Introduction to Cell Biology
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Complexity and Compartmentalization in Cells – Part 2

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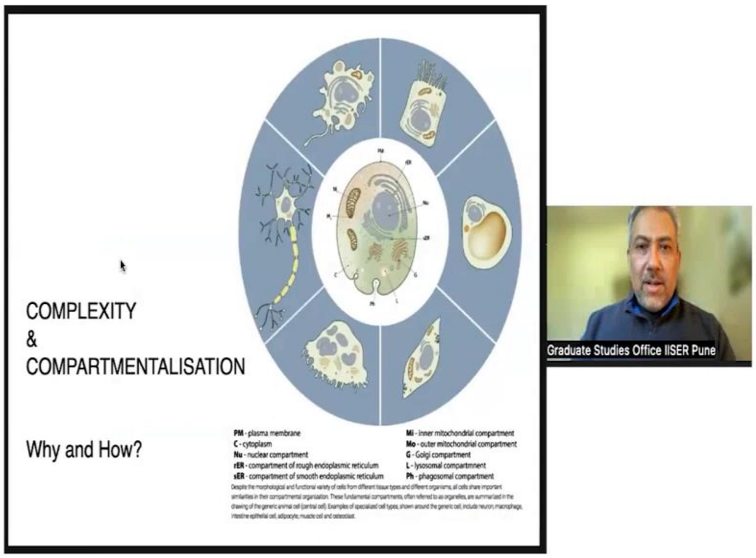

The question however now to think about and I want you to maybe give me your thoughts on this A, is one, is the why and how, of this of both of these parameters. Now, let us just pick compartmentalization. And because we just talked about all these different players that are present, and how in a eukaryotic cell a lot of organelles and structures are present, that allow the cell to now have this compartmentalization in a way that is only beginning to maybe happen in prokaryotes or not happening at all in most cases in prokaryotes.

So, the question is, what do you see as the advantage for the cell to really have compartmentalization? And let me hear your thoughts on what you think the advantages or disadvantages of this could be. So, I am going to go to the chat box and let us see what you have got to say. What you see as the significance of compartmentalization per se.

So, Varun has said, efficiency, and that is an important point. And there are two, and efficiency is a very loaded term. And I do not know how many of you can fully appreciate the significance of efficiency. There are two such terms. There is something called efficacy, and there is efficiency. And efficiency, obviously, is how efficiently the cell does things and that efficiency, Varun thinks, will get affected by the fact that there is compartmentalization.

Varun: Sir, like taking a real life example. We see the compartmentalization even on campus, I know where the chemistry faculty is, I know where the physics faculty is and I know where the bio faculty is. So, if I have a doubt with the math faculty, I can go to that place and come back very swiftly rather than…

Professor Nagaraj: So, let me play devil's advocate and say that, if the faculty all had nice like, geotags that they sell now, and you know where they are on a screen. They can be moving around anywhere in campus, and you will be able to still find them specifically. Is it only about finding something in a particular place that affects efficiency? Sarthak, what do you think?

Sarthak: I guess, it has to do with specialization, because suppose like you are a bio-faculty, for example. And if you would have been a general science faculty and you would have your education in general science, then I guess.

Professor Nagaraj: Sure. So, I see your point. So, now, if you do not know which bio-faculty to meet as well, as long as you know that this is where all bio-faculty sit, going there will kind of allow you to meet, whoever you think will be appropriate, provided you know where to go for the bio-faculty. So, you are right.

The fact that there is compartmentalization allows for segregation in a way of not just reagents or resources, but importantly function and that could indeed affect efficiency. And Sarthak your point which is a function and efficiency, being both regulated and both being actually connected might be what is very particularly interesting about compartmentalization.

Let us go to the listing again and see what else comes. Allows for more complex functions, allows for division of labor, allows for distribution of function, yes, that we talked about division of labor, again, processing, processes occurring separately, which is essentially the fact that functions can be segregated and processes can be segregated. Division of labor is an important point. Yes, that different things are done in different areas.

I do not know how many of you know about this, but when cars were being built at the beginning of the 19th century, the way they were built is a bunch of people will get together and build an entire car. And then there is this innovator in the United States who decided that there is a better way of doing this, and which is why does everybody have to know how to build the car. Why cannot we just say that this person learn how to build this particular part.

And the car essentially goes from one person to another, which means it takes less time to train people, because I have to learn only a very small part. I do not have to learn everything about how to build a car. And it is very easy, therefore, for you to create something or build the entire car, where individual people are assigned very specific or distinct roles. And this was the origin of the assembly line. And the innovator who went on to create this built an empire, essentially, of motor vehicles and he was Henry Ford.

Ford developed this idea of an assembly line. And this ensured that they could make significantly more cars. They could spend less time training people, which is a very big thing. The compartmentalization and the division of labor that you guys spoke about ensures that, in this compartment everything that is needed to do one or two things very specifically, is built in such a way that it does this really well. It cannot do anything else.

So, if you ask this compartment to go do something that another compartment does, it will not be able to. So, there is very little redundancy built-in in this system. And if you do not know what redundancy is, please go look this up. It is a term that will keep coming. And I will ask you again what redundancy is. And, but this compartment does its job really well. So, it dramatically affects the efficiency of this compartment, because it has to do one or two things, and it does it really well. And that division of labor that you guys have talked about and this ensures better coordination and it ensures better efficiency, and outcomes are far better.

The other interesting aspect, and I do not know if anybody is alluded to this here, is the quality that this compartment puts out can also be better monitored, because this compartment does one little thing. And this is again something that became evident when the assembly line was put together by Ford that they could now have a much greater control on the quality that a particular compartment is generating. And this could be another important addition.

I am just looking through the list and many of the thoughts are kind of now repeating, wastage of resources from different structures. And I think what you are referring to Yash is that resources are better utilized. And that may actually be true in some cases, that indeed, because of the compartmentalization, the way resources are distributed, they could be more effective and more efficient in this process.

Side reactions, Gautam has said, side reactions between different processes can be prevented, which essentially says that segregation, I guess, is more clean. And that ensures that this compartment does not actually go trouble another compartment or affect another reaction, because everything that it does is separate. Now, one of the things that is a fallout of this kind of compartmentalization. And when you think about the assembly line, also this probably occurs to you is that if you generate this kind of compartmentalization, you also need two things. One, as I said, is the quality control.

You need to be able to kind of know that this compartment has done its job well before something leaves and reaches another compartment. And the other interesting thing you need to have is a way for compartments to communicate with each other. So that is another additional step that comes in because of compartmentalization and that may come with a certain cost. But the benefits here of having compartmentalization might significantly outweigh the costs that you may incur to build some that is a connecting bridge between two compartments.

Let us go through the list again. Help cells to separate different type of reactions which are mutually exclusive, like light and dark reactions. Yes. So, we can separate functions. Help to resolve confusion for selecting the substrates and thus increase efficiency. Increased efficiency is something we have also alluded to. Vignesh is saying that I do not see any advantage if there was a significant advantage should not prokaryotic organisms have gone extinct. Good question and we will come to that Vignesh at the end. Let me take that at the end.

Compartmentalization, energy needs of the cell, yes. So, that it obviously the energy requirements have gone up. And the only way compartmentalization has come to play a role is because now there is a surplus of energy. And this is an important thought to have in mind that the development of both complexity and compartmentalization is in some ways, quote, unquote, a luxury, because it now allows us to do things with greater efficiency, it allows segregation of processes, but all of this comes at a cost, cost in terms of space inside the cell, in terms of energy requirements inside the cell.

And so this could be possible only if the, only and only if the energy availability for those cells have also changed over a period of time. And that might also explain why the availability of oxygen and the availability of now more energy, because we are able to harness, not just sunlight, but also the oxygen availability, that we are now able to develop complexity and compartmentalization at a later point in the evolutionary process.

There is a commentary on the Indian government as well. Which is just great. And only nucleus controlling all the processes, yes, exactly. So, just as we, you remember we talked about the more benign example of the network of trains. And so there is a regulatory center. And obviously, there are individual regulatory centers as well. So, if you are looking at an individual compartment, its quality control, and its control in general, not just quality, has a certain amount of investment made towards that, which is, again, as I said, these are all energy costs, and the cell is saying, okay, I have the energy, so now it is worth investing in something like this.

And so, there is not any struggle to survival. Compartmentalization increases coordination, which we already spoke about, make cells more efficient, the ability to multitask. And the, because we are talking about complexity and compartmentalization, the thought that I want to kind of raise here is that of whether these two are connected and how, like whether compartmentalization drives complexity and vice versa.

So, in part compartmentalization could add to this complexity that exists in cells. But some of the complexity that was evolving in these cells may have also contributed to how compartmentalization was made possible in eukaryotes, because the way they were able to process energy. See one of the things to consider here is that the energy requirement of the cell might have been a major rate limiting step. So, finding a way to say we will be able to break the energy barrier and have enough energy to do some of these things could have been that rate limiting step, something that said, this, when it starts happening and there is enough energy, then and only then can we really think of compartmentalization and evolving that complexity.

So, that could have been the rate limiting step, which, and let me just quickly run through this. Most of these seem like repetitive thoughts which we have kind of covered earlier.

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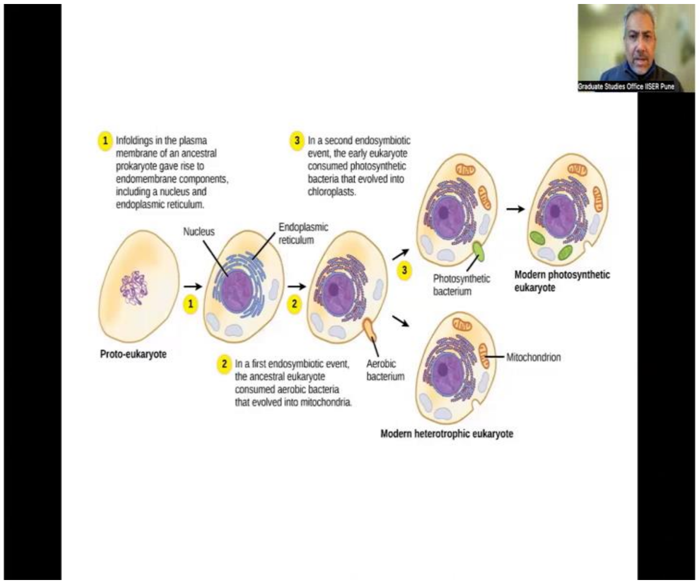

This energy requirement that I was telling you about is probably what, this theory or this idea of how complexity and compartmentalization may have evolved, because energy seems to be the early requirement for this kind of complexity to be developed, it is likely that that may have been one of the early changes that happened in cells. And the endosymbiont theory is a theory that essentially addresses this. Our next class will focus on the endosymbiont theory. So, this slide essentially just kind of captures a snapshot of what the endosymbiont theory would mean. And some of you are probably familiar with it already.

And what it suggests is essentially, some kind of engulfment of a slightly bigger cell now engulfing a smaller cell and now these two kind of existing with each other. And once it engulfs more than one of these, like an aerobic bacterium being taken up, these complex, like beginning to be complex cells, start now having the energy to do more things and that now they decide to invest in generating more complexity. Remember, one more thing to consider here and this is what we will talk about in the next class, so I am not getting into that right now.

The other interesting thing to remember in all of this is that there is a lot of trial and error here involved. So, do not be going around thinking, well, this fantastically evolved Golgi system or endoplasmic reticulum system is what, it is amazing that the cell evolved, and bingo, it had a Golgi, it did not. It had something that was the early form of the Golgi, so to speak, and it probably was very inefficient and it did a poor job. And then with changes that happen in the cell, the changes that were beneficial, so the Golgi changed in five or six ways.

The one or two ways that the Golgi changed with repeated divisions of the cell that were beneficial gave those cells a small advantage over the others. But in the big scheme of things, that small advantage may have been enough, and these cells started doing slightly better than the others, which means now the changes that happened in these cells that made them even a little more better were being selected for. And this kind of selection may have eventually give us, given us the kind of cell that we know about today and that we will look at today and the kind of organelles that we see.

So, with time now and now in this environment that we live in our cells are exposed to so many new things. These cells may actually be evolving as you and I speak today, and making small steady changes in the way they do things because of the environment because of how we eat and all the other things that the cells are coming in contact with and actively changing, and this process is continuing, as we speak. So, what we see right now and what we study right now is work that has taken millions of years to happen, billions of years to happen, and to lead up to a cell that does a remarkable number of functions in a very coordinated manner. And it does it so beautifully that it can live in groups and work as groups and give rise to complex organisms like you and me. So, that is where this stands at this point of time.

So, in the next class, we will talk about the endosymbiont theory. And we have a few minutes. So, what I am going to do is some of you have your hands raised, and I have had your hands raised for a while. So, let me just take those questions. Devesh, you had a query, please go ahead.

Devesh: Sir, could you go to the slide where you showed the graph.

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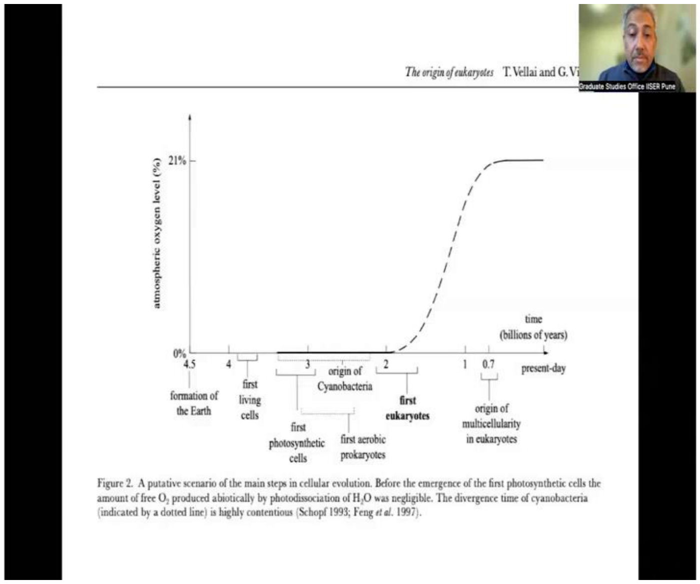

Devesh: Sir, did the rising oxygen level create the complexity in organisms or the…

Professor Nagaraj: No, no, no. So, it is not just the increasing oxygen levels. See, oxygen levels, and remember, even small incremental changes in oxygen levels could allow cells to now do things slightly better. So, these things are, these changes are happening over many millions of years. And they are very small incremental changes. So, the net oxygen level may have changed for you to be able to see a distinct enough rise in that curve would have required a significant number of changes to happen.

So, the first eukaryotes and the first complex architecture in cells that we know of, could have evolved significantly earlier and it could have contributed to building up of the oxygen levels in such a way that kind of that climb that you are seeing is becoming visible. But remember it is not the only factor, if that is what you are asking.

Devesh: Sir, I meant, like what is the cause and what is the effect? Is the growing complexity the cause of rising atmospheric oxygen?

Professor Nagaraj: Both ways. So, initially, the development of complexity, the presence of oxygen, the critical thing that I want you to understand is that increase is not the cause of the complexity. It does not need a lot of increase to happen for complexity to have been initiated, because the changes that we are looking at, a very small incremental changes, as are the changes in complexity very small and incremental. So, it is not going to be a dramatic shift.

And so it is a give and take. So the having bacteria or prokaryotes that can now survive under aerobic conditions and can use oxygen or produce oxygen could have driven the development of prokaryotic systems first, which then could have supported the development of eukaryotes and then that leads to a slow steady development or increase in oxygen. Remember, plants are the major contributors to the increase in oxygen content. They, it is not eukaryotic cells in complex animals. And that could have been a major factor in how this changes. Sneha, you had a query.

Sneha: Sir, centrioles have the pattern, nine plus two. So, is it same for eukaryotes and prokaryotes?

Professor Nagaraj: Why do not you look this up. Go find out and tell me whether centrioles are similar, because you have asked a complex question. We have not come to centrioles at all. But you know enough about centrioles, which means go look up to find out whether prokaryotes and eukaryotes have different arrangements for centrioles. Find out whether prokaryotes have centrioles at all, whether they do or not. Will you come back and tell me next class?

Sneha: Yes, sir. I will come.

Professor Nagaraj: Look this up. Vignesh, next query please.

Vignesh: You said that, when prokaryotes evolved they had compartmentalization and that was in greater efficiency and so on. how exactly do we measure that efficiency? Like quantitatively if you wanted to give something?

Professor Nagaraj: I do not think you can measure this quantitatively. The only way you can measure efficiency in my opinion is the fact that they kept evolving further, and they lived long enough to kind of develop more complexity. So, I do not think there is a measure to say that you can expect this kind of compartmentalization to have benefited in very small incremental levels to allow for them to sustain slightly better. As I said, in this environment is small difference in sustenance could mean a big difference over many millions of years.

So, I am not sure whether there is a real way to measure the improvement in efficiency. It could have been very, very marginal. It could have been something very singular, sometimes, not even a big change. But that singular change could have given just that little bit of advantage that over a few million years this thing that has the advantage became the predominant variant that existed, and this eventually kind of went away. And as I said, this is a process that could take millions of years to happen. Vaishnavi, yes.

Vaishnavi: Sir, are there theories other than the endosymbiont theory that can explain why eukaryotes evolved from prokaryotes?

Professor Nagaraj: Will you look this up? See what you find, because we have not talked about the endosymbiont we will next time. It is a good point. Is there another explanation for this that is as interesting as or as effective as the endosymbiont theory. Endosymbiont theory has its question marks by the way. Not everybody believes in it. The endosymbiont theory is developed by Lynn Margulis, and, yeah, there are question marks with it. So, why do not you look up and this could be a good thing to kind of raise next time, saying, are there any other theories that have tried to do what the endosymbiont theory has tried to do. Prerna, you have a query.

Prerna: Sir, I wanted to ask, I do not know if it is the right time to ask this question. But, like, I do not understand why there is a debate going on between the success of prokaryotes and eukaryotes. I understand that eukaryotes have evolved from prokaryotes, but still prokaryotes are very much there and they have succeeded to survive. They have not been…

Professor Nagaraj: I could not agree more with you. So I do not know what the debate is. Is there a debate going on about whether? So, the truth of the fact is that they are still around. And chances are, you do not know, they may outlive the eukaryotes. So, another 10 billion years from now we may go back. So, you do not know. So, at this point of time, clearly, there is a evolution that has happened to generate complexity. That does not necessarily mean, say complexity comes at a cost, and prokaryotes have clearly survived long as well. So, it is not like they have not. So, it is a valid point. It is a valid point.