the entire science center who's causing the change.

No matter the reason, the perception of "science is distant" is less common which affirms to Ersen & Muhlis (2015) study that students improve on their scientific process skills when they visit science centers. However the concept that science is finding proof is still present. Why this is left unchanged is unclear but could come from the format of the lab, there was a definite answer, the rock is either this or that, the facts are given as proof.

Their conception about what a proof is still changed though, from a very direct but vague idea of just the truth to something more nuanced. The radioactive rock could contain cesium, but it could also contain uranium or thorium, two things can be correct at the same time. Answers have changed from saying that proof is *truth* to *reliable* and *tested*, which is in direct correlation with understanding the scientific method.

The biggest difference is definitely how the idea of a boss changed. It went from something almost all students purposed as a key figure in some sense to something that only a handful even mentioned. Since the lab was done in such manor that there was a clear leader, Bob, who decided what the students were to do. One reason could according to Hollett & Brock (2023) be that students perceive their own status based on their ability to avoid conflict and how they deal with teammates that under-performed. Although their study was made on students in a sports team many parallels can be drawn such as working together towards a shared goal, diversity in skill and of course to avoid conflicts within the group. DeWitt & Hohenstein's results (2010) seem to affirm to this as students in science centers do seem to cooperate. Since most of the groups managed to figure out the answer to all the questions, their status was perceived as higher than before, leaving less room for a boss to take that spot.

The conception about ethics did not change much, which was to be expected since no part of the lab was to challenge the students perception of ethics. The only real difference was that after the visit, money was also seen as a motivation for doing unethical science, where as power was mostly present before. The concept of incompetent science was brought up more frequently after the visit, although this was the only part of competence/incompetence that was part of the lab. Discussions about what happens if you put the wrong substance under the gamma detector or how the radon capsules were meant to be handled was meant to give the student some insight into what can go wrong when doing science.

Only one student brought up the idea of fake news and cherry picking results to make it seem like the it says something entirely different. The students in the same interview group all agreed but did not contribute to this thought. Many students are aware that misinformation are widely spread throughout the internet. Do they not believe it has affect on science as well? Students often overestimate their ability to critically fact check (Petrucco & Agostini 2020) which could be the reason they don't see that as a thing in science.

Furthermore, it's impressive how the students started out unsure if they did or did not want to pursue science, to be quite sure of it after the visit. Many that were unsure before the visit became certain after that they wouldn't. Likely as a result of the labs topic, radioactivity and molecular science are often seen as highly difficult, perhaps scaring away those who aren't very good in natural science's subjects (Kihwele 2014). If this is because their perception had changed and they now have a clearer view of what science really is or that they just found it to be boring is not clear. One student might have radioactivity as a favorite subject but found the lab to uneventful to be worth pursuing. In this case the perception has changed but not the interest.

It is worth nothing that the students' answers could reflect other subjects that they're also taking. This study was not made in a vacuum as there's plenty of things going on for teenagers that could influence them. During the study the students were also taking the course "Religion 1" which briefly touches on the difference between science and faith. This could very well be the reason it was brought up during the interviews.

Although all groups were interviewed before and after the visit, the time between interviews were different. This was mainly because of time-management. Each interview took at least 20 minutes (including prepare time) so it was difficult to find time for each group without disturbing their classes or my own for that matter.

The last concern is that of peer pressure. The interviews were chosen to be in groups to keep the work load reasonably low. This does however make it harder for shy or introverted students to give their answers, as well as students who feel that their answer might not be accepted by the others. By having groups a space is set in which some answers are OK and others are not, this is made informally and is different for each group. This could mean that there would be less spread of answers, hiding some of the true thoughts of the students. However the groups were set by the teacher in such a way that the groups would consist of friends and by such minimize the risk for the students to feel trapped or that their answers are bad.

Lastly, this study has given me a deeper understanding of pedagogical research as a whole. How difficult it is to conduct many interviews, transcribe them and then analyse them, but at the same time, how difficult it is to draw conclusions from few examples. While looking back at the interviews, after analysing them, it feels as though the results are right there for anyone to see, opposed to the feeling I had while transcribing them. Illustrating that the knowledge gained from the study is not necessarily in the results or data, rather in the study itself.

The use of science centers should not be undermined, rather used for the right thing. Students in their late teens has little to gain, curiosity wise, from a single visit. However, their scientific literacy skills are improved. It would be interesting to see the effects of using science centers frequently on students in their late teens. Perhaps noticeable changes in their curiosity would appear.

13.1 Future pedagogical research

This study was made on 17-18 year old's with no real experience of research. It would be interesting to see if the results look the same for either much younger students, say 12 years, as well as older alumni and compare those who continued to study versus those who started to work after gymnasium.

An interesting aspect to study is the change in perception if the visit were to a science center with a different topic than natural sciences, such as: pharmaceutical research, marketing research or sociology research. Since this study only focuses on physics and natural sciences we don't get the full picture of their collective complete picture.

14 Conclusion

From the technical part of this study we can observe that even small networks can, to some extent, forecast seismic activity with relative precision. When scaling the network up there was increased improvement to its precision, timing and magnitude, indicating that larger networks were better suited for analysing this type of simulated data. When these large networks were further improved by implementing more advanced formulas for its learning algorithm the precision increased further, leaving a less than 5 % error overall when forecasting simulated earthquakes, in regards to the earthquakes magnitude, location and time to rupture when given the data one day before the rupture. When adjusting this to capture and analysing the data 10 days in advance this precision increased to right about 5 %, which still is of great accuracy. In this simulation 5% represent a time error of 2 days, either early or late and a distance error of about 30 km in any direction.

From the pedagogical path of this study we can observe that the students' concept of science changes in a way not far away from what one might expect. Their scientific process skills increased about the same amount as their use for stereotypes decreased. The idea of a boss making all the decisions were very prominent before the visit and almost nonexistent afterwards. This result was unexpected and no reason for this could be extrapolated from the interviews. The students' overall scientific literacy seem to have increased even further looking at their perception of the purpose of science. Students went from a very direct, stereotypical, approach saying that scientists find the truth about something. Their answers were at first black or white, it's true or false, but later on they became much more nuanced saying it's goal depends on the context, not everything can be proven but progress towards an understanding can still be made. The students' motivation and interest did not show any improvements, perhaps as it's hard to see an already motivated student become more motivated, many students that were unsure if they wanted to pursue science before the visit became quite adamant that it was nothing for them afterwards.

15 Sources

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B. and Wong, B. (2010), “Doing” science versus “being” a scientist: Examining 10/11-year-old schoolchildren’s constructions of science through the lens of identity. Sci. Ed., 94: 617-639. https://doi.org/10.1002/sce.20399

ArtEmis, (2021). Awareness and resilience through European multi sensor system (101061712 — artEmis— HORIZON-EURATOM-2021-NRT-01). https://artemisproject.eu (Accessed 2024-05-22)

Bennetts, M. (2017). Soviet officer who averted cold war nuclear disaster dies aged 77. The Guardian. 18 September. https://www.theguardian.com/world/2017/sep/18/soviet-officer-who-averted-cold-war-nuclear-disaster-dies-aged-77. (Accessed 2024-01-03).

Bevis, J & Michell, J. (2012). The History and Philosophy of Earthquake. https://www.google.se/books/edition/The_History_and_Philosophy_of_Earthquake/IAHUcD0FwnkC?hl=en&g (Accessed 2024-01-03)

Björndal, R. P. C. (2009). Det Värderande ögat. Liber.

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology, Qualitative Research in Psychology, 3:2, 77-101, DOI: 10.1191/1478088706qp063oa

Chambers, D.W., 1983. Stereotypic images of the scientist: The draw-a-scientist test. Science education, 67(2), pp.255-265.

Dahmani, L. & Bohbot, V.D. (2020). Habitual use of GPS negatively impacts spatial memory during self-guided navigation. Sci Rep 10, 6310. https://doi.org/10.1038/s41598-020-62877-0

DeWitt, J., & Hohenstein, J. (2010). Supporting Student Learning: A Comparison of Student Discussion in Museums and Classrooms. Visitor Studies, 13(1), 41-66. doi:10.1080/10645571003618758.

Deci, E. L., & Ryan, R. M. (1994). Promoting Self-determined Education. Scandinavian Journal of Educational Research, 38(1), 3-14. doi:10.1080/0031383940380101.

EarthquakeList. (2024). Greece Earthquake Report. https://earthquakelist.org/greece/#all-latest-earthquakes (Accessed 2024-01-03)

Ersen Cigrik, Muhlis Ozkan. (2015) The Investigation of The Effect of Visiting Science Center on Scientific Process Skills. Procedia - Social and Behavioral Sciences, Volume 197, 2015, Pages 1312-1316, ISSN 1877-0428. https://doi.org/10.1016/j.sbspro.2015.07.405.

Forbes, James. (2013). XIII. On the Theory and Construction of a Seismometer, or Instrument for Measuring Earthquake Shocks, and other Concussions. Transactions of the Royal Society of Edinburgh. 15. 219-228. 10.1017/S0080456800029914.

Goff, J. & Dudley, W. 'Boxing Day: The World's Worst Disaster of the 21st Century', Tsunami: The World's Greatest Waves (New York, 2021; online edn, Oxford Academic, 18 Mar. 2021), https://doi.org/10.1093/oso/9780197546123.003.0016, accessed 3 Jan. 2024.

Harambam, J., & Aupers, S. (2015). Contesting epistemic authority: Conspiracy theories on the boundaries of science. Public Understanding of Science, 24(4), 466-480. https://doi.org/10.1177/0963662514559891

Hollett, N. and Brock, S. J. (2023) "What makes you the boss?' Understanding student perceptions of social status in sport education', Sport, Education and Society, pp. 1–13. doi: 10.1080/13573322.2023.2174965.

Igarashi, G., Saeki, S., Takahata, N., Sumikawa, K., Tasaka, S., Sasaki, Y., Takahashi, M., & Sano, Y. (1995). Ground-Water Radon Anomaly Before the Kobe Earthquake in Japan. Science, 269(5220), 60–61. http://www.jstor.org/stable/2889150

Illeris, K. (2007). Lärande. Lund: Studentlitteratur.

J. Planinić, V. Radolić, B. Vuković. (2004). Radon as an earthquake precursor. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. Volume 530, Issue 3, 568-574. https://doi.org/10.1016/j.nima.2004.04.209.

Karlberg, L.A. (2015). Vägde 60 ton – körde över flottbro som pallar 4. Ny Teknik. 25 March. https://www.nyteknik.se/nyheter/vagde-60-ton-korde-over-flottbro-som-pallar-4/861258 (Accessed 2024-01-03).

Kihwele, J, E. (2014). Students' perception of science subjects and their attitude in Tanzanian secondary schools. World Journal of Educational Research. Vol. 1, No. 1, January 2014, PP: 1- 8. http://www.wjer.org/WJER_Vol.%201,%20No.%201,%20January%2020

Kungliga Tekniska Högskolan. (2019). LT200X Examensarbete inom teknik och lärande, avancerad nivå 30,0 hp. https://www.kth.se/student/kurser/kurs/LT200X (Accessed 2024-01-03).

Lindahl, B. (2007). A longitudinal study of students' attitudes towards science and choice of career. Presenterad vid NARST Annual Conference, April 15-18, 2007, New Orleans. Hämtad från https://urn.kb.se/resolve?urn=urn:nbn:se:hkr:diva-6093

Marton, F. Phenomenography — Describing conceptions of the world around us. Instr Sci 10, 177–200 (1981). https://doi.org/10.1007/BF00132516

Maryann Mott. (2005). Did Animals Sense Tsunami Was Coming? 4 January. https://www.nationalgeographic.com/animals/article/news-animals-tsunami-sense-coming (Accassed 2024-02-09)

Murray Campbell, A.Joseph Hoane, Feng-hsiung Hsu. (2002). Deep Blue. Artificial Intelligence, Volume 134, Issues 1–2, 57-83. https://doi.org/10.1016/S0004-3702(01)00129-1.

NOAA. (2023). What is Tectonic Shift?. National Ocean Service. https://oceanservice.noaa.gov/facts/tectonics.html/# (Accessed 2024-01-03)

Nisbet, M. C., Scheufele, D. A., Shanahan, J., Moy, P., Brossard, D., & Lewenstein, B. V. (2002). Knowledge, Reservations, or Promise?: A Media Effects Model for Public Perceptions of Science and Technology. Communication Research, 29(5), 584-608. https://doi.org/10.1177/009365002236196

Petrucco, C. and Agostini, D., 2020. Student Perceptions of Fake News: A Matter of Information Literacy Awareness. International Journal of Digital Literacy and Digital Competence (IJDLDC), 11(2), pp.28-43.

Rennie, Leonie & McClafferty, Terence. (1995). Using Visits to Interactive Science and Technology Centers, Museums, Aquaria, and Zoos to Promote Learning in Science. Journal of Science Teacher Education. 6. 175-185. 10.1007/BF02614639.

Shake Alert. (2023). Geoscience Research and Technical Papers. https://www.shakealert.org/research/ (Accessed 2024-01-03)

Sjöberg, S. (2011). Naturvetenskap som allmänbildning - En kritisk ämnesdidaktik. 3rd ed. Studentlitteratur AB.

Skinner, B. F. (2014). Undervisningsteknologi. Lund: Studentlitteratur.

Skolverket, (2011). Gymnasieskolan. https://www.skolverket.se/undervisning/gymnasieskolan/laroplan-program-och-amnen-i-gymnasieskolan/laroplan-gy11-for-gymnasieskolan (Accessed 2024-03-08)

Skolverket. (2019). Naturvetenskapsprogrammet - Uppföljing av Gymnasieskolan 2019. Skolverket. https://www.skolverket.se/download/18.6bfaca41169863e6a65f03b/1555426189637/Naturvetenskap.pdf (accessed 2024-01-13)

Skolverket. (2019). Teknikprogrammet - Uppföljing av Gymnasieskolan 2019. Skolverket.

https://www.skolverket.se/download/18.6bfaca41169863e6a65f03e/1555426189868/Teknik.pdf (accessed 2024-01-13)

Stewart, I.S. & Piccardi, L. (2017). Seismic faults and sacred sanctuaries in Aegean antiquity. Proceedings of the Geologists' Association, Volume 128 (5–6): pp 711-721. https://doi.org/10.1016/j.pgeola.2017.07.009.

Svenska Science Centers. Hitta STEM! https://fssc.se/hitta-stem/ (Accessed 2024-01-13)

USGS. Can you predict earthquakes? https://www.usgs.gov/faqs/can-you-predict-earthquakes (Accessed 2024-01-03)

Vilius Petkauskas. (2023). The '1977 trinity' and other era-defining PCs. Cybernews. 15 November. https://cybernews.com/editorial/the-1977-trinity-and-other-era-defining-pcs/ (Accessed 2024-01-05)

Vygotsky, L. S. (2010). Tänkande och språk. Göteborg: Daidalos.

Y. Yasuoka, T. Ishii, S. Tokonami, T. Ishikawa, Y. Narazaki, M. Shinogi. (2005). Radon anomaly related to the 1995 Kobe earthquake in Japan. International Congress Series. Volume 1276. 426-427. https://doi.org/10.1016/j.ics.2004.10.011.

16 Appendix

16.1 Appendix 1

1. Vad är den vetenskapliga metoden?
   (a) Måste man använda sig av den?
   (b) Varför använder man den?
   (c) Hur ser den ut?
2. Hur ser en arbetsdag ut för en forskare?
   (a) Vad forskar man om?
   (b) Vem bestämmer det?
   (c) Hur länge forskar man?
   (d) Vad tar tid i forskning?
3. Vad gör man när man fått sitt resultat?
   (a) Varför gör man så?
   (b) Vad gör man inte?
   (c) Vad är det viktigaste med sitt resultat?
4. Vad är dålig forskning?
   (a) Hur skiljer sig det från bra forskning?
   (b) Hur skiljer sig det från otur?
   (c) Varför finns dålig forskning?
5. Vill ni forska?

16.2 Appendix 2

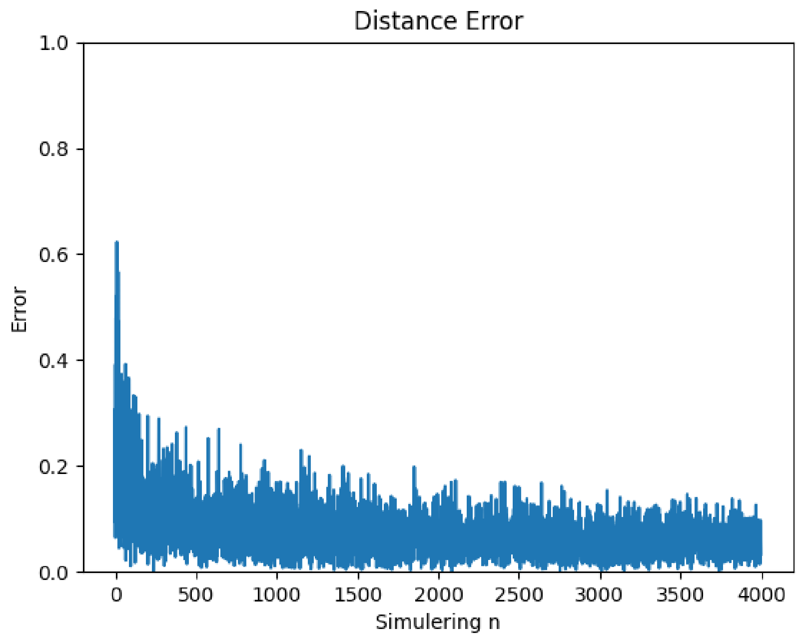


Figure 14: Distance Learning Curve of network 800-70-40-20-4

16.3 Appendix 3

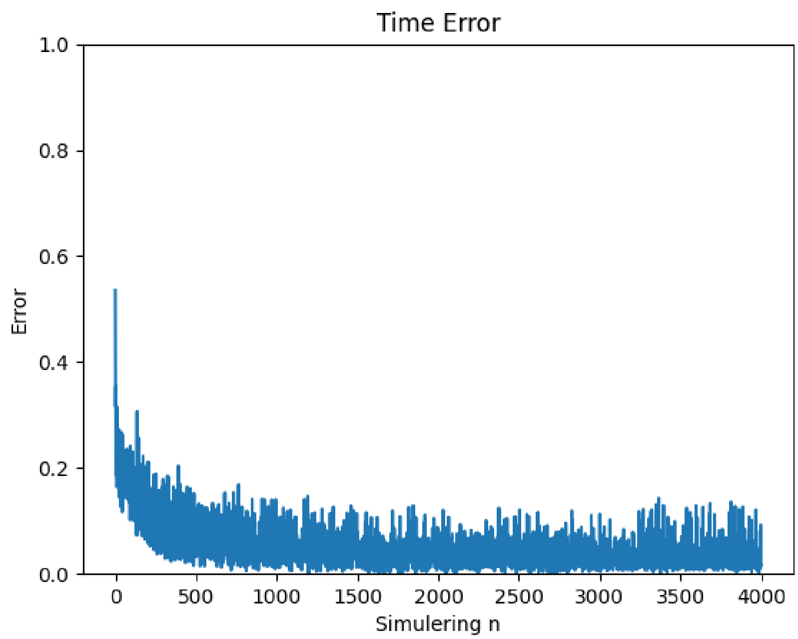


Figure 15: Time Learning Curve of network 800-70-40-20-4

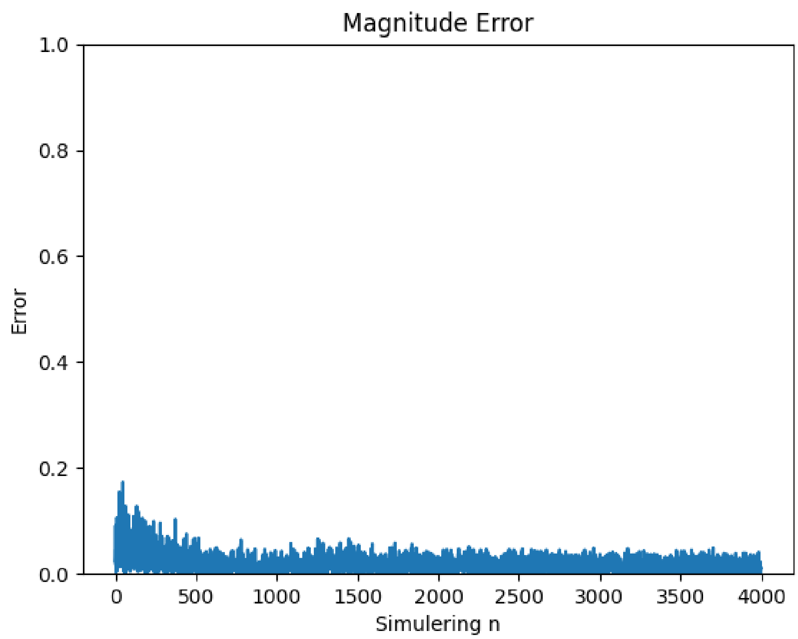


Figure 16: Magnitude Learning Curve of network 800-70-40-20-4