A Sound Beginning: Mr. B and Biology

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The first several days…

Mr. B starts the course in a way similar to his friend Mr. P, the eighth grade Physical Science teacher (first reading at least the introductory part of the article A Sound Beginning: Mr. P and Physical Science is recommended). He greets the students as they meander into his Biology class. Administrative details take up about half the first class and then the real teaching begins.

The logical starting place is for Mr. B to explain what Biology is and why it is worthwhile to study it. Engaged students wonder how they will be approaching the subject and how it relates to what else they will be learning in other classes. They are expecting Mr. B to say something about this. Less engaged students are, for the most part, at least open to hearing whatever Mr. B has to say. It is the first day, after all.

He mentions that Biology is a science, one of several sciences. He writes a definition of science on the board:

Science a unified body of knowledge that considers a particular subject matter according to a particular aspect

He then engages the class in an exercise similar to the one Mr. P did for his Physical Science class. This exercise not only defines biology but also helps students make sense of how biology fits into their overall education. Sometimes students hear the word "science" and think of a monolithic force that sweeps away all voices daring to oppose it. This exercise helps to counter this simplistic cultural notion by pointing out that there are different sciences, that it is possible for sciences to be related harmoniously and that we can understand how good scientific thinking works. Much of the following chart is filled out based on input from the students:

EXAMPLES OF SCIENCES

SCIENCE	Subject matter	Aspect considered
GEOLOGY	Rocks, the earth's physical structure	History and formation of land features
MEDICAL SCIENCE	Human body	Health and illness
IMMUNOLOGY	Immunity in humans and other organisms	How to promote immunity from diseases
EQUESTRIAN SCIENCE	Horses and their riders	How to promote excellence in horsemanship and the welfare of horse and rider
ECONOMICS	Money / wealth / resources	How goods and services are produced and distributed
SOCIOLOGY	Particular groups of people	How these groups behave on average and what we can predict based on data analysis
BIOLOGY	Living things	As alive and interacting with their environment
PHYSICAL SCIENCE	Material objects	Changes these objects undergo, both "accidental" (motion, work, temperature) and "substantial" (chemical reactions)
METAPHYSICS	Being, what exists	The ultimate cause and the first and most universal principles of reality
THEOLOGY	God	What God has revealed to us and, in "natural theology," what we can know about God from unaided reason

Mr. B continues his lesson, shifting to the methods of science. The class notes written on the board continue as well:

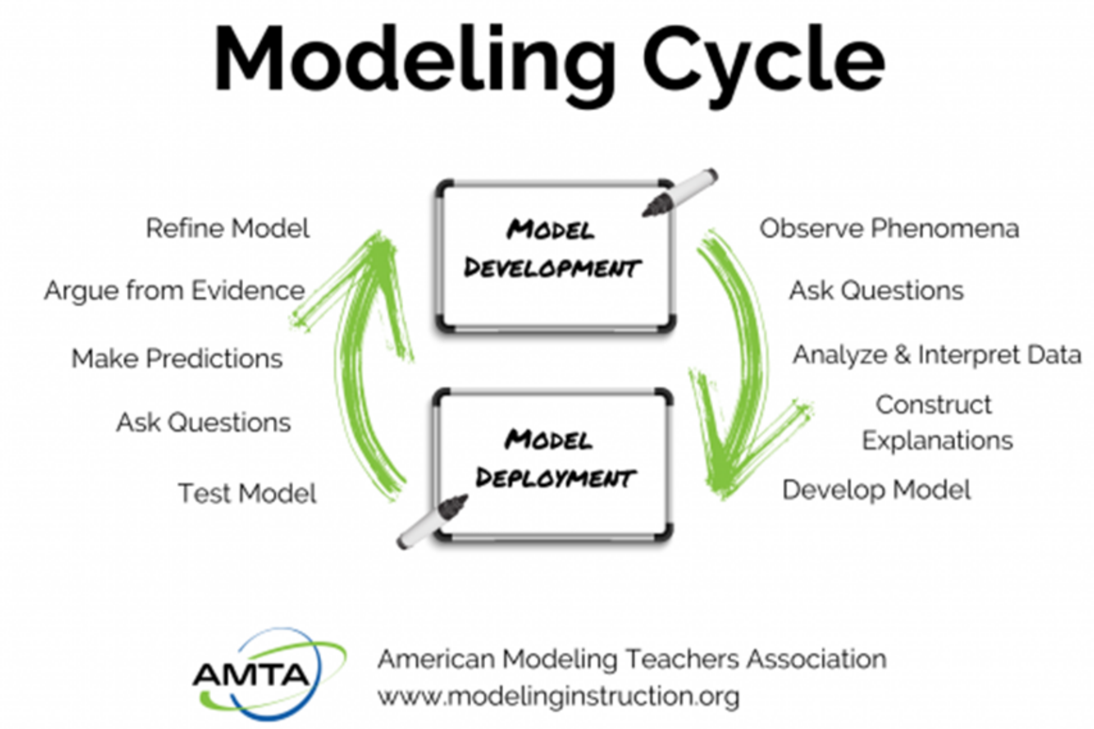
The Methods of Science

- All science reasons from "givens" to further knowledge
- All science seeks order and explanations

Traditional science (pre-modern)		• The "givens" are accepted truths from which a body of knowledge can be derived (for example, from 5 propositions Euclid derives a significant body of geometrical knowledge) • Ethics, politics, logic, natural philosophy, metaphysics and theology are all sciences that can proceed by this pre-modern "deductive" method

The modern scientific method		• The "givens" that form the starting point of modern science are often observations, typically aided by technical instruments, carefully recorded as a data set
		• Laws summarize patterns / order in the data
		• Theories attempt to provide coherent explanations of the principles behind the observed order
		• Laws and theories are models
		    ○ It is fair to say that they are approximately true, meaning that they have explanatory power and limitations (ex: F = ma works for normal conditions but breaks down at extreme speeds)
		    ○ All scientific models have limitations, and can be improved

Key distinctions	*Traditional science (pre-modern)*	Narrow scope / only a limited number of things can be known Certainty is possible – there is such a thing as settled science Deductive reasoning
	Modern science	Broad scope / many things can be investigated Certainty is impossible – settled science is a myth Inductive and deductive reasoning



Then Mr. B asks what he considers to be a crucial question, a question rarely asked at the beginning of a Biology course: is Biology best thought of as a traditional (pre-modern) science, a modern science or both? He writes this question on the board and mentions that how we answer this question makes a tremendous difference to how we approach this course.

Mr. B begins to argue that the best answer is both, although most people today think of Biology only as a modern science, an approach that results in some problems and even contradictions. *We can do better!* The key is to define what is meant by life. Here is what goes on the board:

Biology	Can be defined simply as "the study of life"
Key question	What is life?

Mr. B challenges the class to attempt to define life. This results in a rather lengthy class discussion as students articulate different ideas and Mr. B summarizes the mentioned points on the board. The first suggested definition is that a living thing is something that grows. At first glance this seems plausible. From an acorn grows a majestic oak tree, just as an adult grizzly bear was once a playful cub and, even before, inside his mother. But students quickly realize that this definition is inadequate because some non-living things like stalagmites and stalactites or certain crystals also grow. They also note that many living things reach a certain size and stop growing but remain alive. Growth seems to be important for living things but not what clearly defines life.

The next suggestion is that a living thing is something that reproduces something like itself. This seems to be a better definition because it is significant that living things, whether plants or animals, have offspring that are typically very much like their parent organism(s). But when Mr. B asks if anyone can think of a problem with this definition several challenges emerge. First, one student points out that some (all?) animals are sterile for part of their life cycle but yet still alive. Another student points out that a computer virus does not seem to be alive but yet it replicates itself under the right conditions. Like growth, reproduction may be important for living things but it does not appear to define life.

A few other possibilities are suggested and challenged before Mr. B askes the class to take out their textbooks and see if a definition of life is given. The class is surprised to see that the textbook provides a list of characteristics of life, including all that have been mentioned thus far and a few more. In total there are eight characteristics of life given:

1. Made of one or more cells
2. Displays organization
3. Grows
4. Reproduces
5. Responds to stimuli
6. Requires energy
7. Maintains homeostasis
8. Adapts or evolves over time

The class realizes that none of these characteristics of life, taken alone, are adequate to define life. Counterexamples to any one characteristic are not difficult to find. Mr. B asks the class if all eight characteristics taken together are an adequate definition of life. The textbook, after all, defines an organism as anything that has or once had all eight of these characteristics. Is this true?

The class starts to think of counterexamples to disprove this definition. Fire is suggested as something that may be a counterexample. It is not difficult to argue that characteristics two through eight apply to fire. This results in a discussion of the first characteristic as a possible standalone definition of life. Is it possible to define life as something made up of one or more cells? The class searches for counterexamples and someone mentions that a dead plant or animal still has cells, although dead ones. A particularly astute student notes that the claim that a living thing is something made up of cells begs the question since it really does not tell what it means for the cell to be alive. After all, couldn't a 3D printer print a plant cell that would be a cell but not alive? And if fire is burning dead tree cells then perhaps fire is a counterexample as something that can arguably display all the eight characteristics but yet not be alive. And another counterexample is mentioned: a self-replicating robot with artificial intelligence, a cyborg. So, the question remains: what is life?

The class is mostly baffled and Mr. B knows it. Even so, he is unrelenting. *Class, if we cannot define life how can we possibly be bold enough to claim that we are going to study life throughout this course? Is it even legitimate for us to claim to be students of life if we cannot even say what life is?* One of the students pushes back. *Sir, this is not entirely fair. It is obvious to us now that the textbook does not define life. A listing of characteristics of a living thing is not a definition of life. But maybe it* *is not possible to define life.* Mr. B responds that some modern biologists think that giving a definition of life is not possible because life is not an objectively real concept. But yet in their work as biologists they act as if there is something called life. Some people see this inconsistency as a problem.

Mr. B explains that it is possible to define life, but doing so requires knowledge from pre-modern science. The knowledge necessary to define life is unfamiliar to most modern biologists. This is why any study of biology should be broader than just considering the subject from the perspective of the modern scientific method. Biology should be studied both according to what was known before modern times and according to what is known by modern methods.

At this point Mr. B goes off on a tangent that some of the students find quite interesting (a few others seem a bit sleepy as Mr. B lectures on). He explains to the students that the textbook sitting on their desks is not so much a comprehensive study of life as a study of certain aspects of life. Its main focus is on the mechanical workings of individual living things and ecosystems. In some ways it is more like the study of death than life. More time is given to looking as the component parts of organisms, as when a dead organism is dissected and its tissues are carefully examined. Less consideration is given to considering the organism as a whole, and what it reveals of its nature by the way it interacts with its environment. At its worst, modern biology is agnostic as to whether the category of "life" is meaningful, whether it has real objective content. This is incredibly ironic. How can we have a science devoted to something, specifically "life," that does not really exist? Some modern biologists focus on the workings of what are commonly called living things while not really believing that the concept of "life" is real. What matters most to them is how we can manipulate what are commonly called living things, hopefully for the benefit of society. But there are other biologists that are not in favor of this reductive approach. In fact, there is a renewed focus on the whole organism in some areas of modern biology (like emergence).

Mr. B goes on to explain that the key to defining life is understanding how a living thing differs from a machine. The digression ends and the class starts to work through this in a systemic way. Here is what the class notes look like:

Non-living vs. Living Things

- The eight characteristics of life are not adequate to distinguish between a machine and a living thing (ex: think of an imaginary – *for now?* -- cyborg that appears to be a human person)
- But it is clear that there are differences between a machine and an organism:

Machine		Living Organism
Artificial: machine is assembled externally by man.	Form	Natural: organism develops from within. (e.g. a seed develops into a tree)
Unity of order: parts can be arranged to support its function, but are interchangeable, not unique. It can be reduced to its parts.	Unity	Unity of substance: every part of an organism, down to each cell, is identifiable to that particular organism. It cannot be reduced to its parts.
Machines can be turned off and then back on.	Activity	Constant: organisms must constantly act or die
A machine converts fuel into heat, motion, or a certain function, but not its own substance.	Self-sustenance	An organism converts food into its own substance and the energy required for it to act.
Machines cannot inherently regenerate. Broken parts are fixed externally.	Self-repair	An organism constantly renews cells and tissues. (e.g. healing)
Machines cannot naturally replicate themselves; any replication is artificial.	Reproduction	Organisms are naturally able to reproduce similar organisms.

- These differences show that there is an objective reality that we can call "life" that distinguishes the best possible robot from a living thing.
- 2 definitions of life:
  - Less technical -- Life is the capacity of an organism to initiate and sustain self-movement ordered to perfecting the organism according to its nature.
    - An organism is a naturally organized body of a living type.
    - If one understands nature correctly then this definition may be sufficient even for the case of the cyborg.
  - More technical -- Life is the first act of a natural body which possesses a potency for that act within it and, therefore, is a kind of activity conferred by a substantial form on a subject with operations intimately related to the kind of being it is.
    - This definition is rigorous and sufficient even for the case of the cyborg.
- Both of these definitions are based on concepts from natural philosophy:
  - Nature
    - The technical meaning of nature refers to a thing as having a nature (ex: as when we say that it is "human nature" that people act in a particular way)

    - Nature is a principle and a cause of being at motion and of being at rest that is in the thing to which it belongs, primarily and in virtue of itself, and not incidentally (Aristotle). It is an intrinsic principle, a principle within the thing.
    - By contrast, something artificial, like a machine, has external order imposed upon it. It lacks an internal organizing principle.
  - Act and potency have to do with the perfections (act) that a thing has and its ability to change or develop in a particular way (potency): what a thing *actually* is and its *potential* to develop.
    - It is not possible to define motion (in the broad sense of all possible change) without recourse to act and potency.
    - Motion is the actualization of what exists in potency insofar as it is in potency.
  - A substantial form is an intrinsic (natural) form; it is that through which a thing comes to be the type of thing that it is. It is the intrinsic organizing principle. By contrast, a machine lacks a substantial form. It has an artificial form that is extrinsic, meaning imposed upon from without, to the thing that it organizes.
  - Every organism (living thing) has the capacity for self-perfective motion; meaning that it contains within itself its own principle of organization, self-regulation, growth, and reproduction. The diverse parts of an organism are unified, being ordered toward the good of the whole being, a good determined by its nature. Life is the first act of an organism that makes all of this possible.

At this point there are two distinct reactions in the class. The students are either struggling mightily to understand this or they have given up and are disengaged. Mr. B was able to keep their attention early in the discussion by referring to transhumanist ideas from people like Elon Musk or from popular movies. The students were interested in considering the possibility of building a cyborg indistinguishable from a human or the limits of incorporating computer technology into a person. But when Mr. B started to define nature, act, potency, form and life he progressively lost more and more students.

Even so, some important points were conveyed. It is possible to define life. Life is a word with real meaning that relates to the objective world. To clearly define life requires thinking that is difficult and uncommon today. And most of the students, even if their understanding is imperfect, have the sense that life has to do with an intrinsic organizing principle that is naturally within the organism itself as opposed an analogous type of order that can be imposed from without by a craftsman. Some understand that this has to do with the concept of substantial form that they have learned about before, and will learn more about next year in Natural Philosophy.

Mr. B asks the class if it is necessary for a modern biologist to know all of this to work as a modern biologist? After some discussion the point is made: even though the methods of modern biology are inadequate to define its subject matter, namely "life," once a biologist receives or assumes the validity of this knowledge he can go ahead and do modern biological research, for the most part without considering how life is defined. In fact, even biologists who do not believe that life is real, who assume that what appears to us as a living organism is really nothing more than a complex machine, are still able to do proper research and publish results that advance our understanding.

Mr. B is mostly satisfied that this is enough for now but he wants to drive home the key point through an example. He asks the class if it is possible for scientists to manufacture a new organism in a laboratory from component elements, from scratch? Most students indicate that they think the answer is no. It is definitely possible to modify existing organisms through genetic engineering but to create an entirely new organism from scratch seems impossible. We cannot currently imagine a new type of plant and build a seed that will grow into that plant. Could it ever be possible to do this? Mr. B notes that to his knowledge scientists have not yet successfully 3D printed seeds that grow, although they have successfully cloned animals in the lab, a technique that starts with a cell that is already alive. In both of these cases (one hypothetical and perhaps impossible, one real) the scientists are replicating a substance with a natural form, not creating a new one. If it turns out to be impossible to control life to such an extent that a new, unique organism can be created from scratch it will be because it is not within our power to create a substantial form. Our power would extend only to being able to replicate or modify substances with substantial forms and imposing an artificial form to yield incredibly complex machines. If this is the case, our limitations will be because we cannot bridge the chasm between a living thing and a machine.

By way of contrast, the process of evolution involves actualizing a potential in a particular species to change over time into a different species. It is not so much a mechanical process of making a new species from preexisting materials as the organic development of a capacity that existed according to the nature of the previous species. It is a natural process.

A few summary points

Mr. B has started to make the argument that modern biology benefits from considering what life is from a broad perspective, a perspective that includes scientific knowledge from pre-modern times. That modern biology needs foundational principles from traditional biology should not be seen as a deficiency or as something atypical for modern science. All modern science rests on rational principles, such as the principle of non-contradiction or the principle of causality, that must be borrowed from other sciences, such as natural philosophy or metaphysics. The same can be said about the way modern science borrows from mathematics.

But a further argument could be made that the best thinking in biology is supported by those who have a more complete understanding of life. This knowledge may not show up from day to day in one's work in the laboratory. But it could help in strategizing about directions for research, in considering, for example, that there are properties of a whole organism that resist being understood merely in terms of the organism's parts. The best biologists are aware that the whole is not reducible to the sum of its parts.

Onwards…

At this point Mr. B is ready to proceed through the content of the course. Much of what he covers is in the textbook, although Mr. B will often depart from the way the textbook presents the material. Aware that the tendency in modern biology is to consider living organisms as if they were machines, as if a mechanical explanation of the workings of the organism is what is most important, Mr. B makes an effort to focus some on the behaviors of whole organisms. This approach is familiar to those students who learned natural history in lower grades.

Mr. B does cover the component parts of organisms. He covers cells and the amazing complexity of cellular processes. Students learn about different biological systems, as is typical in most biology classes. Throughout all of this, however, Mr. B consistently thinks about the question of biology as the study of ***life***. From time to time he will explicitly circle back to the foundational material with which he began the class. Without being critical of modern biologists, he does look for places in the textbook where the authors fall into an overly reductive approach, through making too much of a mechanical explanation or absolutizing a scientific model. And when it makes sense to do so he points this out to the class, further helping them to recognize the problem. This approach ends up educating students who understand specific topics in modern biology exceptionally well, and, perhaps even more importantly, have a grasp of the overall landscape, the overall context, into which this understanding fits.