Course Name: I think Biology

Professor Name:Sravanti Uppaluri

Department Name: Biology

Institute Name: Azim Premji University

Week:1

Lecture:2

W1L2_Pillars of Biology

Hello, welcome to iThink Biology again. In this session, we pick up where we left off last time. We discussed what is the discipline of biology really is. And we came to the conclusion that biology is the study of living things. We also realized that defining what how something rather defining whether something is living or not was not that easy. So today, we'll take another approach to try to look at the pillars of biology.

What I mean by that is what are the main concepts that are really important for us to study living things. So the first really important concept is actually genetics. What is genetics? What we are familiar with really when we talk about genetics is DNA right? So DNA is found in our cells.

And these cells are all over our body, right? Our entire body is comprised of cells. The next concept is evolution. And evolution is really an idea that tells us about why we have so much variation in nature, right? So on the right hand side, the image that you see are actually Darwin's famous finches. Darwin is considered "the father of evolution". And Darwin has managed to explain why finches that presumably are of the same species start to look different over time and that these species start to diverge.

So why does this happen at all? Alright, so let's look at these two concepts in a little bit more detail. What is evolution? So evolution is the change in characteristics of a species over several generations. So in regular language, we often use the word evolution and evolve as something to represent, let us say change or adaptation to a new situation, right? But in biology, evolution has a very precise meaning. So let's have a look at this definition in a little bit more detail. So evolution really is change.

But here we are referring to characteristics that change in a population. So not just in one individual, but in a population, so in a species, and that this is over several generations. Right? So it's not the same as saying I've moved to a cold city or a cold country. And I've become used to the cold. That is not evolution, right? Because it's happened to an individual, not in a population, and not over several generations.

You will learn a lot more of the nuances about evolution later on in the course. The next thing is genetics. What do we mean by genetics? Genetics is really the study of genes. What are genes? Genes are specific sequences in your DNA, right? Sequences of letters. So your DNA is basically nothing but an instruction manual, and this instruction manual is written in the language of DNA, which has four alphabets, ATGC.

Yeah, I'll just write this down for future reference. And this sequence of ATGC, right? there are in say the human genome, there are billions of these bases of these alphabets that result in our in a specific sequence that gives us our characteristics, right? And any change in the sequence leads to genetic variation, which is what makes you and me look different, right? Not only that, this sequence is passed on, at least some part of the sequence is passed on from one generation to the next. So inheritance, the study of inheritance, how genes are passed on, which genes are passed on is a really important aspect of genetics. And you will see later on why genetics and evolution are so strongly tied together. Okay, so let's come back to what we discussed in our last session, which was to say, what are the characteristics of living things? And some of the things that we had written down were the fact that living things can move, that they require fuel, some sort of fuel, right?, some sort of energy intake that they reproduce.

And perhaps that they produce waste, or another way of putting it is that they metabolize, they have some input. And that input gets processed, and it's used for something, but in turn that there's also some waste that's produced. And there is so some output. And at the end of the session last time, we discovered that, well, not all living things actually have all of these characteristics, right? So it's only a subset of these characteristics. So we weren't really able to come up with a really nice definition for everything that is alive.

So another way of thinking about, of, you know, sort of trying to think about life is to start to see what are the relationships between living things. So you may have seen this kind of representation before the tree of life, right? So at the very top here, right, you see now, so in present day, these are all say, this is a representation of all of the sort of branches of life, right?, from bacteria, bacteria also called prokaryotes, eukarya, and archaea. So these are the three branches of life as we know them, right? But they are, if you go further back in time, about 4 billion years ago, is when we think life actually originated, right? And you start to see if you look carefully at this nice image, you start to see that it starts to branch out further and further and further as you move along in time. So this is a nice representation, but perhaps one that is a little bit more accurate is what you see on the left hand side, again, with the same three branches of life, bacteria, archaea, and eukaryotes. And what you see here, which is very clearly represented, is that these three branches of life have come from one single origin, right? And the single origin is labeled “Luca”, the last universal common ancestor.

What this means is that all of these branches of life, right?, whether you're a bacteria, whether you're archaea, whether you're a eukaryote, so whether you are a human being, a mango tree, a fungus, or E.coli, right? All of these species and organisms, if you go back in their evolutionary history, would have actually arisen from a common ancestor, right? So this tree, of course, doesn't represent all of the species that we know of. Another way of representing these is this tree on the right hand side. And it will be very difficult for you to see it at this resolution. But hopefully you can see that there is an origin here where my cursor is, and, you know, branches start to branch out.

And eventually you get all of these multiple branches, which represent eubacteria, protists, plants, invertebrates, vertebrates, and of course, humans fall under mammals under vertebrates. And we are here somewhere along this evolutionary time. Okay. And how do we actually come up with these, these trees, right? How do scientists figure out these relationships? So let's look at this tree, for example, in a little bit more detail. This is just one that's a little bit easier to, to sort of analyze.

So what you see here first is that Luca, the last universal common ancestor was the origin. Then there was a branch. In other words, there was a kind of divergence, right?, which produced bacteria and archaea. And between archaea and eukaryota, there was again another branch, right? Again, this is over time, how these species diverged. And how do we know this divergence at all? How are we able to figure out that these relationships really exist? So how we are able to figure out these relationships are actually through the use of genetics.

So, what we do is we look at sequences of DNA, right?, sequences of DNA that some of them code for genes, sorry, some of them code for proteins. And these sequences, in some cases, look very similar, and in some cases look very different, right? So the closer these sequences are, right?, the closer they are, better match they are, right? That means that they are sort of closer in evolutionary time. So I've simplified it a little bit, but that's basically the gist of it, right? The more similar you are, you've probably between species, right?, if probably diverged more recently, right? The species have diverged a little bit more recently. And why do these divergences occur in the first place? They occur because there are errors in inheritance. A better way of putting it is there are errors in replication.

So when reproduction occurs, reproduction means there's a faithful copy of the parent to the progeny, right? And if there is an error in the DNA sequence, that can eventually lead to either an error that leads to a positive sort of fitness or adaptation, which means that the organism is actually better off. So there's an improvement. And so that gene may be passed on further. On the other hand, if the error in replication or cell division happens, that is detrimental, so that causes an organism to be less fit and is less likely to have progeny that will be successful, that error will slowly die out. So you can see now that there is a propagation from of errors from one generation to the next, right? And if this gets propagated, it starts to take over the population.

So all of this together really means, what does it mean that there are these errors that are propagated? And that all of this has come about from just one universal ancestor, right? So what it means actually is that we have all living things on this earth, right? Have two things in common. First, we are all made up of cells. When I say we again, I refer to all living things, right? We are all made up of cells and we all have DNA as our genetic information. Let's break this up in a little bit more detail. What do I mean when I say we are all made up of cells? Cells are basically the compartments in which our basic unit of sort of function are encompassed, right? In unicellular organisms, here is the image that you see here is basically cartoon pictures of various microbes, unicellular organisms.

And you can see they come in a plethora of shapes and sizes. So too you see cell types that are very, very different in multicellular organisms. you can you know It's really beautiful to see different cell types. There's such a wide variety of shapes and sizes. And these are often matched to the specific function that they have or the environment that they have that they are in.

The other thing is DNA. So DNA is the genetic information. It's a set of instructions basically that determines our traits, our shape, our size, and often some of our behavior, right? And what is DNA made of? That's what's image on. This DNA is a molecule that you see on the right hand side. And it's basically a polymer of bases, okay, of nucleotides actually. We'll talk more about this in later classes.

But basically, you see that there's an alphabet, right? I referred to it earlier ATGC. In this particular sequence, we have A, G, T, A, C, G. And so this sequence will be important for the function of whatever gene it's part of, right? If there isn't any alteration, that is called a mutation. But what's really cool is that all cells, right, all cells contain DNA.

All living things contain DNA. And this DNA is a set of instructions. Okay, there are still some viruses that use RNA, right? The difference between RNA and DNA is really this sugar backbone, the sugar in the backbone. And RNA is a little bit less stable than

DNA. But all living things use DNA, whereas some viruses still use RNA, which is also one of the reasons why viruses are sort of considered to be on the border between living and non-living. All right, so if all living things have DNA, what does this mean? If all living things are made up of cells, what does this mean? So let's talk about what this means that all living things are made up of cells.

The first thing is that whether you are unicellular or multicellular, you are either made up of one cell or multiple cells. And if you are made up of multiple cells, if you're a multicellular organism, those cells take on individual cells or collections of cells have a division of labor. In other words, the white cells, these are unicellular organisms. A little below it is a multicellular and abstract multicellular organism. And what you see is that potentially these green cells have a different function than the ones that are not colored in, right? So there is a division of labor, right? So for example, the cells in my eye have a very different function than my skin cells, right? So there's a division of labor when you go to multicellularity.

But either way, all living beings are composed of one or more cells. The other thing is that the cell is a basic unit of structure and organization. So having these compartments is also a way of organizing an organism, right? So just like we have drawers and we organize our papers in different ways, the same way the cell is a particular unit, right? And this unit actually arises from pre-existing cells. So you will never get a cell that sort of spontaneously assembles.

That's not the case. A cell actually always comes about from something that, from a previous cell that existed before. Now, this might make you ask, what about LUCA? Where did LUCA come about? So this is actually a major field of study, which is called the origin of life, right? So people want to understand how basically at one point on earth, everything was abiotic, so non-living. And then there was a kind of transition from abiotic to biotic. And LUCA is considered exactly this, right? There was some sort of self-assembly of abiotic factors that led to something that was biotic or living. So you can see that this is a very, very interesting idea to pursue, is the origin of life, right? How did the first cell arise in the first place? Because now, in present day, everything that is alive has actually come about through pre-existing cells, right? So it's the basic cells are the basic unit of reproduction.

Okay. So as we said earlier, cells can be unicellular or multicellular. Not only that, some organisms in their life cycle have the ability to transition from being a unicellular organism to being a multicellular organism, right? And every multicellular organism has the same, so every cell in a multicellular organism has the same DNA. That means it has the same set of instructions, even though, as you recall, I said there was division of labor, right? So in some organisms, they can transition from being single-celled, unicellular to multicellular in their own life cycle, and they can go back and forth. A very good example of this are some amoeba, right? They can exist as individual cells, but sometimes come together and form spores and have really, within the spores itself have different functions.

Okay. In our own body, we have different kinds of cells, right? These are images of intestinal cells, Red blood cells, muscle cells, fibroblast cells, neurons, and as you can see, they have vastly different shapes, sizes, and functions. Not, but what is interesting is that even though they are so different, both in terms of the way they look and in terms of the function that they carry out in the body, they carry the same exact set of instructions, right? So the question to ask, which we will again talk later, is how are these instructions, if they're exactly the same, how do cells end up being completely different, right? And this is the whole field looking at gene regulation, right? How are genes regulated in order to give rise to such a diversity in cell types? Okay. So we said that living things have two main things in common. One is that they're all made up of cells and they all have DNA.

Okay. So what does this mean? That means that in order to carry out these functions that we talked about earlier, right? Everything from movement to, you know, some form of combustion of fuel, reproduction, metabolism, all of these things actually require both this compartmentalization, this basic unit of structure and organization, which are cells and DNA, which are which is basically the set of genetic instructions, right? And these instructions, as I said earlier, are passed on from one generation to the next. So what does that mean? There is this genetic information, right? All organisms have genetic information and this genetic information is in the exact same language, right? So it is not that bacteria speak French and archaea speak Hindi and eukaryota speak Tamil. No, that's not the case. Rather, they all have the same language, right? But within that language, they have a different set of instructions. I mean, for me, that is actually a really, really profound concept, right? It's a really, really profound thing to think about.

It actually means that whether I am looking at the tree in the park or whether I'm looking at the dog or I'm looking at bacteria under the microscope, all of these organisms, all of them actually speak the same language, right? So if we can speak the same language, what is the consequence of something like that? So this commonality is really relevant and it's very, very important for various applications, right? It means that genetic engineering is possible. What does genetic engineering mean? It often really means that you can take genes from one species and put it in another. If you pause and think about this, it's really mind blowing because it means that you can take genes, so a set of instructions from an organism that is completely different, right? So say you could take you could take something potentially from a bacteria, right? Which is microscopic in nature. It does not so say the same bacteria that doesn't photosynthesize. You can take it, take a gene from that bacteria and then you can put it into a plant, right? A plant that is much larger in size that has a completely different life cycle and lifestyle, right? And that gene, that set of instructions will actually be followed by the plant, right? Because it understands that language, right? So this is really for me, this is really mind blowing.

So what does it mean? So what I described was actually just the process of genetic engineering where you can take a gene from one organism and put it into an organism of different species. So BT cotton, for example, and BT brinjal also are basically engineered variants of cotton, right? Where there is a gene that confers pest resistance that is found in bacteria in Bacillus tungenesis, that's what the BT stands for, and it can be transferred into, it has been transferred into the cotton plant, right? And now this plant is pest resistant. Of course, there are many ethical and ecological issues related to this, and we will talk about this later on, but the fact that this is even possible, right? Opens up, you know, such a wide variety of applications and these applications actually just keep growing. So in agriculture, of course, genetic engineering has been extremely important and very prevalent actually. In health, right? In medicine also, this has been very important.

So in medicine, for instance, insulin production, right? How do we get insulin now? So you know that insulin is used for diabetes treatment, right? This insulin actually comes from the human gene that is put into bacteria, and because bacteria understands the language of this gene, right? The sequences of ATGC, because the bacteria understands this language, it is able to produce insulin that we in turn can use for medical purposes, right? So we use bacteria as kind of a workhorse because they understand the same set of instructions that our own cells carry. Vaccines in turn, not just vaccines actually, all medicines, right? We use first by testing on model organisms. You can read more about model organisms in the Rotavirus chapter in I think biology. So because we are so closely related to everything from worms, mice, and other primates, we're so closely related to them again, you know, in terms of evolution, right? We believe that a lot of what how we may react to new drugs would be similar in worms, mice, or other primates for that matter, right? And so we can test vaccines and drugs and other kinds of products on these organisms, model organisms, before we try it in humans. Of course, there are other ethical implications to this and important ones we should which we should think about carefully, but the point is that this commonality, right, this common language that we have, both in terms of genetics and our evolutionary relationships with other species is very important.

Now, not only that, right, understanding this commonality in terms of the language of

DNA helps us understand our own evolutionary history, right? It helps us understand where we've come from. Finally, what's really important is that this idea of common language, right?, the genetic information, the genetic instructions that we talked about actually gives us a way to tie all living beings together, right? And this comes back to what we discussed of how you define something that is living. All right, so let's quickly summarize what we've talked about, right, in this session. First, we have two important concepts or pillars of biology that we refer to. One was genetics, the study of genes, genetic variation, and inheritance.

The next is evolution. Both of these we will discuss in detail in future sessions in this course. Then we discussed that all living things are made up of cells and DNA. And finally, we talked about why these concepts are very important for various applications and a fundamental understanding of biology and of living things, right? The first was genetic engineering, both in food and agriculture, as well as medicine and human health. And the second was for us to understand our own evolutionary history. So in the next class, we will discuss how these concepts?, how understanding what it means to be living?, what are the different functions of a living being?, actually can help us understand our own society and perhaps even help in dealing with our environmental issues. I look forward to the next class.