Ways to maintain DNA readability over a time span of 1 billion years on the moon

INTRODUCTION

Lunar mission one is a project which aims to send an archive of human life to the moon where it would remain buried in the South Pole for at least a billion years. The Shackleton crater landing site is shown in (image one) .The archive is expected to survive because the natural conditions in the borehole are almost perfect; with low temperatures, a complete vacuum ,completely dry and relatively little disturbance from external factors e.g. radiation ,elemental particles, meteorites due to the meters thick encasing of rock which provides protection.[1]

The DNA is expected to be stored as a strand of hair, this has many storage advantages because it is lightweight and this will result in a greater number of DNA samples being stored and fewer costs.[2]

ABSTRACT

My chosen topic is looking at the preservation of the DNA on the moon in the borehole. My main aim is to find ways to maintain the DNA's readability over a period of a billion years so that in the future a complete information sequence of the genome could be successfully reconstructed. I have researched various different ways to achieve the desired aim through two options; regeneration or repair of the DNA .My research aims to provide a solution to the problem of inevitable DNA damage and decay. Another point of importance is that human DNA will evolve in the future, therefore replacing the DNA with a more up to date new undamaged sample in the future would not be very accurate to our own time period and consequently the entire aim of the DNA archive would be defeated.

[1] https://lunarmissionone.com/lunar-mission-one/the-lunar-archives
[2] https://lunarmissionone.com/lunar-mission-one/the-lunar-archives

Figure 1The Shackleton Crater landing site

I found the majority of my information online in articles, science journals and papers etc. It was difficult to understand the expert terminology and detailed information in the articles which usually were written for people that were familiar with the subjects. However, this has just made me even more curious and I really hope to understand everything in the future. It was definitely more helpful to have face to face contact with Dr Momna Hejmadi in Bath University who is carrying out research into the characterisation of photolyases (DNA repair enzymes) , she gave me great advice but also made me realise that some of my ideas were too complicated to achieve. I also spoke with Sue Dimond who helped me to focus on particular ideas.

METHODOLOGY

I first brainstormed my ideas,these are some of my initial ideas and I now realise that not all of them are possible...
We could engineer a self-sustaining virus/bacterium that could feed on materials readily available on the moon and its function would be to regenerate the DNA constantly at time intervals by copying the original cell and creating a younger undamaged version.
We could engineer the cell cycle and instruct it to last for our own specified lengths of time so that this regeneration would only take place a set number of times and not become out of control.
I could also look at extremophiles or abnormal organisms and look at the ways they are adapted to survive in such extreme conditions. Perhaps their DNA could have advantageous additions that would make it more likely to survive. I would then apply these ideas to Lunar Mission 1, for example if there was a chemical mechanism which made the DNA more stable I could isolate some elements and suggest that they could be tested on human DNA to find the effects. However there would be definite drawbacks with this approach since the human DNA would be altered from its original form.

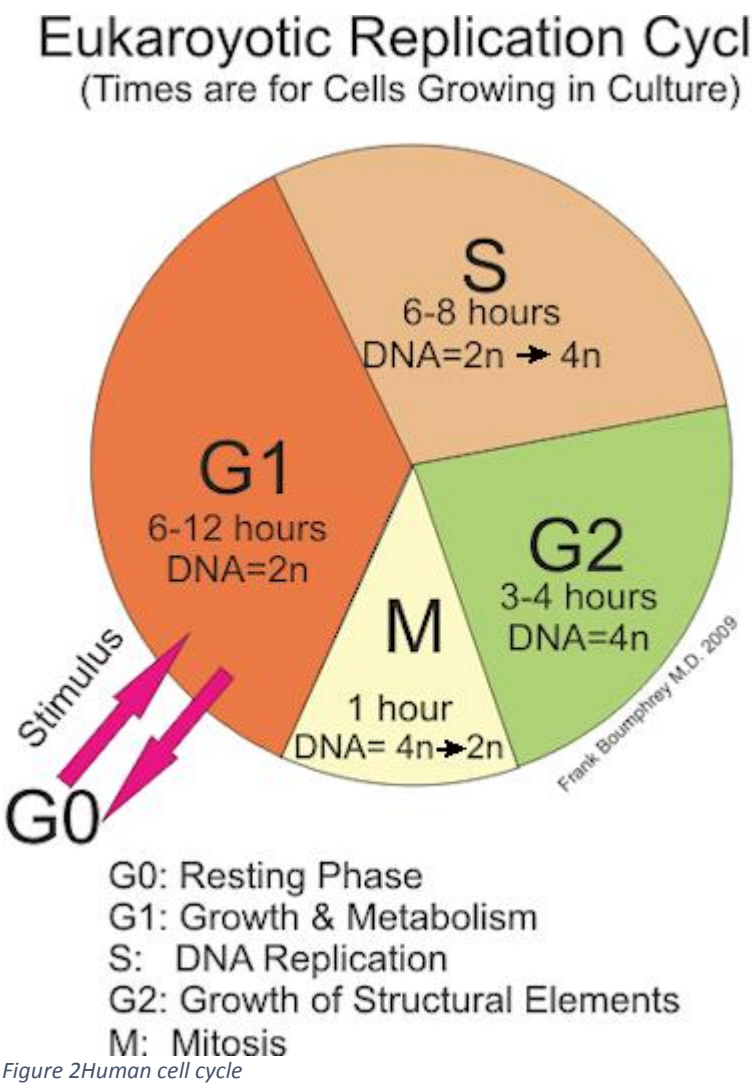
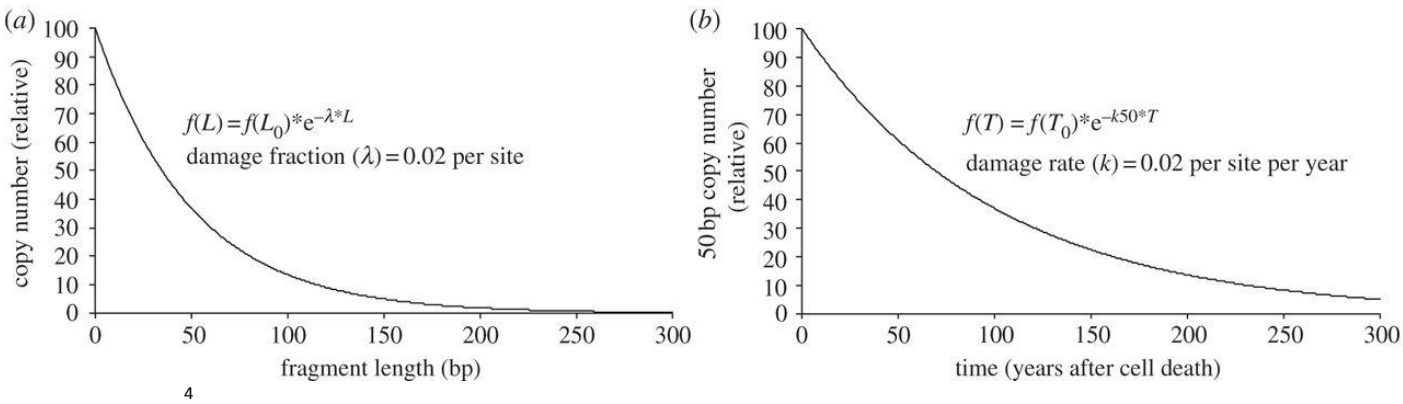


Figure 2Human cell cycle

RESULTS AND DISCUSSION

LOOKING AT DNA DECAY

My first step was to do some background research into how long DNA can last for and its rate of decay in a natural state. It was quite difficult to find an accurate answer because modern humans evolved around 200,000 years ago and our ancestors who have been around for about six million years had different DNA to us.[3] My reason for researching this was to find out approximately how often the DNA would have to be regenerated or repaired and therefore be replaced by a newer copy and since we need to make the DNA last for a billion years it would be important to find out how many materials would need to be used and the periods of time in which this would occur.



[4]

Figure 3 DNA fragmentation theory: (a) The exponential relationship caused by random fragmentation of DNA (b) A hypothetical signal of temporal DNA decay. The number of DNA copies of a given length (L) will decline exponentially with time—hence the notion that DNA has a half-life.

Research carried out by Morten E. Allentoft et al. states that the hydrolysis of amino groups accelerates depurination and this results in strand cleavage. The DNA fragmentation is random and generates a "characteristic negative exponential correlation between DNA fragment length and number of molecules" This article suggests that DNA would cease to be readable after 1.5 million years; "The team predicts that even in a bone at an ideal preservation temperature of −5 ºC, effectively every bond would be destroyed after a maximum of 6.8 million years."[5]

There are issues with these results in relation to lunar mission one because the DNA they were looking at belongs to a New Zealand Moa and was obviously not stored in the same conditions as the borehole.

However, the longest-lasting sample of human DNA had a survival age of 7000 years but was not fully readable .This is because DNA has limited chemical stability and will decay without the enzymatic repair mechanisms of living cells.[6]

I could not find enough research which related to the specific conditions in the borehole and since this DNA preservation in space has never happened before

[3] http://www.universetoday.com/38125/how-long-have-humans-been-on-earth/

[4] http://rspb.royalsocietypublishing.org/content/279/1748/4724

[5] http://rspb.royalsocietypublishing.org/content/279/1748/4724

[6] http://mentalfloss.com/article/48815/how-long-does-dna-last

there is not any reasonable prediction to be made for how often the DNA will need to be replaced /regenerated. However the conditions in the borehole are much better than the conditions the DNA from these experiments was preserved in, therefore all we can do is make a reasonable prediction.

RADIODURANS

Deinococcus Radiodurans are an extremely Radiation-Resistant Bacterium and I have looked into the adaptations they have which makes them so successful. They are resistant to DNA damage from many high forms of radiation and other factors and this is mainly down to their extremely efficient DNA repair mechanisms[7]. Unfortunately there has not been enough research into their genome but it would be amazing if we could utilize these mechanisms for Lunar Mission one.

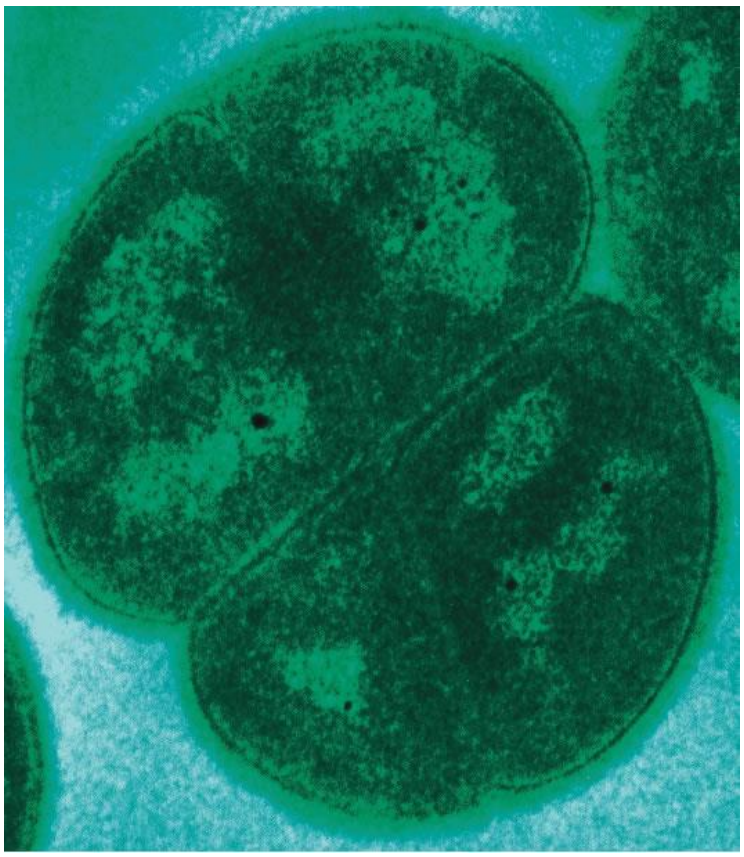


Figure 4Radiodurans Microscope image https://upload.wikimedia.org/wikipedia/commons/7/73/Deinococcus_radiodurans.jpg

[7] http://www.annualreviews.org/doi/abs/10.1146/annurev.micro.51.1.203

DNA REPAIR /DNA REGENERATION MECHANISMS

REGENERATION IN MICE

I decide to look into regeneration because I thought that we could use the mechanisms on the DNA for LUNAR MISSION 1.*The article ".Epigenetic Basis of Regeneration: Analysis of Genomic DNA Methylation Profiles in the MRL/MpJ Mouse" by Bartosz Górnikiewicz et al. states that every organ originated from a zygote ,therefore single genome must contain the information needed to grow organs and tissues and restore lost or injured structures.*[8]*Their research looked at MRL/MpJ mice that can carry out mammalian regeneration .For example; the ability to close 2mm ear holes in the ear pinnae ,an enhanced regenerative response in other tissues including cornea, retina, digit tips, heart ,articular cartilage, and spinal cord. This type of regeneration is similar to the type observed in amphibians so could perhaps be more easily applied to LUNAR MISSION 1 because it is looking at mammals.It is suggested the mouse has this remarkable ability partly because of a deficiency in the p21 gene which inhibits cell cycle progression. The p21 gene could be used to control the cell cycle of the DNA in LUNAR MISSION 1 so I carried out more research into it.*

THE P21 GENE

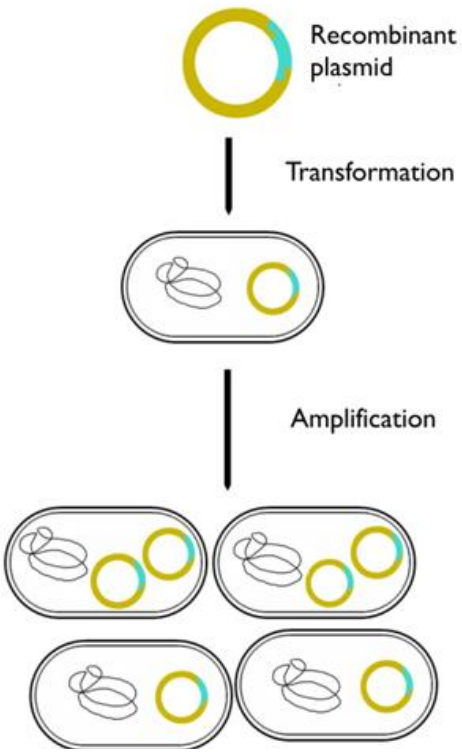


Figure 5 The basic process of transformation with bacteria http://usmle.biochemistryformedics.com/wp-content/uploads/Bacterial-transformation.png

The p21 gene is one of the main mechanisms for tissue regeneration and healing in a variety of organisms and it is involved "in response of cellular stresses such as DNA damage"[9] . I researched further into whether a bacterium or microorganism could be engineered to carry out the function of this gene. This would be through the process of transformation which is "genetically altering a cell by incorporating other genetic material"[10]. Genetic recombination brings to light many ethical issues, for example whether we would be contaminating the moon if the bacterium was somehow removed from the archive.

The drawback to this idea is whether the Bacteria would survive the extreme conditions on the moon and this creates another problem of keeping the bacteria alive for long time periods. Also, the DNA sample could become contaminated and mutations could occur during the process therefore this is not an idea I would recommend.

[8] www.ncbi.nlm.nih.gov/pmc/articles/PMC3859327/
[9] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3152998/
[10] https://www.boundless.com/microbiology/textbooks/boundless-microbiology-textbook/microbial-genetics-7/genetic-transfer-in-prokaryotes-81/bacterial-transformation-442-6842/

After talking with Dr Momna Hejmadi I realised that this was impossible to achieve because the DNA itself would be non-living so the same functions that take place in living cells could not be applied to the DNA used in Lunar Mission 1 unless we preserved a living cell. I also briefly researched Newts and Amphibians which possess the ability to regenerate limbs but came to the same conclusion.

DNA CLONING

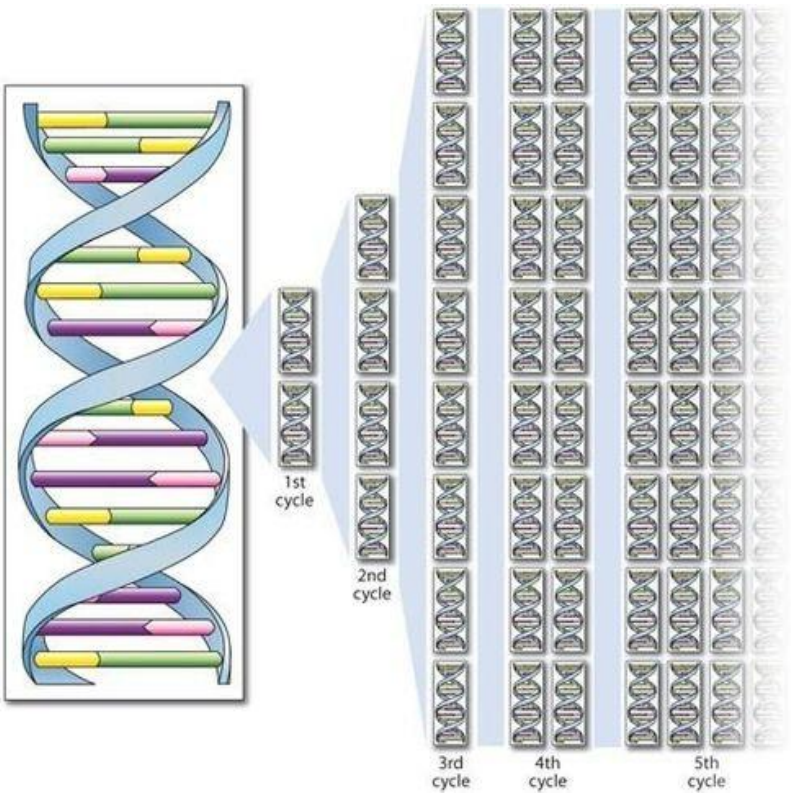


Figure 6DNA cloning http://biotechlearn.org.nz/themes/dna_lab/images/dna_cloning

This DNA cloning sounds quite promising however I am not sure whether an entire genome could be pasted into a vector.If the host cell was a bacterium it could be genetically engineered to survive in space like a tardigrade or Radiodurans.

"To get multiple copies of a gene or other piece of DNA you must isolate, or 'cut', the DNA from its source and then 'paste' it into a DNA vector that can replicate (or copy) itself."[11]

[11] http://biotechlearn.org.nz/themes/dna_lab/dna_cloning

"The four main steps in DNA cloning are:[12]

Step 1. The chosen piece of DNA is 'cut' from the source organism using restriction enzymes.
Step 2. The piece of DNA is 'pasted' into a vector and the ends of the DNA are joined with the vector DNA by ligation.
Step 3. The vector is introduced into a host cell, often a bacterium or yeast, by a process called transformation. The host cells copy the vector DNA along with their own DNA, creating multiple copies of the inserted DNA.
Step 4. The vector DNA is isolated (or separated) from the host cells' DNA and purified."

CELL CULTURE IN SPACE

Before you continue I really recommend you read this article: http://er.jsc.nasa.gov/seh/cell_growth_in_zero_g.pdfI

I realised that one way to "regenerate" the DNA would be by growing a newer copy as a cell culture. However the main drawback is that the original cell needs to be alive in order to be copied so we would have to incubate it for long periods of time to keep it stable and this may affect the DNA. Further research should be carried out to find out which cell type should be stored in which conditions in space for them to survive. The technology would need to have a power source which I suggest could be solar panels or a battery.

Cell life and general structure are not dependent on gravity[13] so the factor of gravity will not negatively affect the cell culture. In fact cells grew better in space conditions because they were not being flattened by gravity into a 2d layer which deformed the cell shape from how it was naturally found in the body.

Engineers David Wolf and Ray Schwarz created one of NASA's bioreactors which they had planned to test in space .however this trip was never able to take place.[14]

More recently NASA has used 3D cell culture technology called Alvetext to grow cell cultures in space[15]. This technology could be utilized for Lunar Mission one because it is very thin and light .

Because the cell would need to be alive before it is copied the cell need to be preserved in an incubator.[16]"The Bioculture System is space biological science incubator for use on the International Space Station (ISS), This incubator supports a wide diversity of tissue, cell, and microbiological cultures and experiment methods to meet any space flight research experiment goals and objectives." This is exactly the kind of technology we would need for Lunar Mission One and I really recommend the Lunar mission one team look at this website for equipment ideas: http://www.synthecon.com/pages/home.asp.

[12] http://biotechlearn.org.nz/themes/dna_lab/dna_cloning
[13] http://celartia.com/easyblog/microgravity-cell-culture-in-the-space-and-on-earth
[14] https://spinoff.nasa.gov/Spinoff2011/hm_1.html
[15] http://www.bbsrc.ac.uk/news/research-technologies/2014/140128-f-3d-cell-culture-set-for-space/
[16] http://www.nasa.gov/mission_pages/station/research/experiments/1125.html

I realised that if the DNA needed to last for 1 billion years we would have to think about how many copies we would need to make of the DNA and how many regeneration stages would need to occur. For example this cell culture would need to take place maybe 5 times with the daughter cells being placed in an incubator after growth. We also need to have enough materials such as nutrients for the cells and also a suitable way to store this for a long time period such as the incubator. I think repair would be far too complicated though because there is nothing that could possibly exist that could carry out the job. We need a simpler solution and this would be cell cultures.

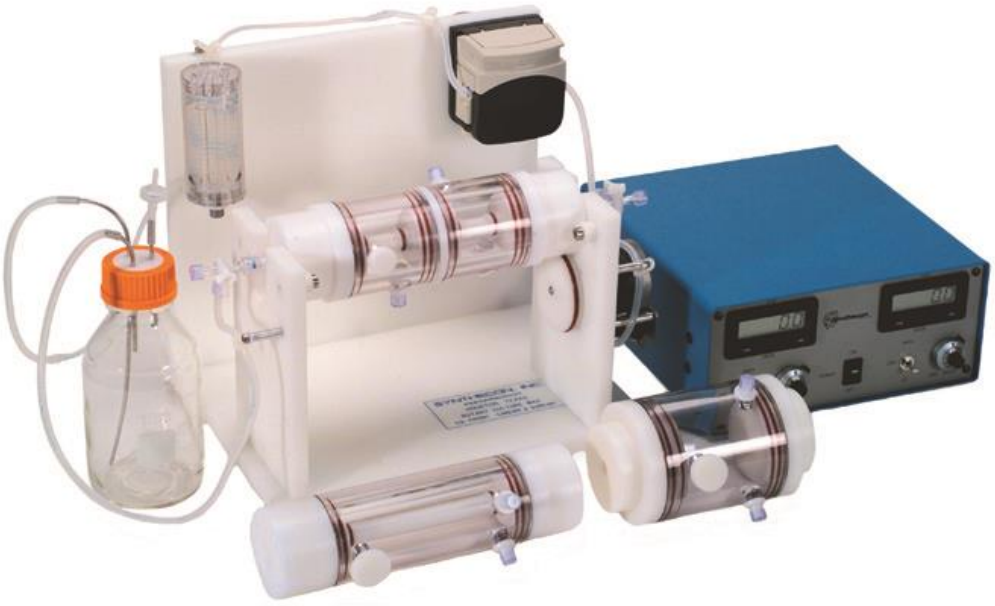


Figure 7 Synthecon Inc.Bioreactor https://www.nasa.gov/offices/oct/home/tech_life_synthecon.html#.V9ilV60Y1sA

Figure 8 Bioculture System with 10 independent cassettes – courtesy of Tissue Genesis, Inc. http://www.nasa.gov/mission_pages/station/research/experiments/1125.html

EVALUATION

If the work was to continue we would need to look into these issues in greater detail: If the enzymes or the genetically modified bacteria could survive on the moon there are further complications to look into e.g. how would they know when to repair the breaks in the DNA? There would need to be some kind of chemical signal. There are also issues with keeping any technology that is used stable enough to fully function for many years. Would solar powered electricity by substantial enough to power this technology?

In my opinion the cell culture option is the most straightforward to achieve because it is functional and has been used before so I would recommend it over the others

Here are some ideas I have only briefly thought about- they should be explored further:

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- Instead I could have looked into strengthening the DNA bonds chemically so they are less likely to break in the first place.
- We could immobilise the DNA molecules in substrates or a glass imbedded probe. However immobilising the DNA could lead to the formation of amide bonds which tend to fragment large polynucleotides, therefore the DNA would be damaged. [17]More research could be carried out to find out whether there is a way to prevent damage and whether this way results in long term readability of the DNA.
    - If the DNA needed to be isolated from the cell micro filters could be used to dissolve the tissue and extract the DNA
    - Future research needs to be done to find a chemical that could preserve the DNA.
    - There needs to be a way to preserve enzymes if they were used to carry out any DNA repair.
    - A synthetic human genome could be created as an example of human DNA in our time period however there are communication issues for anyone who found the archive in the future.
    - Look into Non enzyme based structural characterisation
    - Use CRISPR technology to copy the DNA
    - I read an article about enzymes growing artificial DNA

[17] http://web.calstatela.edu/dept/chem/Zhou/publications/fine-scale.pdf

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