



ASTROBIOLOGY

The Story of our Search for Life in the Universe

Produced by the NASA
Astrobiology Program to
commemorate 50 years of
Exobiology and Astrobiology
at NASA.

Astrobiology

A History of Exobiology and Astrobiology at NASA

This is the story of life in the Universe — or at least the story as we know it so far. As scientists, we strive to understand the environment in which we live and how life relates to this environment. As astrobiologists, we study an environment that includes not just the Earth, but the entire Universe in which we live.

The year 2010 marked 50 years of Exobiology and Astrobiology research at the National Aeronautics and Space Administration (NASA). To celebrate, the Astrobiology Program commissioned this graphic history. It tells the story of some of the most important people and events that have shaped the science of Exobiology and Astrobiology. Beginning shortly after the establishment of NASA, this field is relatively young. However, as you will see, the questions that astrobiologists are trying to answer are as old as humankind.

Concept & Story

Mary Voytek
Linda Billings
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Aaron L. Gronstal

Script

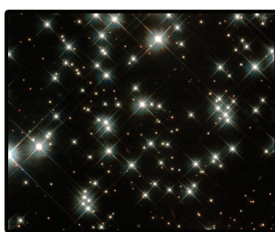
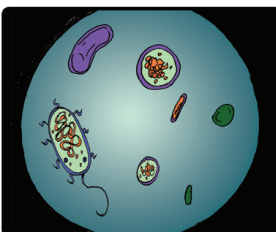
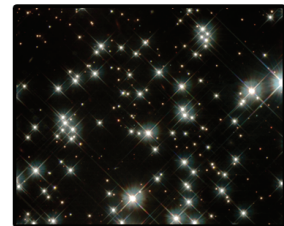
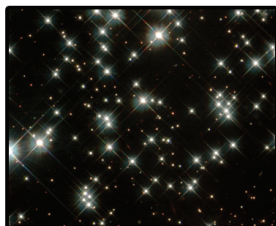
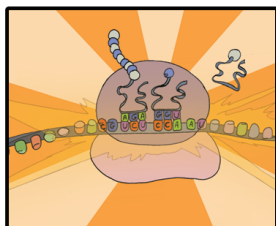
Aaron L. Gronstal

Editor

Linda Billings

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Issue #7—Prebiotic Chemistry and the Origin of Life



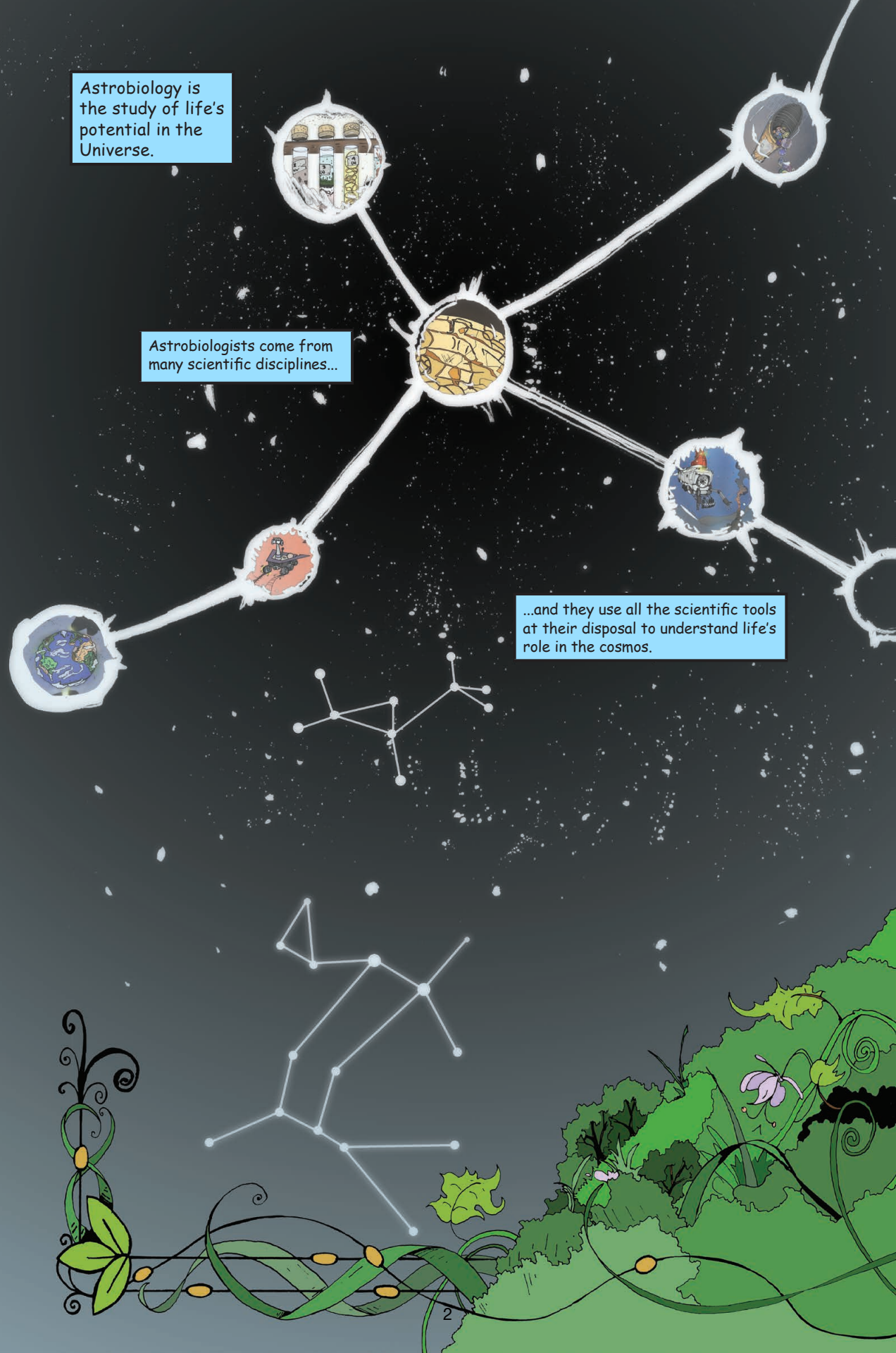
The year 2010 marked the 50th anniversary of NASA's Exobiology Program, established in 1960 and expanded into a broader Astrobiology Program in the 1990s. We are telling the story of how this field developed and how the search for life elsewhere became a key component of NASA's science strategy for exploring space. This issue is the seventh in what we intend to be a series of graphic history books. Though not comprehensive, the series has been conceived to highlight key moments and key people in the field as it explains how Astrobiology came to be.

-Linda Billings, Editor

Astrobiology is the study of life's potential in the Universe.

Astrobiologists come from many scientific disciplines...

...and they use all the scientific tools at their disposal to understand life's role in the cosmos.



We have studied the Earth, the Solar System, and planets around distant stars as we search for knowledge about life.

Nathaniel Virgo,
Earth Life Science
Institute (ELSI)

But in order to understand life's potential out there, we have to figure out how it started here on Earth!

Sarah Maurer,
Central
Connecticut
State University

Right! We need to study the origin of life on Earth if we want to know if and how life could gain a foothold on other worlds.

Irena Mamajanov,
ELSI

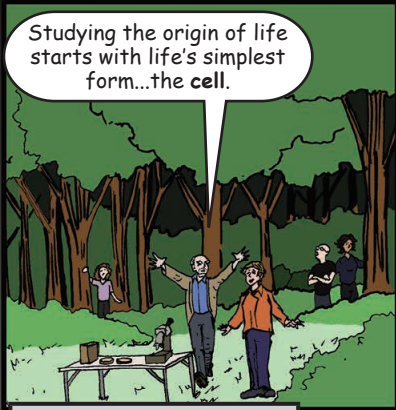
Sara Walker,
Arizona State
University (ASU)

Well, 'life
as we know it'
anyway.

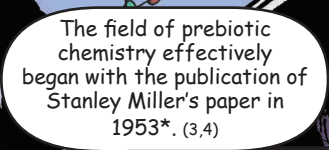
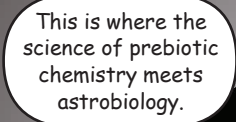
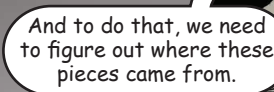
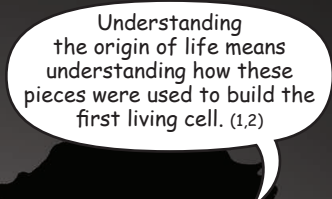
The study of how life began on Earth offers information we can use to consider the possibilities for the existence of life elsewhere. Origin of Life research is at the core of astrobiology.

Mary Voytek, NASA

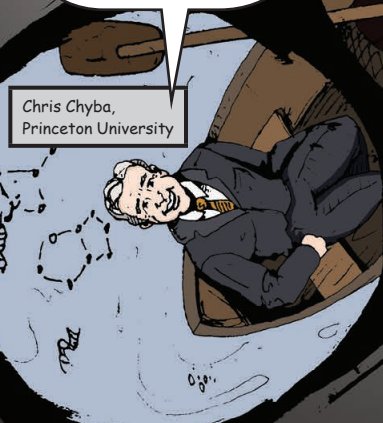
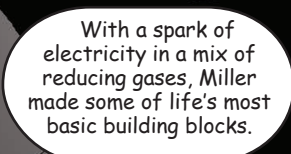
**Issue 7—Prebiotic Chemistry
and the Origin of Life.**



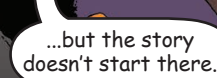
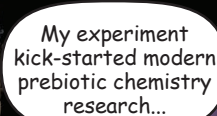
Jeffrey Bada, Scripps Institution of Oceanography, University of California, San Diego (UCSD)



Carol Cleland, University of Colorado at Boulder (CU Boulder)



Chris Chyba, Princeton University



Stanley Miller 1930-2007

*See Issue #1!

Friedrich Wöhler (1800-1882) was the first to get an organic compound from inorganic materials. (5)

Urea can be formed by heating ammonium cyanate...

Was?

Ihr hat nicht alle Tassen in der Schrank...

No animal kidney necessary!

Berliner Gewerbeschule, Germany. 1828

With a simple 'swan-neck flask' experiment... (6)

Bacteria don't just 'spontaneously' generate in sterile liquid. If you leave the flask open, they come in from the air.

Never will the doctrine of spontaneous generation recover from this mortal blow!

...Pasteur proved that life did not simply appear from nowhere.

A bent top on the flask prevents bacteria getting in... and the liquid stays sterile.

Around this time, Charles Darwin (1809-1882) proposed his famous theory of life's evolution.

Although quiet on life's origins, he discussed ideas with colleagues. (7)

Of course, not everyone was a fan. (4)

Evolution? Bah!

Life rode from space on a meteorite!

London, 1871.
Lord Kelvin (1825-1907).

Neugierig...

Ja. Das ist ein gute idea...

Hermann von Helmholtz (1821-1894)

Svante Arrhenius (1859-1927).

But many scientists around the world started looking at the chemistry behind life's building blocks.

Mexico City, 1902.
Alfonso L. Herrera.
(1868-1942)

Mix water and oil and you get cell-like things... is it a clue to the origin of photosynthetic protoplasm... or plasmogeny? (5)



Harvard, 1914

I think the first living thing was like an enzyme. These molecules can be catalysts that help control the rate of chemical reactions.

It probably appeared in the early oceans and could copy itself. (5)

Leonard Troland.
(1889-1932)

Major figures were Soviet biochemist Alexander Ivanovich Oparin...

It's chemistry. Prebiotic synthesis of organic compounds led to a primitive 'broth.' Life must have evolved from this soup of chemicals.

Too right my good chap. A gigantic bowl of primordial soup*...

*A term introduced in his 1929 paper (9)

...and the British-born Indian scientist J.B.S. Haldane. (See Issue 1) (8, 9)

Moscow, 1924.

Cambridge, 1929.

The Royal Institution, London, 1939.

Preposterous.

Fascinating.*

"All proteins that we know now have been made by other proteins, and these in turn by others." (10)

John D. Bernal (1901-1971), pioneer of X-ray crystallography.

How very interesting.**

*Dorothy Hodgkin (1910-1994), Nobel Prize for the development of protein crystallography.

**Rosalind Franklin, see Issue #1

In Dublin, physicist Erwin Schrödinger (1887-1961) gave three lectures on a strange topic.

"How can the events in space and time, which take place within the spatial boundary of a living organism, be accounted for by physics and chemistry?" (11)

The science quickly continued to progress...

WHAT IS LIFE?
THE PHYSICAL ASPECTS
OF THE CELL

Trinity College
Dublin, 1943.

We must show organic compounds form without life. We know they're in meteorites after all!

Oparin guest lecture at the University of Chicago

But how?

Shhh...

In my lab, we tried to form organics in an experiment that simulated the radiation environment of the Earth's crust... no luck.

Melvin Calvin (1911-1997),
University of California
Berkeley (UCB)

Harold Urey (1893-1981),
University of Chicago

I've modelled an early Earth with a reducing atmosphere.

Wheee!

Wait, that gives me an idea!

With our experiment, lots of scientific disciplines joined the fun.

By the 1950s, scientists studying prebiotic chemistry began to join forces with molecular biologists.

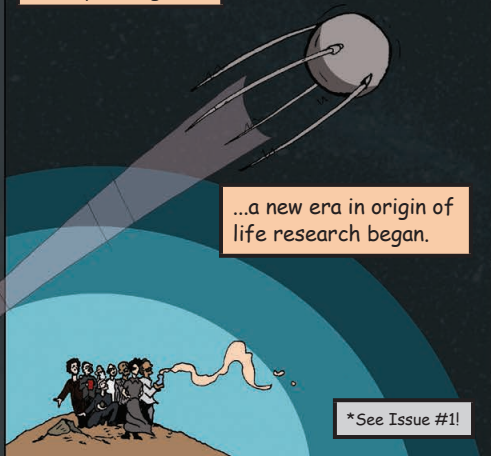
Only together can we solve the question of life's origins!



When the Sputnik launch ushered in the Space Age*...

...a new era in origin of life research began.

*See Issue #1!



We must look to the stars.

Life might have appeared out there whenever the conditions were right! (12)



Michael New, NASA Headquarters (HQ)

Space exploration turned the question of extraterrestrial life into a serious area of study.

And that fueled studies on the origin of life.

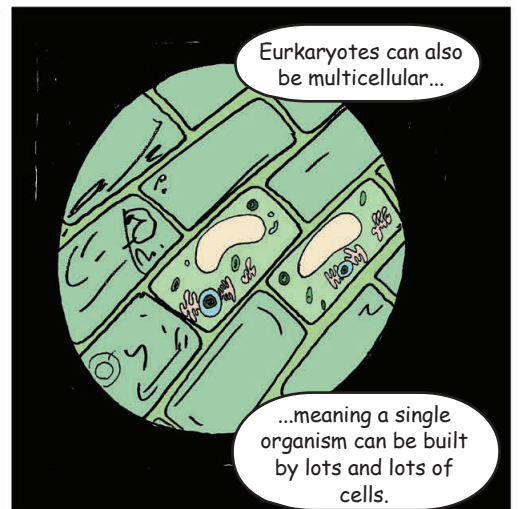
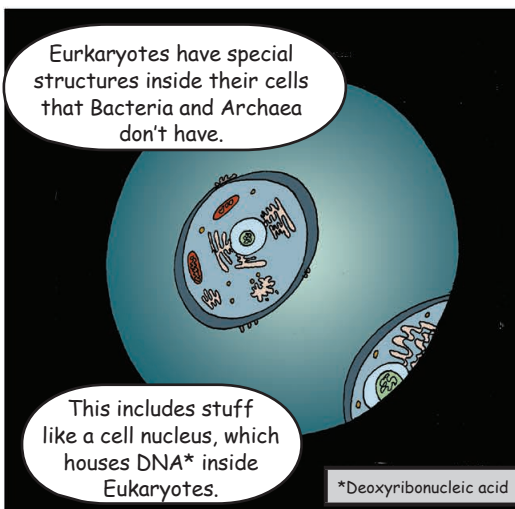
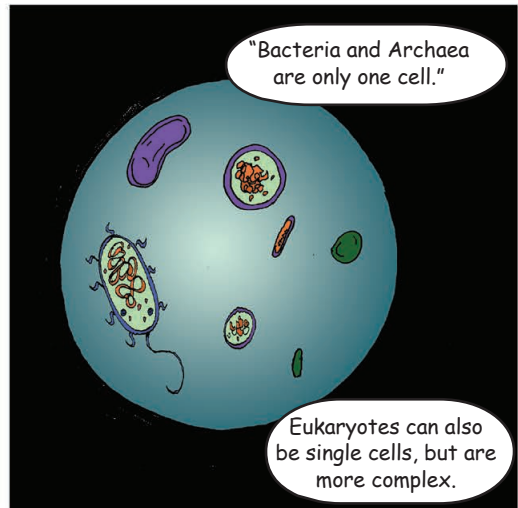
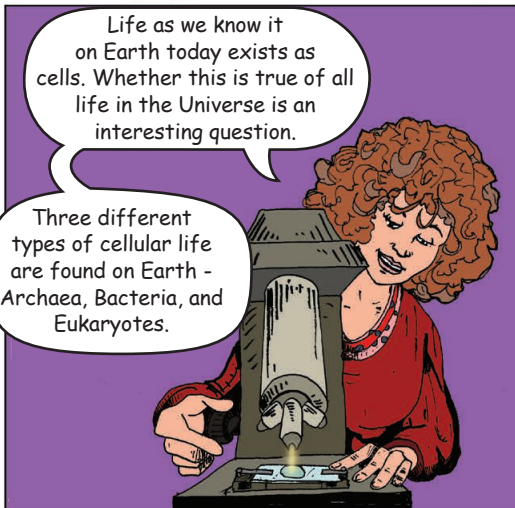
Betül Kaçar, University of Wisconsin-Madison

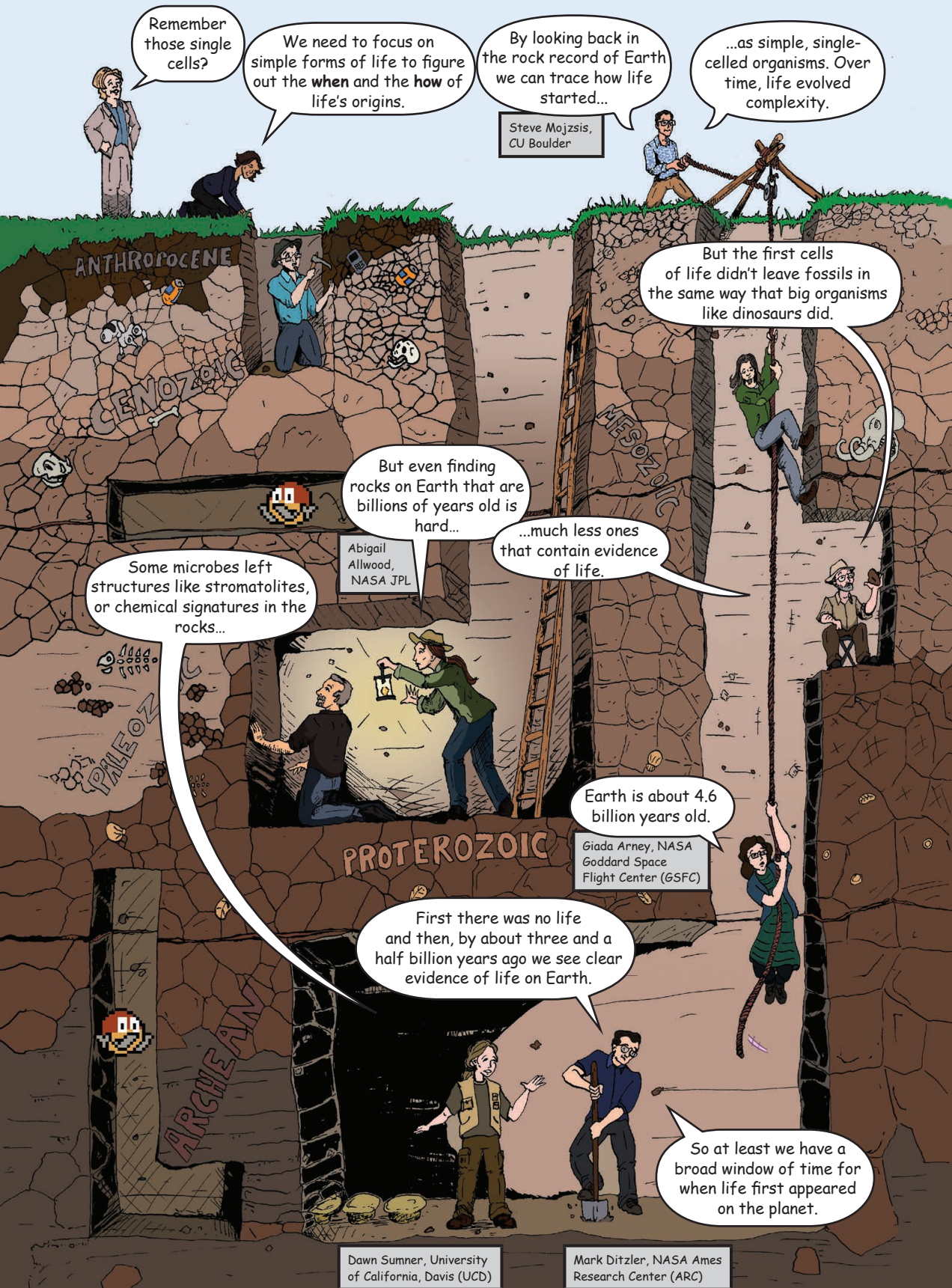
NASA provided substantial funding from the outset.

It was a real boon for the science.

Dave Deamer, University of California Santa Cruz (UCSC)







Remember those single cells?

We need to focus on simple forms of life to figure out the **when** and the **how** of life's origins.

By looking back in the rock record of Earth we can trace how life started...

Steve Mojzsis, CU Boulder

...as simple, single-celled organisms. Over time, life evolved complexity.

But the first cells of life didn't leave fossils in the same way that big organisms like dinosaurs did.

But even finding rocks on Earth that are billions of years old is hard...

Abigail Allwood, NASA JPL

...much less ones that contain evidence of life.

Some microbes left structures like stromatolites, or chemical signatures in the rocks...

Earth is about 4.6 billion years old.

Giada Arney, NASA Goddard Space Flight Center (GSFC)

First there was no life and then, by about three and a half billion years ago we see clear evidence of life on Earth.

So at least we have a broad window of time for when life first appeared on the planet.

Dawn Sumner, University of California, Davis (UCD)

Mark Ditzler, NASA Ames Research Center (ARC)

This is the Archean Eon. This is probably when something happened on Earth to give us life.

If only we could go back in time to see what it was like...

Well... we can at least try to imagine it.

Imagine if we had a portal to the past...



Welcome to the ancient Earth!*

It's like an alien world!

This is where the origins of life happened.

By the end of the '60s, we realized there were two big problems with our knowledge of the ancient Earth.

Jack Szostak, Harvard University

*See Issue #6

We don't know what the Earth's atmosphere and ocean were like in the Archean...

We could look at cells today, and see what pieces have survived over billions of years of evolution.

Right. Stuff like DNA, RNA** and proteins.

... or temperature... and a lot of other stuff.

Those conditions play a huge role in the chemistry of life.

Let's get your samples back to the lab!

**Ribonucleic acid

Molecules like DNA and proteins are things we think all living cells need to have.

Or at least something similar to these molecules...

Some of these molecules could have been in the very first living organisms.

Those molecules passed down through all life on Earth.

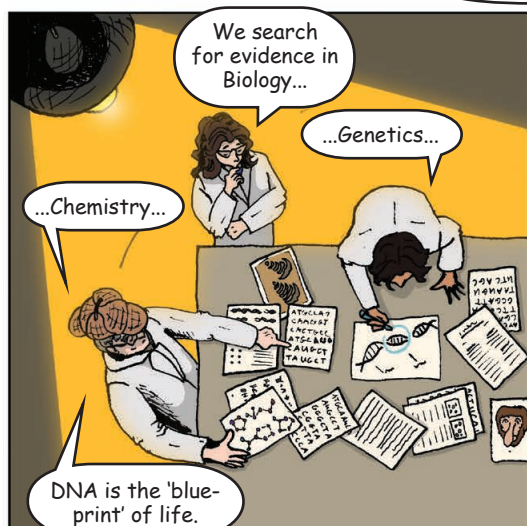
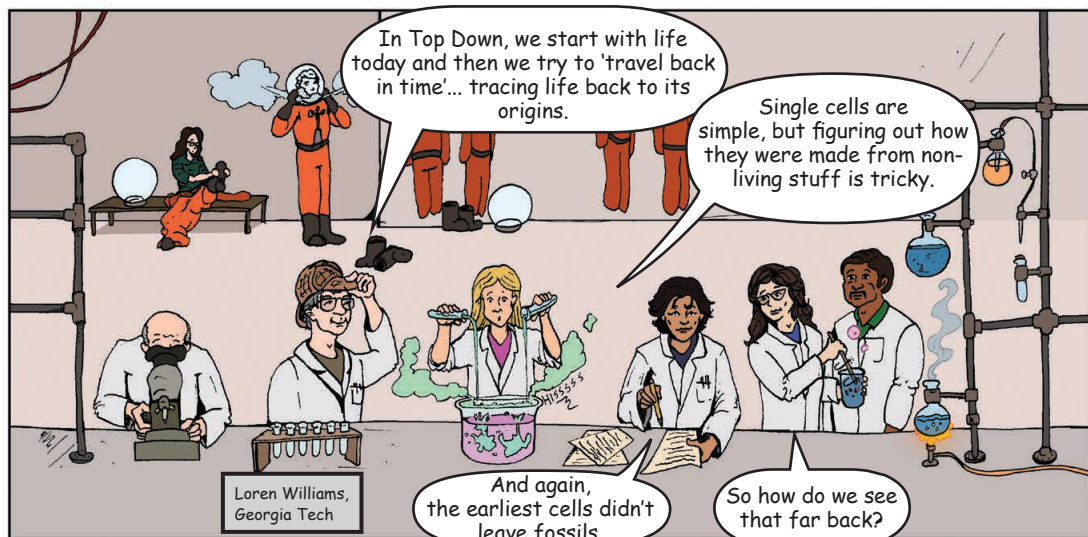
Figuring out how the molecules formed might be the key to understanding the origins of life.

And there's the other big question...
how did life start?

Nicholas Hud, Georgia
Institute of Technology
(Georgia Tech)

Today there are two main approaches to the problem. We call them **TOP DOWN** and **BOTTOM UP**.

Oooooof!



DNA determines the proteins that cells produce. But we also need protein to get DNA.

One problem though.

Proteins act as catalysts for important reactions that, among other things, build DNA.

It's a 'chicken and the egg' problem.

Three scientists independently came up with an important idea. (5)

After all, DNA isn't the only thing that carries information.

Carl Woese (1928-2012)

Maybe the first life was based on RNA not DNA!

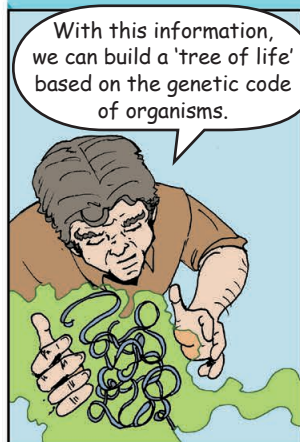
Francis Crick, (1916-2004)*

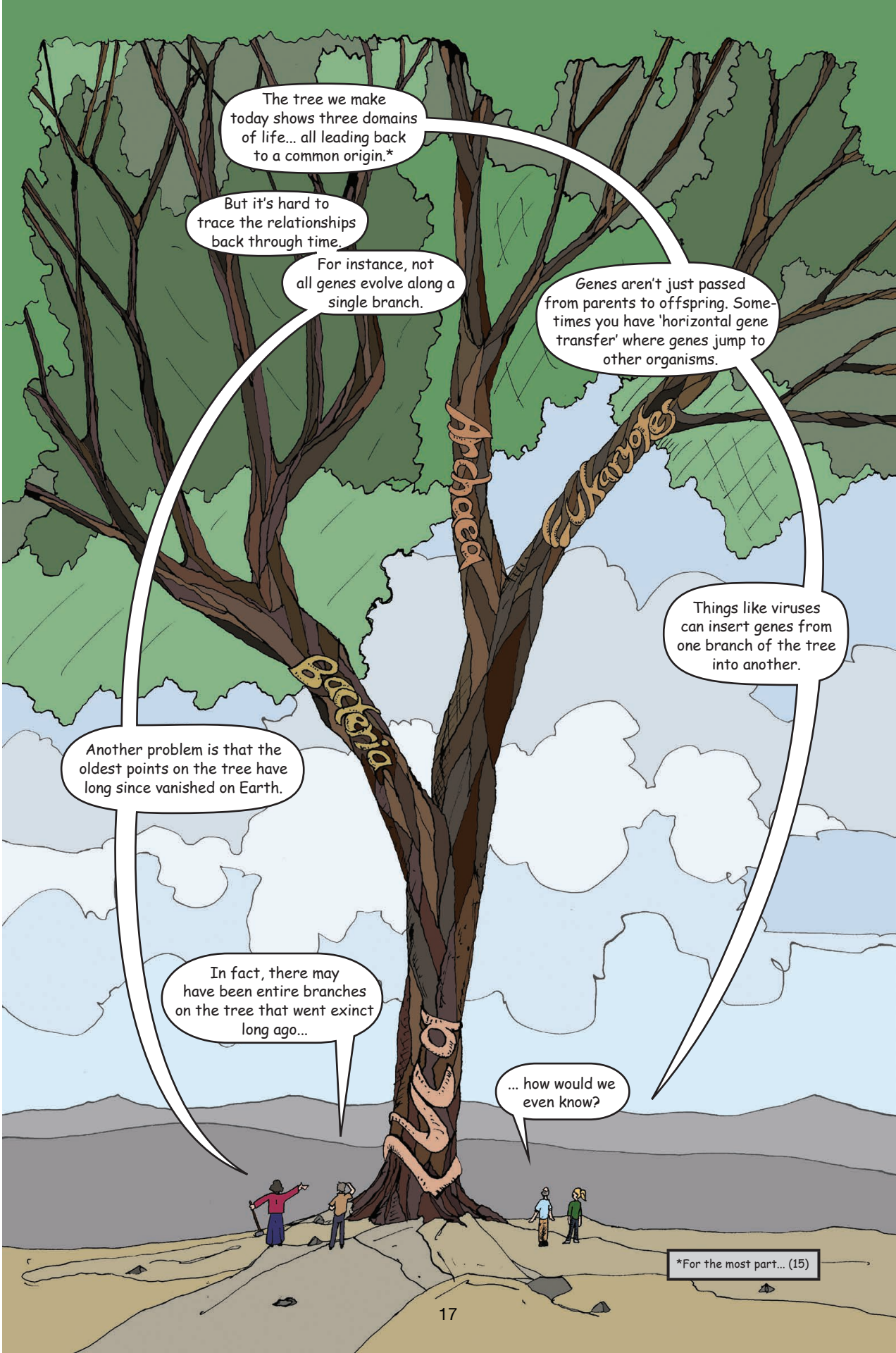
Molecules like proteins can document the evolutionary history of an organism!

Leslie Orgel, (1927-2007)

People were skeptical at first, but further study showed that both genes and proteins carry information about the evolution of life.

* See Issue #1





The tree we make today shows three domains of life... all leading back to a common origin.*

But it's hard to trace the relationships back through time.

For instance, not all genes evolve along a single branch.

Genes aren't just passed from parents to offspring. Sometimes you have 'horizontal gene transfer' where genes jump to other organisms.

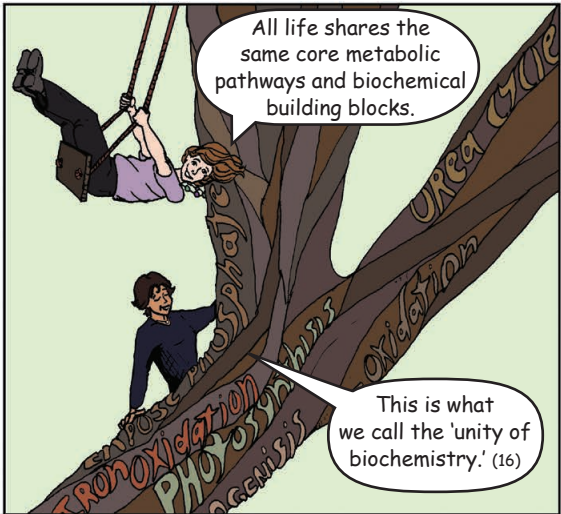
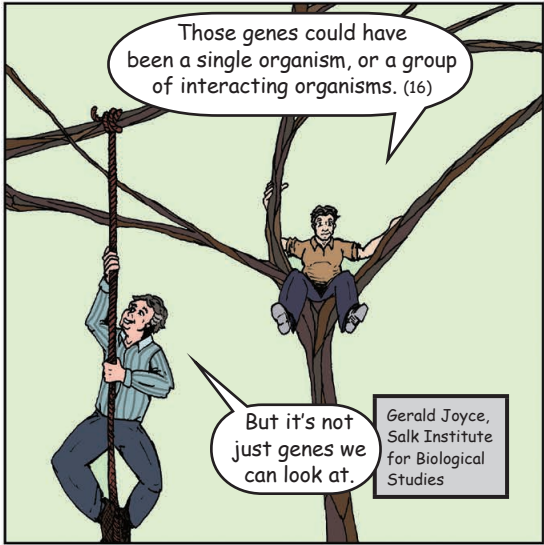
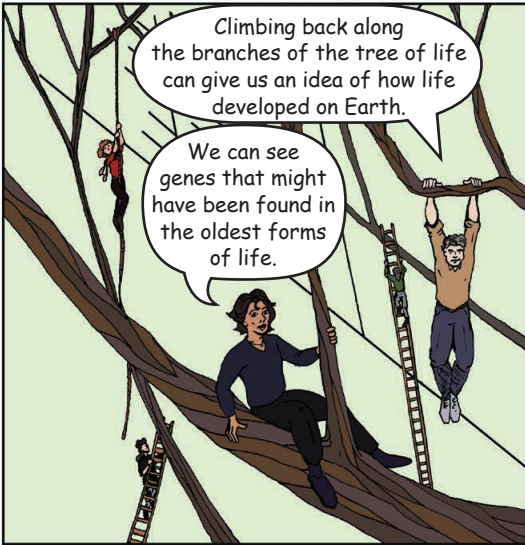
Things like viruses can insert genes from one branch of the tree into another.

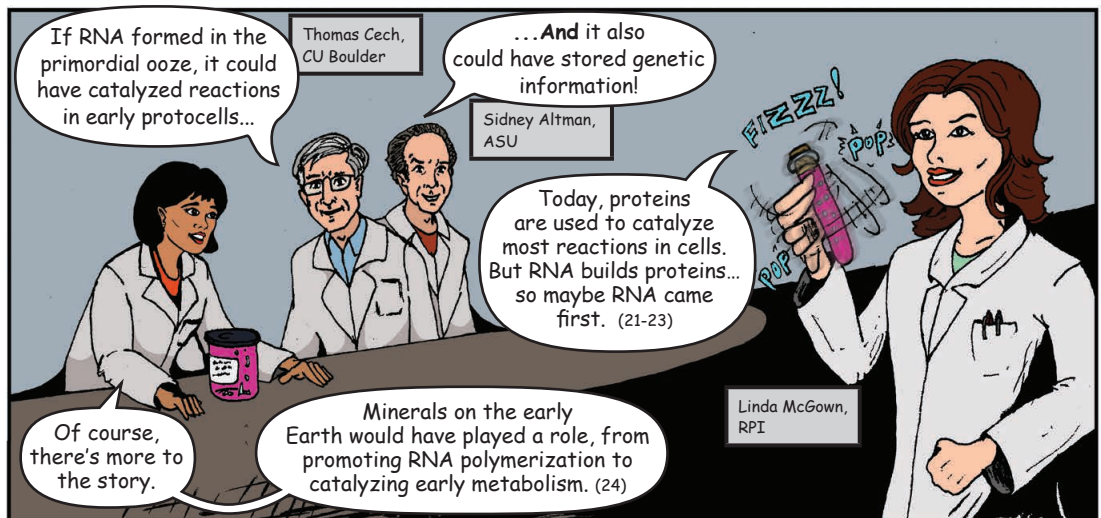
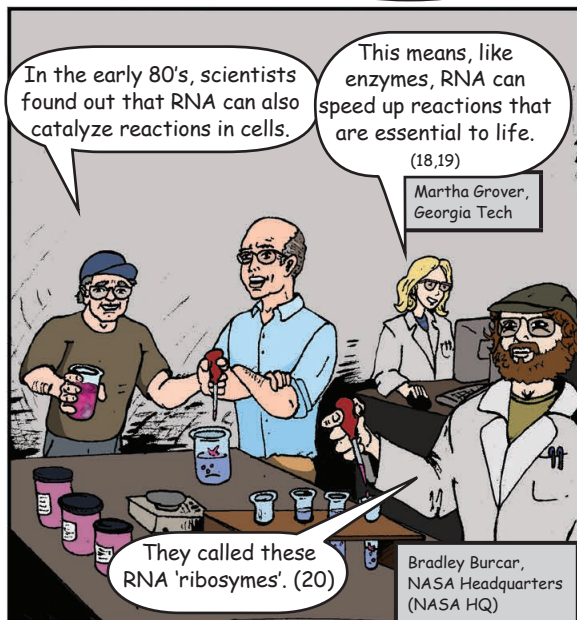
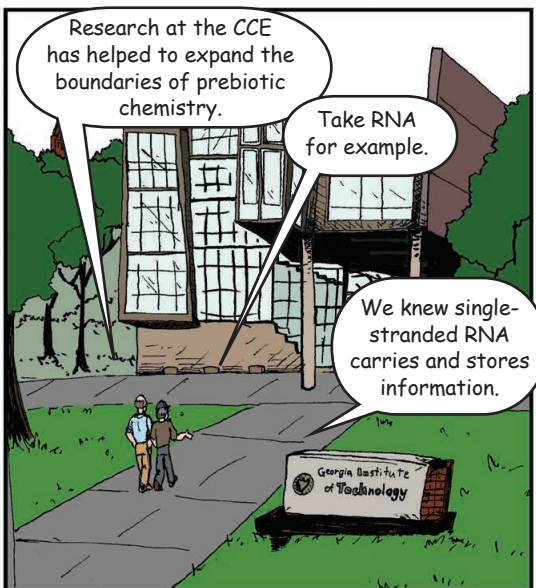
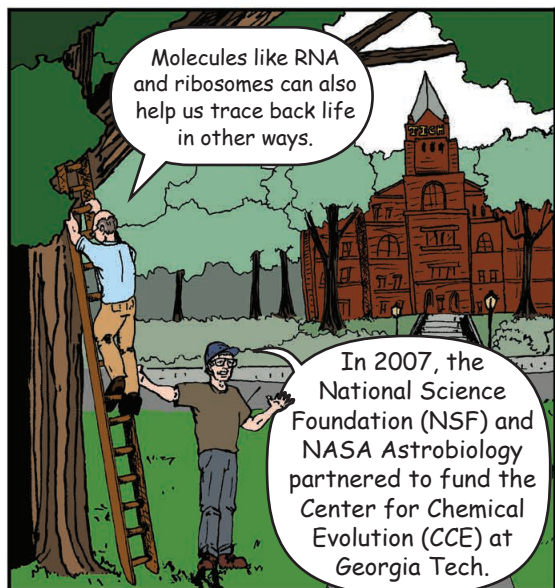
Another problem is that the oldest points on the tree have long since vanished on Earth.

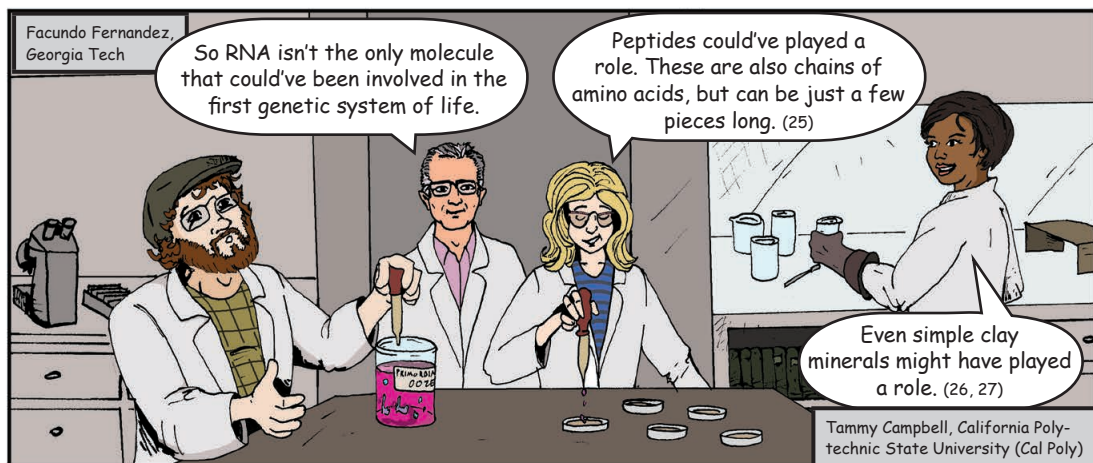
In fact, there may have been entire branches on the tree that went extinct long ago...

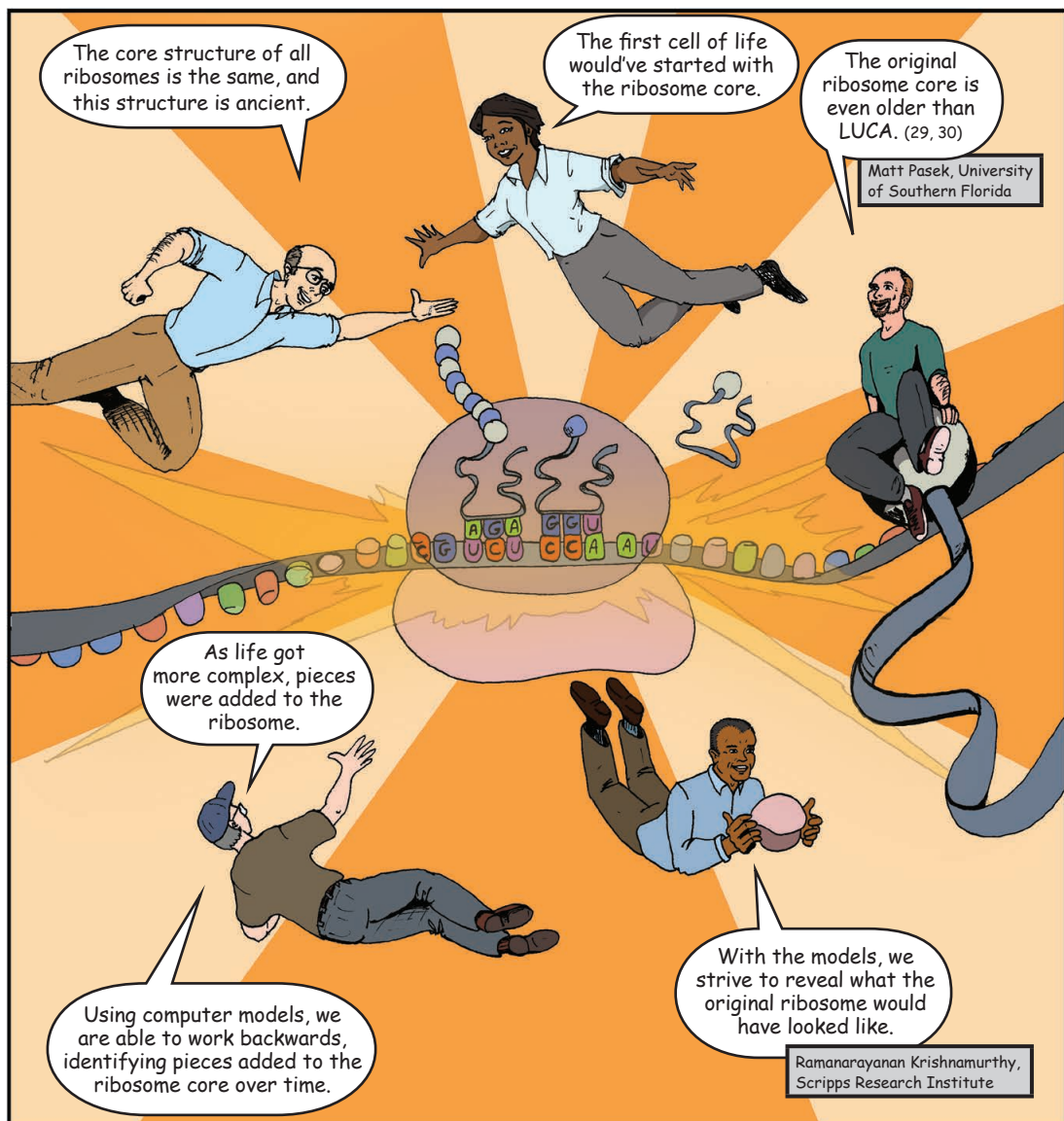
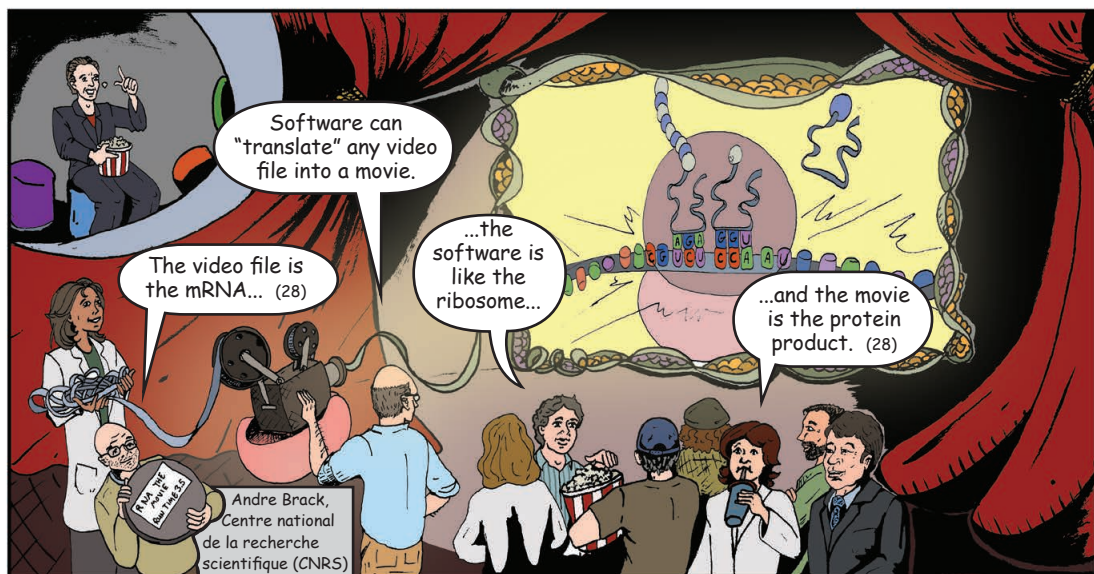
... how would we even know?

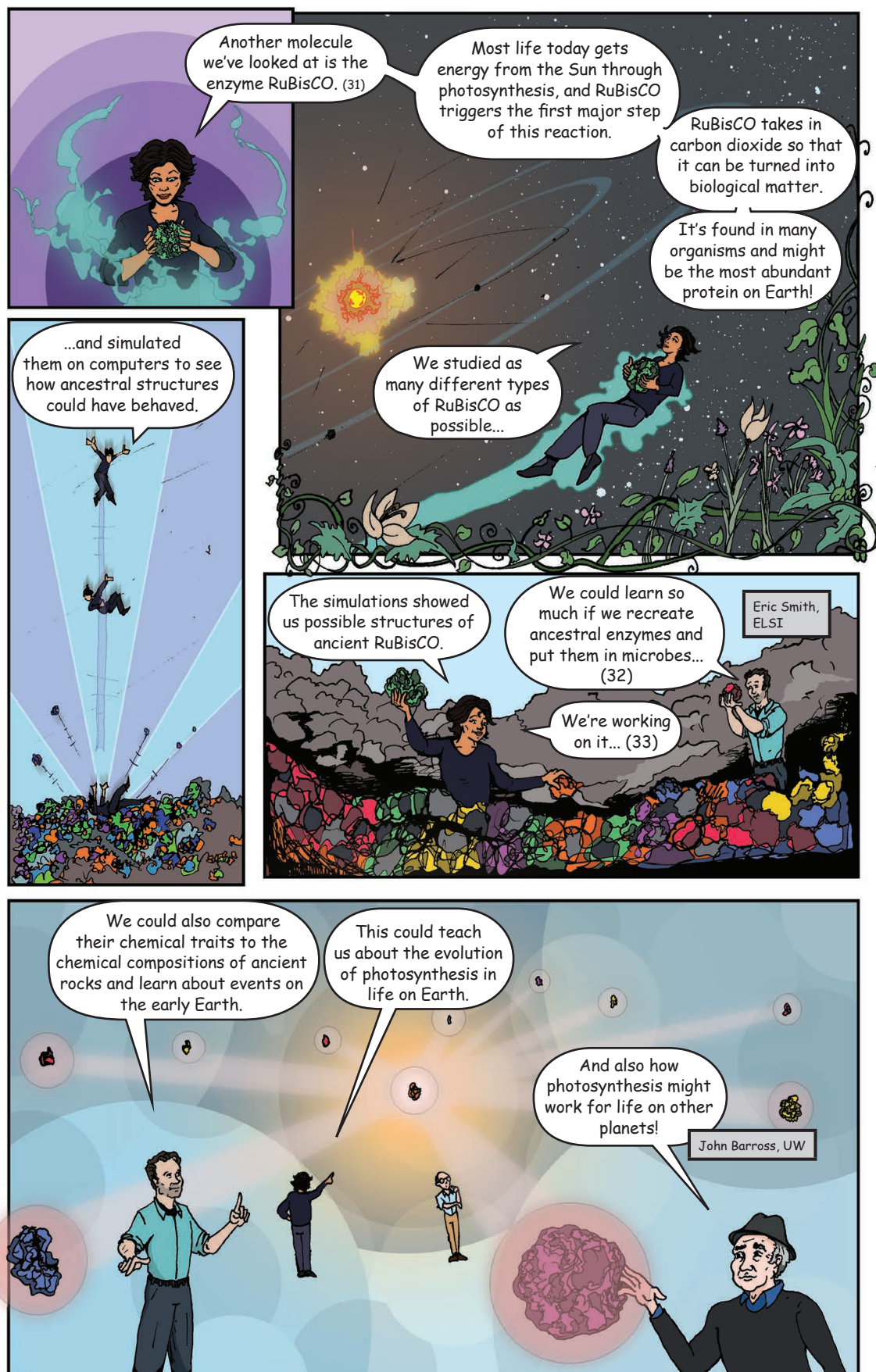
*For the most part... (15)

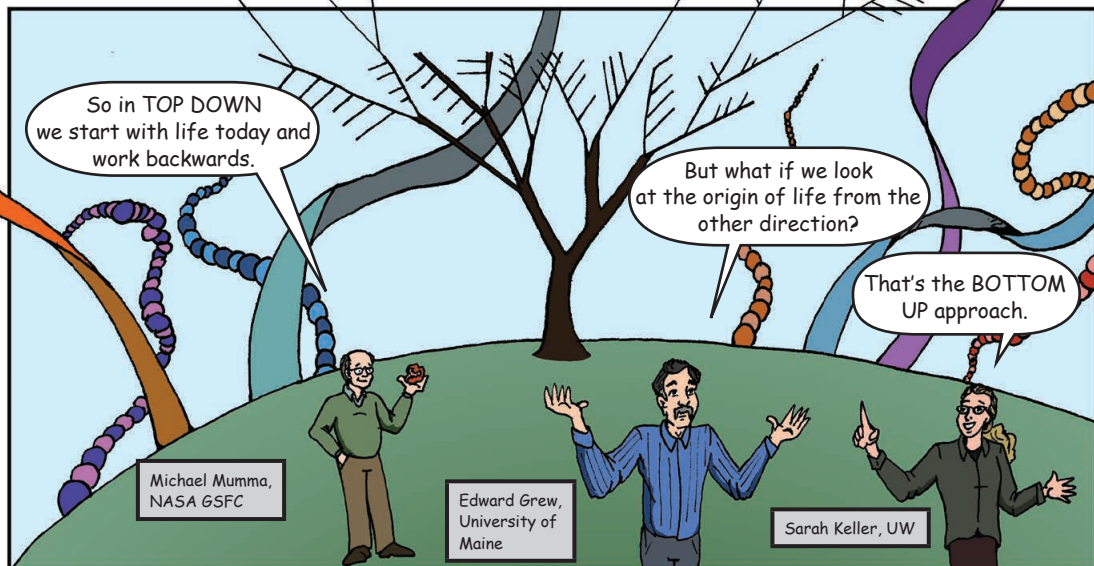


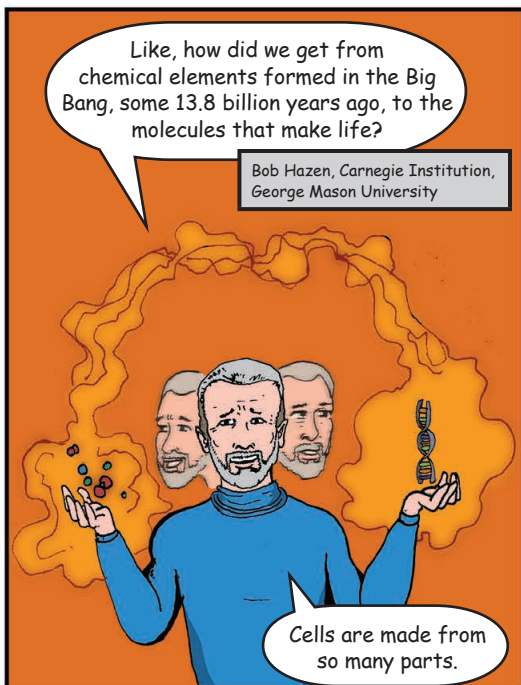
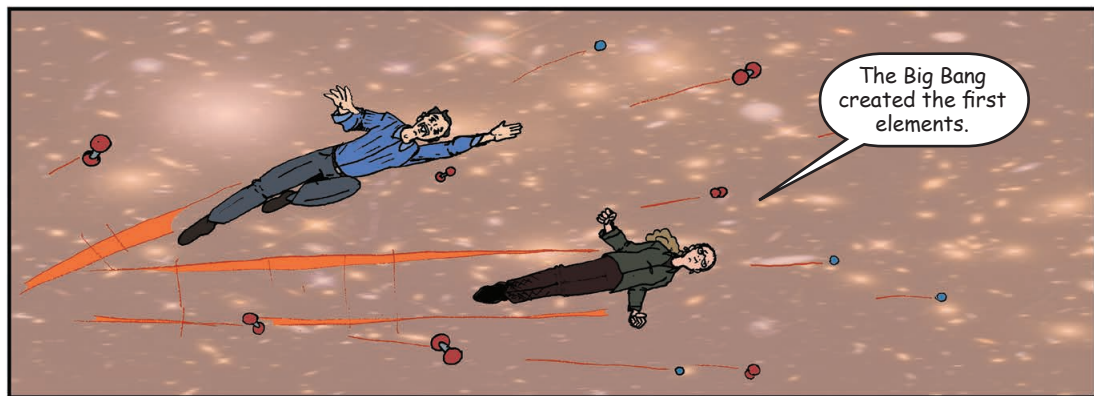


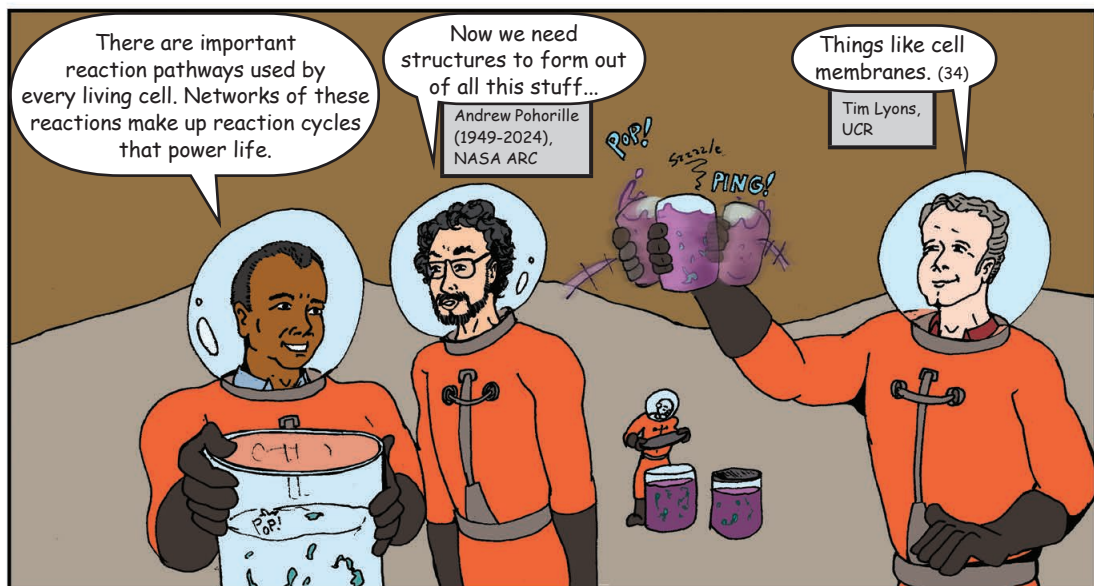
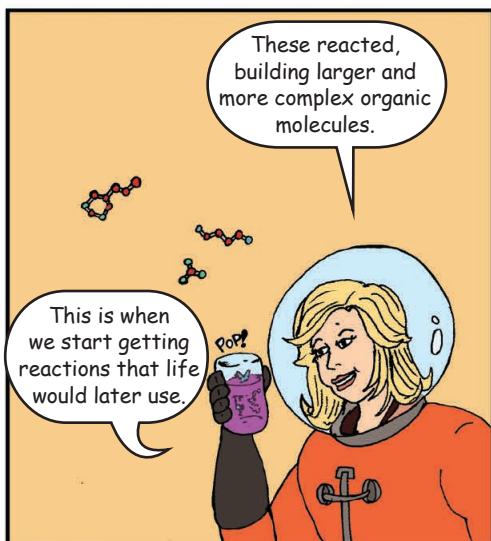
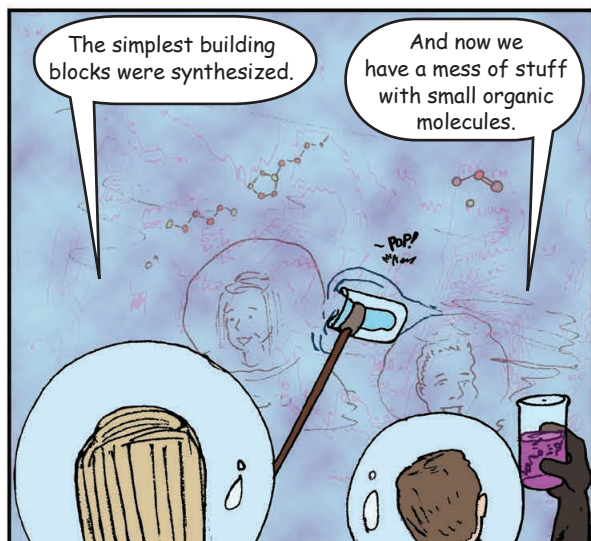
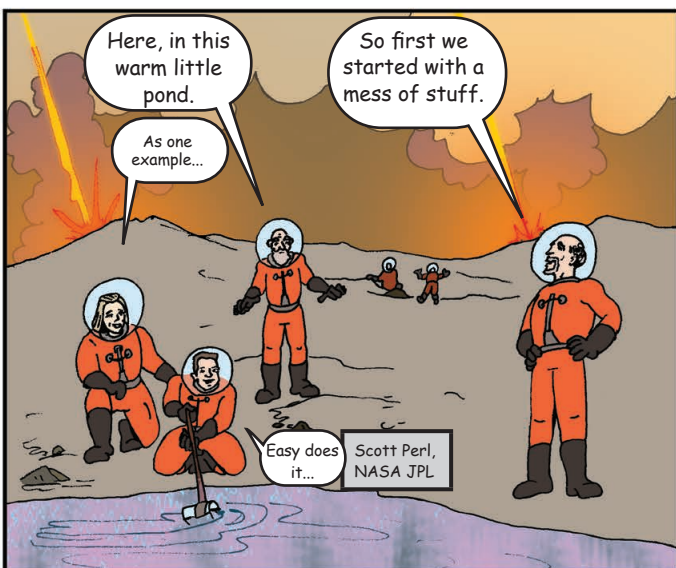
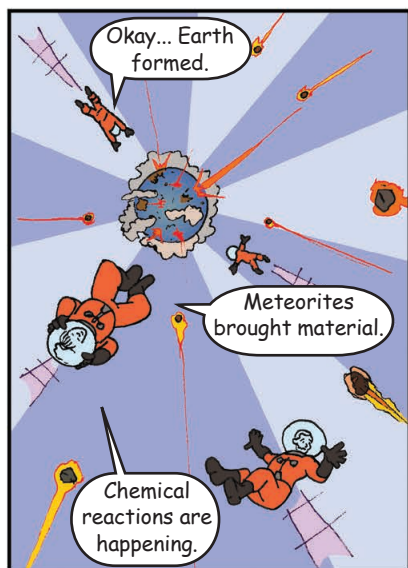


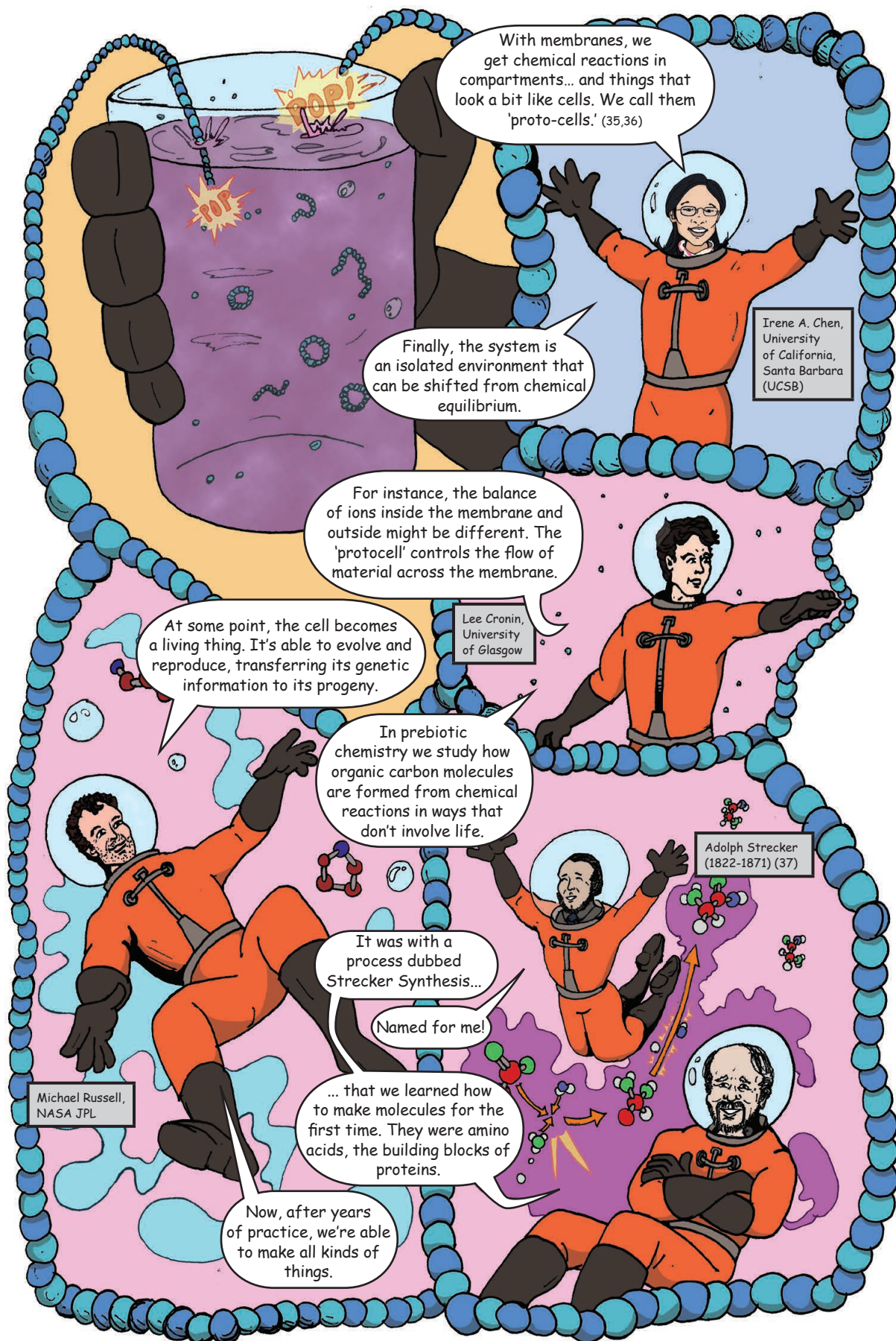












So the 'organic soup' inspired by Miller-Urey, or Darwin's 'warm little pond,' are starting points in the BOTTOM UP approach.

Can we re-create that gooey mess of sloppy chemistry on the early Earth?

But always remember, having the 'stuff' might not be enough.

We also have to consider the planetary conditions...

Basically, we try to make our own 'warm little pond'...

The field of 'chemical evolution' is looking to understand how complex biological systems may have developed on early Earth.

Stefan France, Georgia Tech

In areas like chemical evolution and synthetic biology, scientists look at how complex biological systems might have assembled from simple precursors.

...and recreate what happened on the early Earth.

We try to recreate how genetic material was structured.

How genetic information was interpreted and used in cells...

How membranes formed...

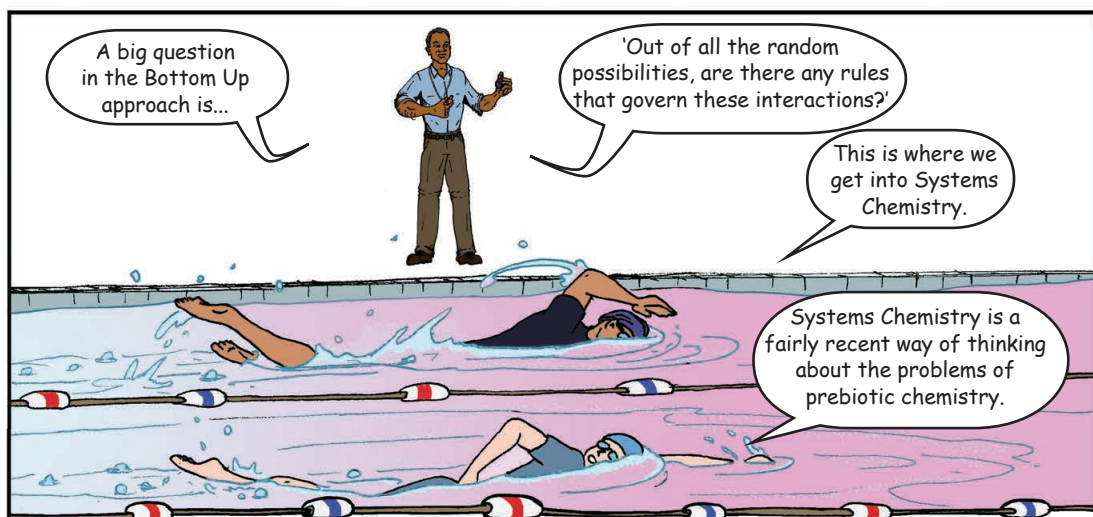
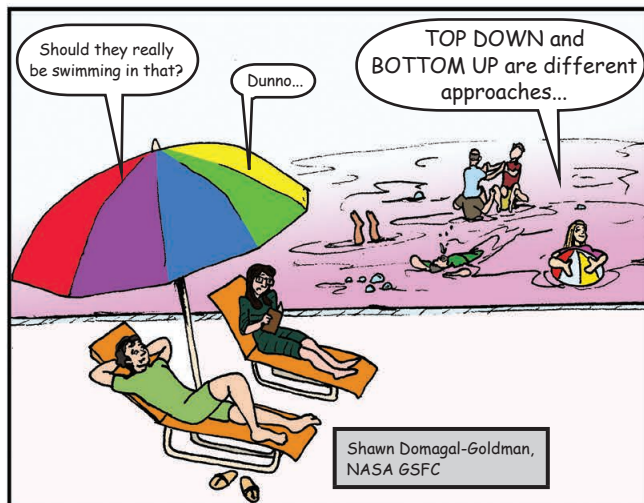
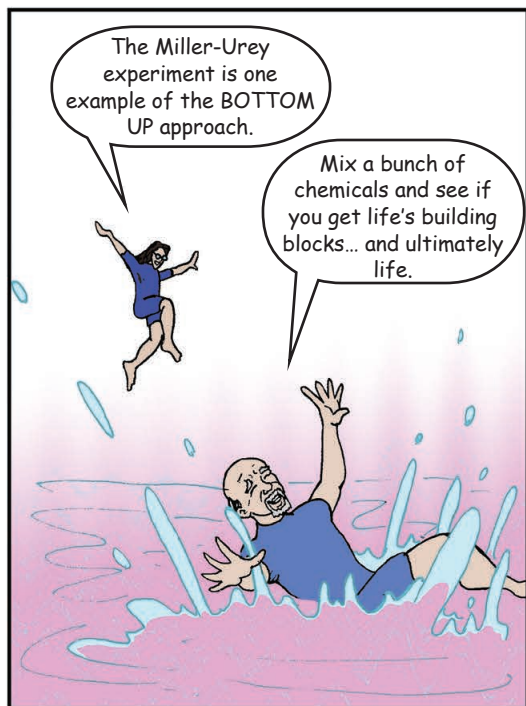
How self-replicating molecules ended up inside membranes.

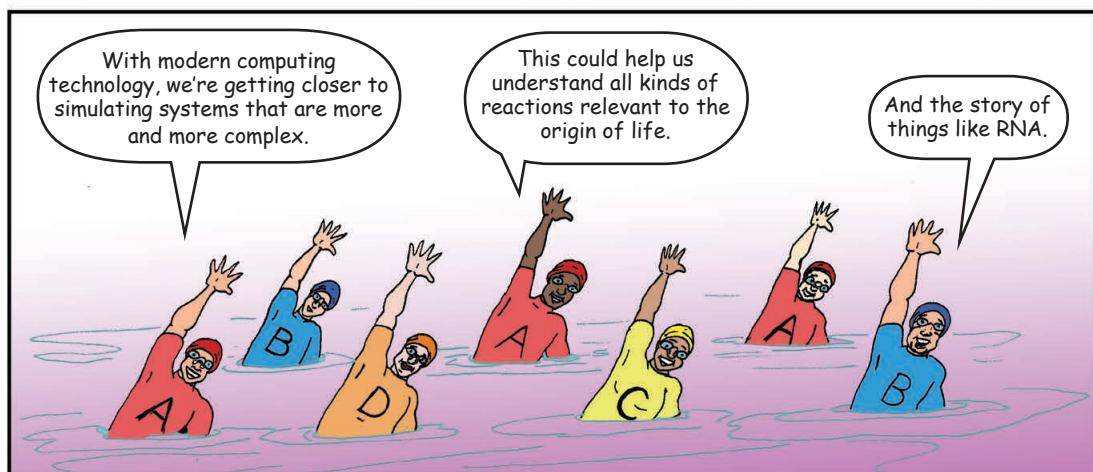
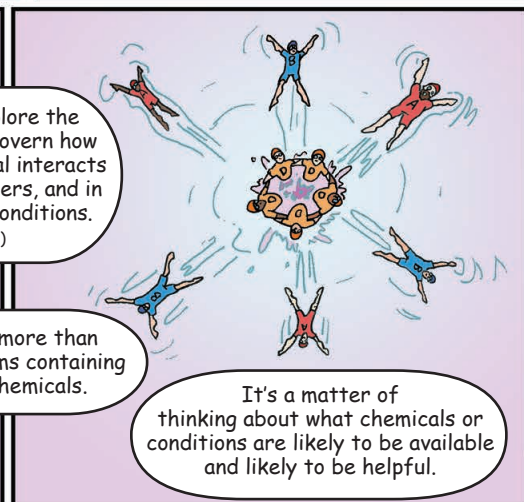
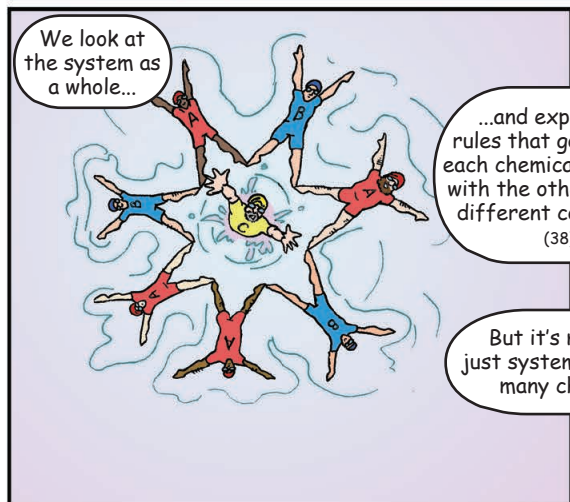
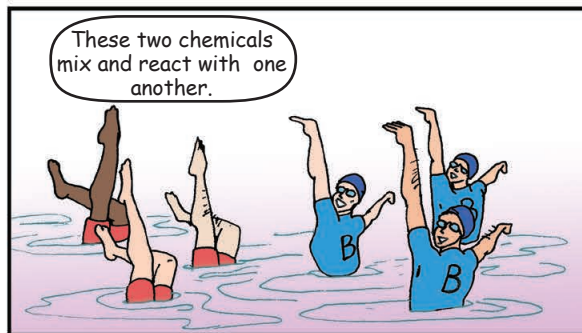
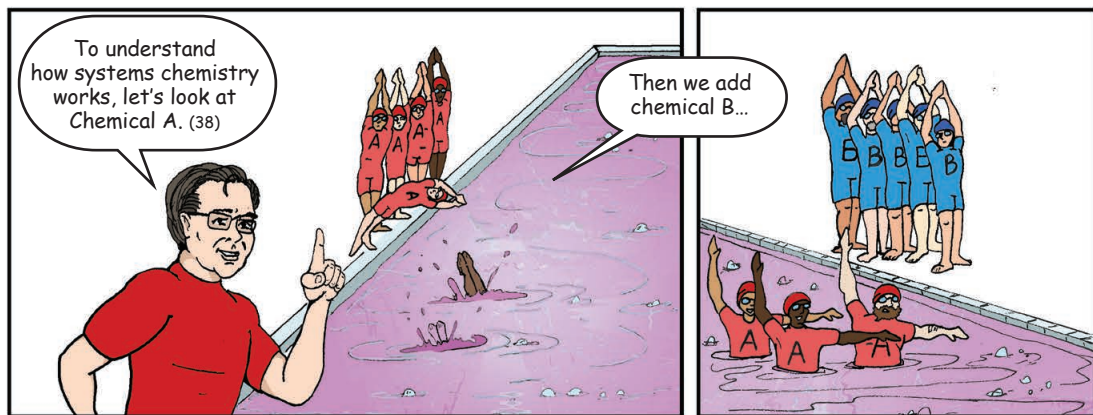
And methods to generate energy.

Jason Dworkin, NASA GSFC

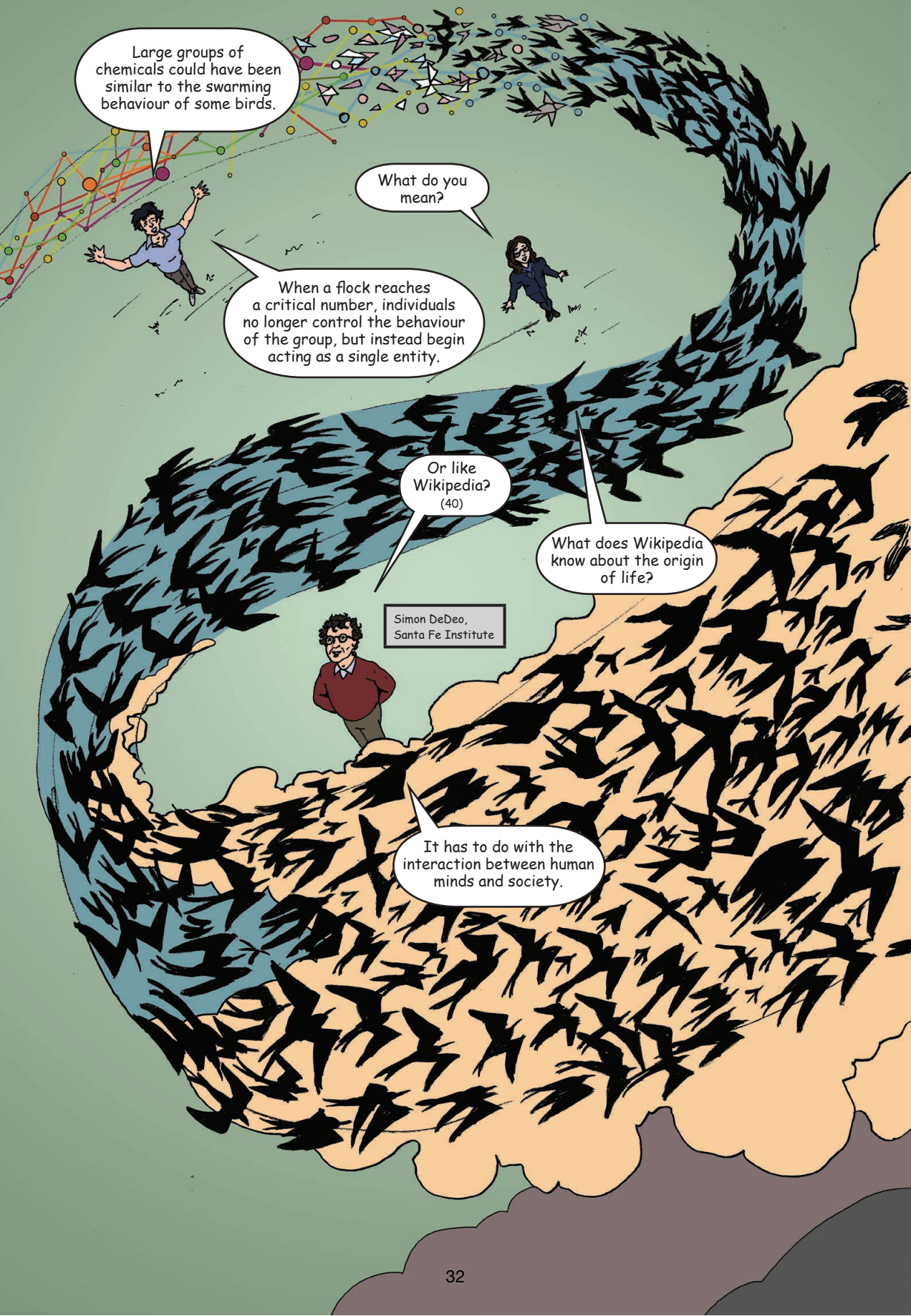
Basically, we're studying the possibility of creating 'new' life in the laboratory.

Luis Campos, Blumberg Library of Congress Chair in Astrobiology, Rice University









Large groups of chemicals could have been similar to the swarming behaviour of some birds.

What do you mean?

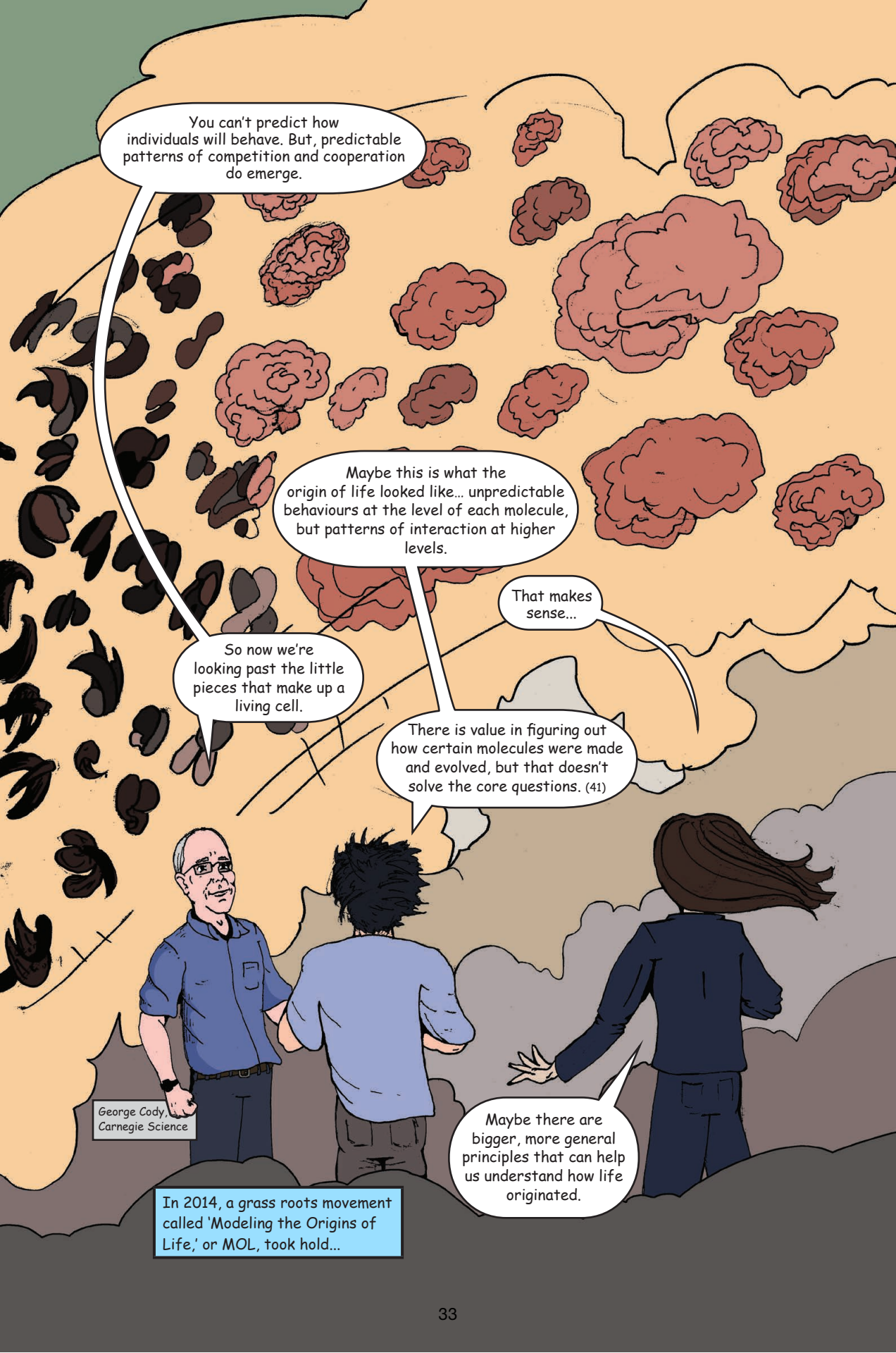
When a flock reaches a critical number, individuals no longer control the behaviour of the group, but instead begin acting as a single entity.

Or like Wikipedia?
(40)

What does Wikipedia know about the origin of life?

Simon DeDeo,
Santa Fe Institute

It has to do with the interaction between human minds and society.



You can't predict how individuals will behave. But, predictable patterns of competition and cooperation do emerge.

Maybe this is what the origin of life looked like... unpredictable behaviours at the level of each molecule, but patterns of interaction at higher levels.

That makes sense...

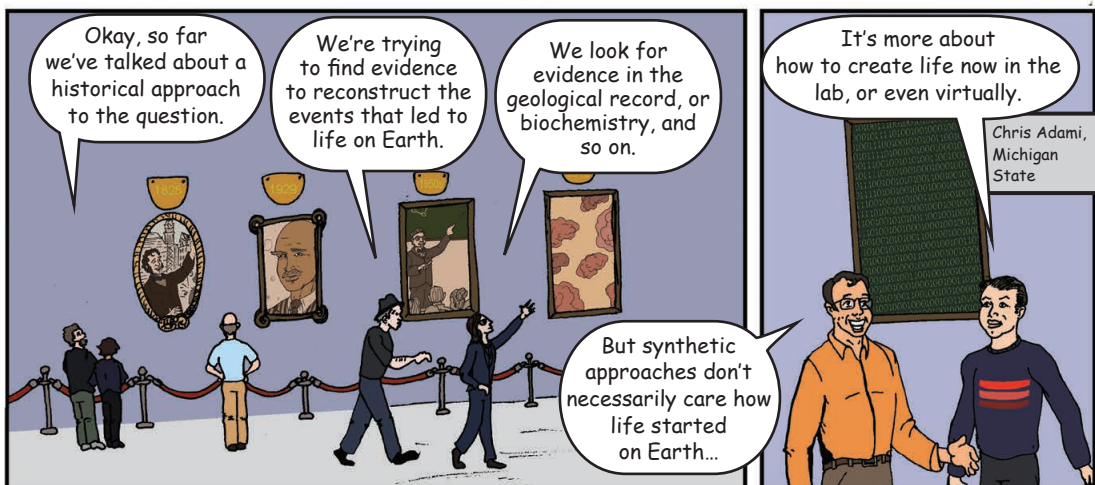
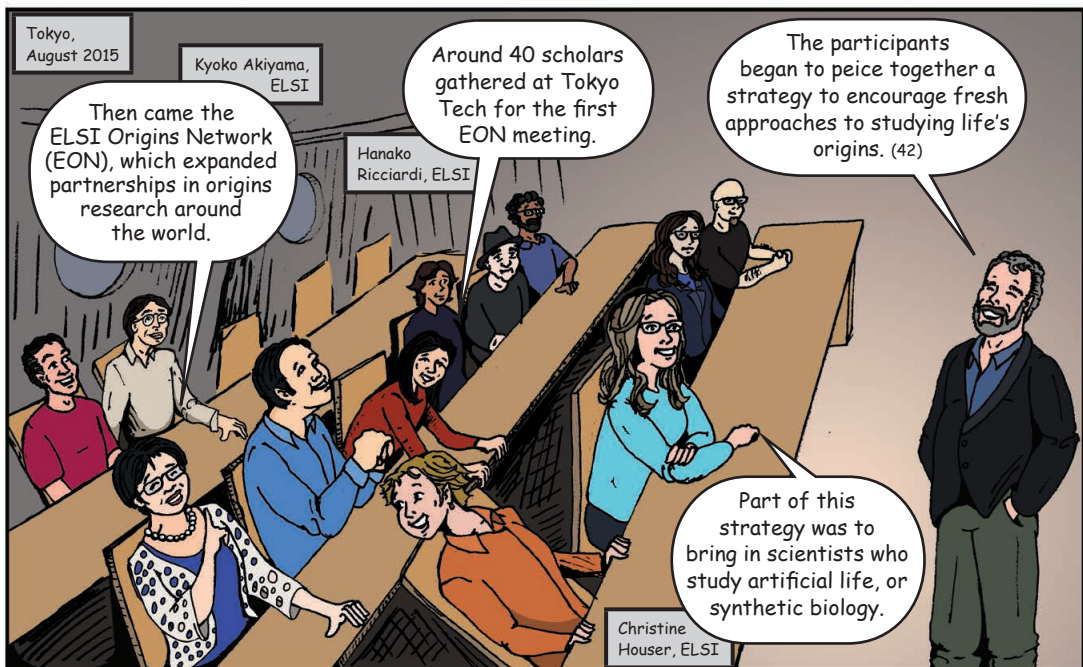
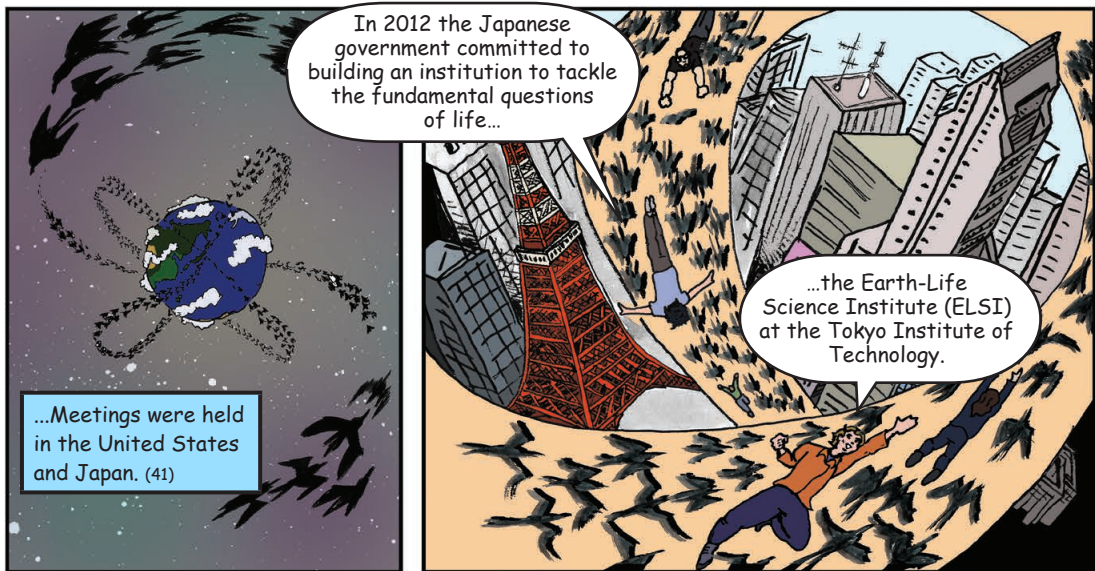
So now we're looking past the little pieces that make up a living cell.

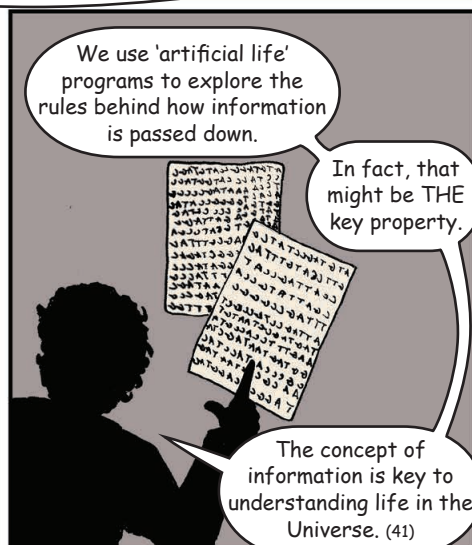
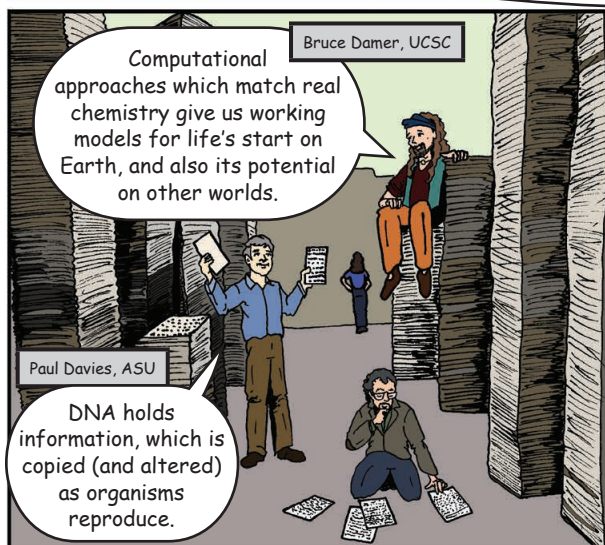
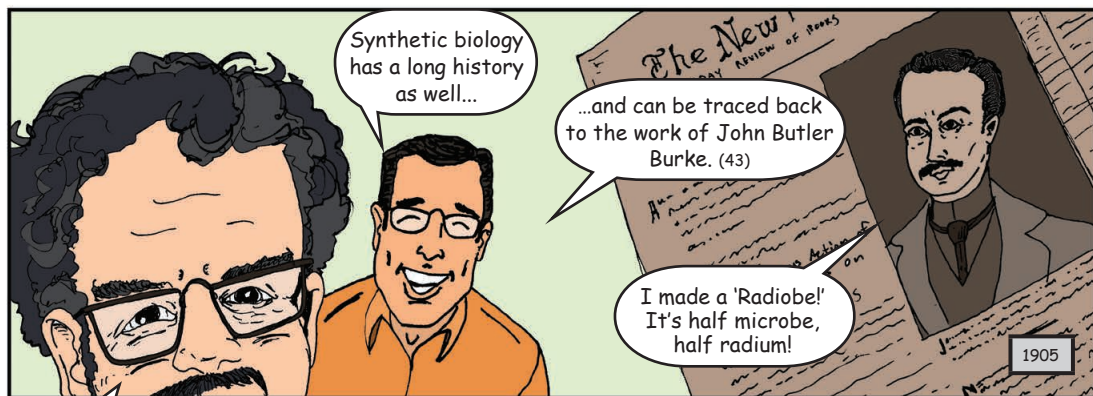
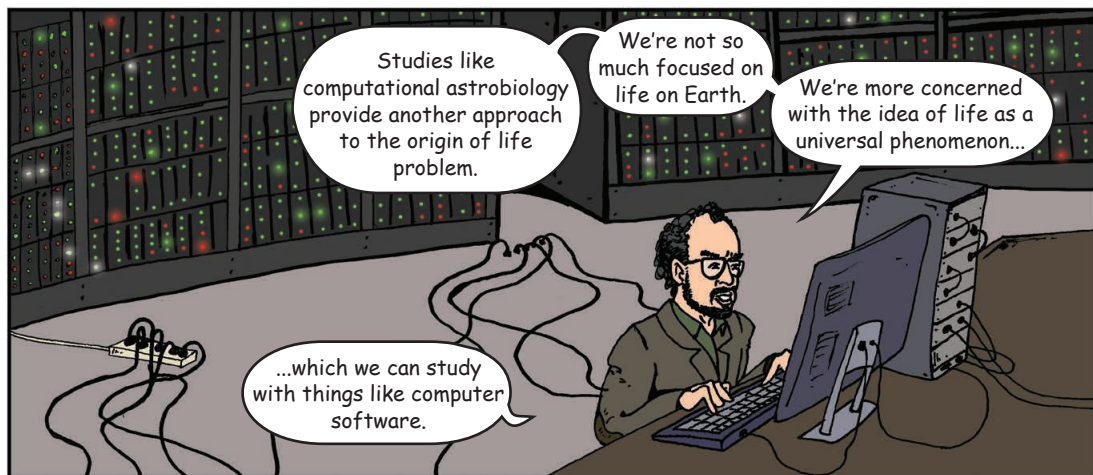
There is value in figuring out how certain molecules were made and evolved, but that doesn't solve the core questions. (41)

George Cody,
Carnegie Science

Maybe there are bigger, more general principles that can help us understand how life originated.

In 2014, a grass roots movement called 'Modeling the Origins of Life,' or MOL, took hold...

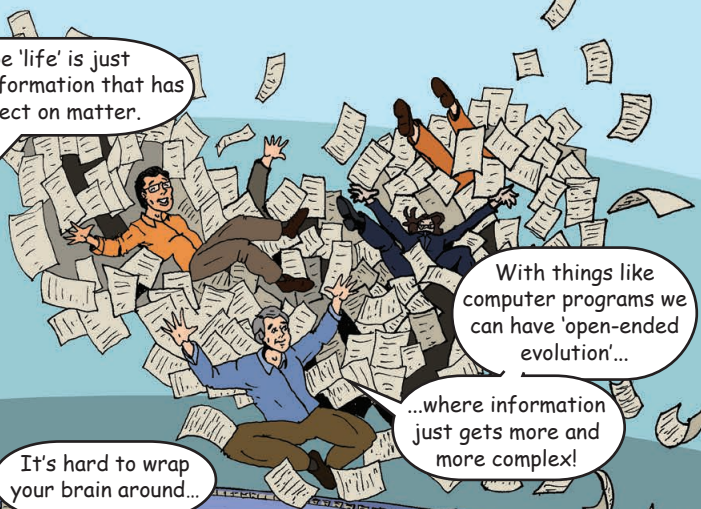






It might not matter if that info is stored in DNA, RNA, proteins or whatever.

Maybe 'life' is just dynamic information that has an effect on matter.



With things like computer programs we can have 'open-ended evolution'...

...where information just gets more and more complex!

It's hard to wrap your brain around...

...but this infinite complexity could be a key to understanding the difference between life and 'non-life.'

Yeah I think my brain is starting to hurt...

...could 'life' represent a domain of physics that we just don't understand yet?

Whoa...

In 'life,' information controls and affects matter...

...We might need new laws of physics to unify our concepts of information and matter.

That's... heavy.

Or what if life is a type of matter?

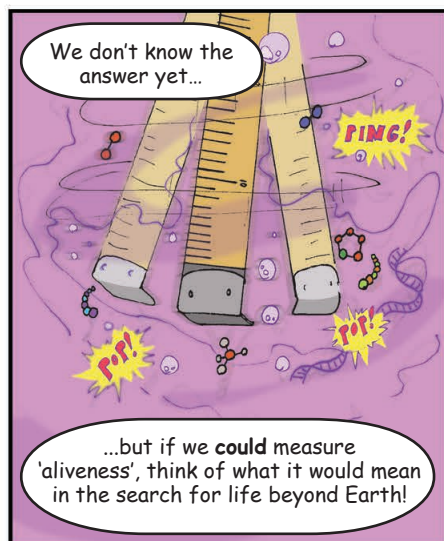
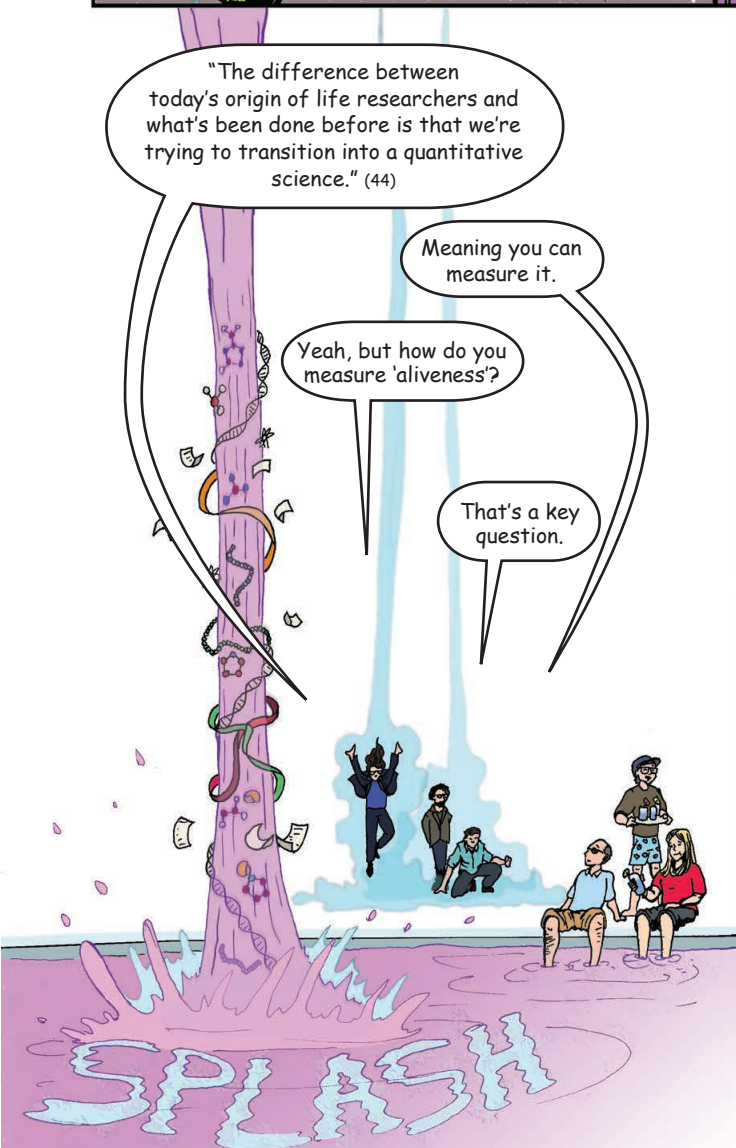
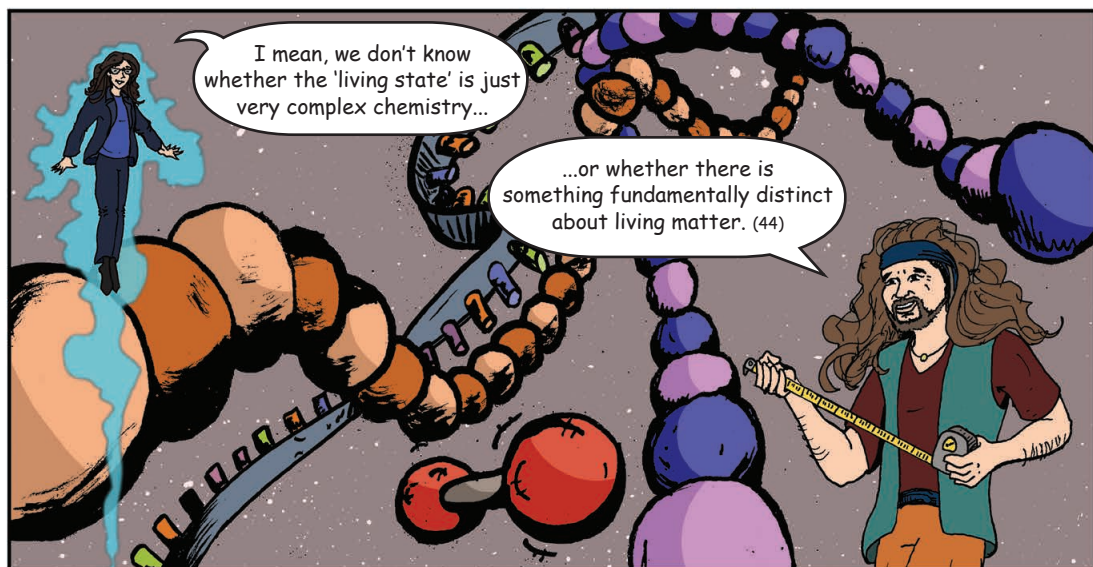
Huh... I think, therefore I am made of stuff?

"Just as matter can be a solid, a liquid, or a gas depending on its thermodynamic properties..."

...matter could - in theory - be living or non-living depending on its information properties." (41)



Okay, now my brain is full of ideas...



More than 60 years have passed since Miller-Urey. We've made progress, but there's still a huge gap between chemistry and biology. (41)

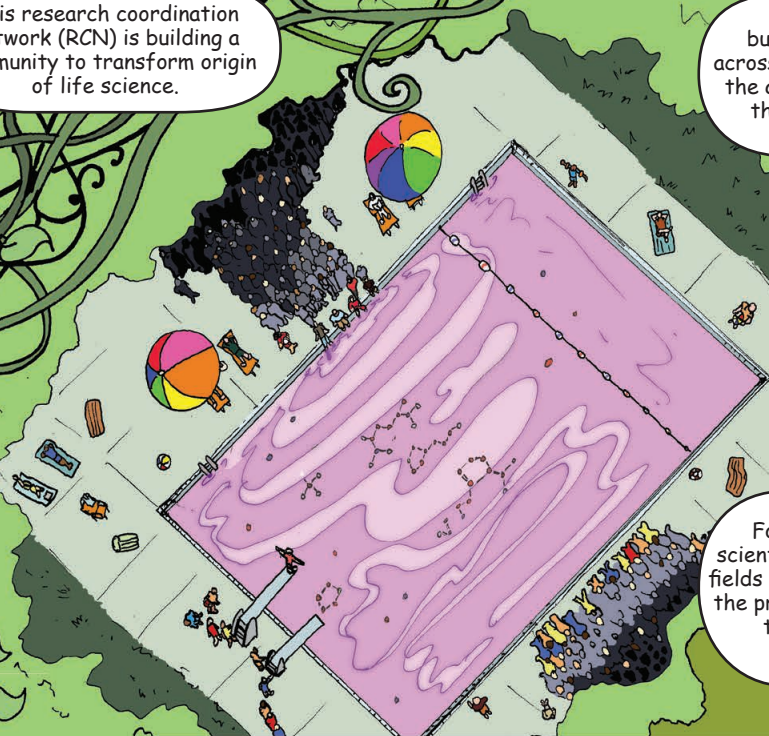
A gap that we need to fill with more science.

In 2018 the Astrobiology Program announced PCE₃ -the Prebiotic Chemistry and Early Earth Environments Consortium.



This research coordination network (RCN) is building a community to transform origin of life science.

The goal is to build communication across disciplines, because the questions are bigger than chemistry and biology.



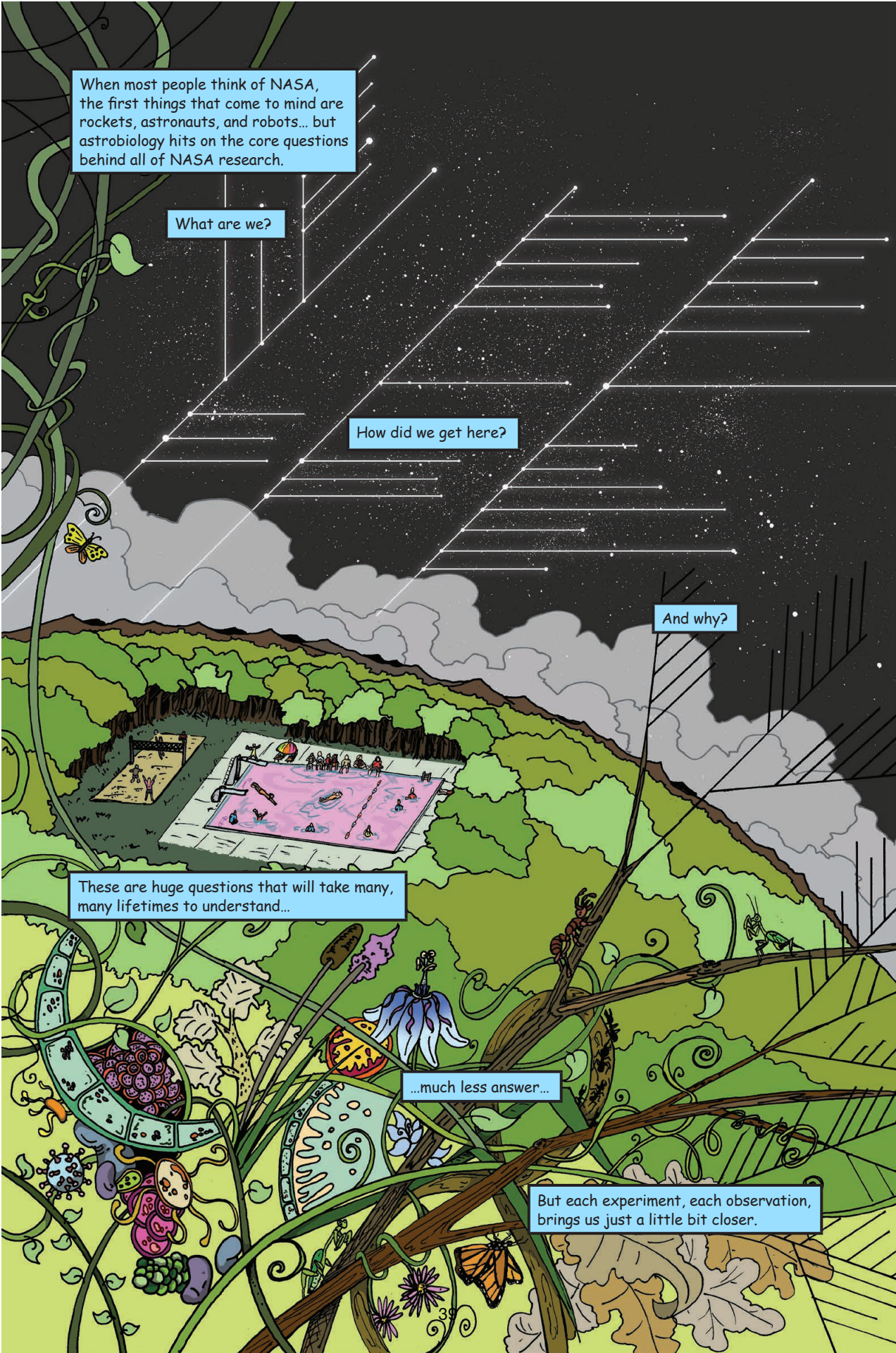
For over 60 years, scientists from different fields have been working on the problem... but we need them all to work together.

We need the knowledge of everyone.

It's time to approach the origin of life with interdisciplinary study rather than multi-disciplinary.

It's like a smoothie versus a fruit salad.





When most people think of NASA, the first things that come to mind are rockets, astronauts, and robots... but astrobiology hits on the core questions behind all of NASA research.

What are we?

How did we get here?

And why?

These are huge questions that will take many, many lifetimes to understand...

...much less answer...

But each experiment, each observation, brings us just a little bit closer.

Astrobiology

A History of Exobiology and Astrobiology at NASA

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