21 How Facts & Problems Evolve when Natural Philosophies Change: Newton and the Theory of Universal Gravitation

There are two pitfalls when you discuss Newton in the history of science. The first is thinking that Newton "got it right"--the first person to have mirrors at the back of eyes so that he knew what he saw was really in nature, whereas the other natural philosophers were just dealing in human 'constructs'. Wrong! Newton's theories were highly successful; indeed they are the best example of a successful paradigm or theory, but this does not mean Newton had the final truth, (especially now in the light of 20th century developments with relativity theory and quantum mechanics). One would be hard pressed to say that Newton unveiled the truth and that is it. Related to that pitfall is the Whiggish view that in the Scientific Revolution everyone was struggling with great problems that only the great Newton could solve.

There are two things to say about that: one is that as a kind of historically understandable process, the Scientific Revolution was largely over before Newton published his *Principia* (or in full, *Philosophiae Naturalis Principia Mathematica*) in 1687. We have seen that the climax of the process of change in astronomy and natural philosophy initiated by Copernicus, was the establishment of the mechanistic worldview and with it the establishment of Copernicanism as commonsense. The mechanistic worldview and the widespread acceptance of Copernicanism had been achieved before Newton was 25 years old! Newton is an important after-thought. So important, that he changed the rules of the game, even after apparently they had just been accepted. But Newton is not the goal or end point of the Scientific Revolution in the sense that the process aimed at him and his work, (or that his work was needed in order to have achieved some sort of closure in the minds of contemporaries or of critical historians). The other point is, that to a very large extent, Newton's problems were not the problems of the people who went before him -- they were not failing to solve Newton's problems, for they had been asking different questions.

Let's illustrate these pitfalls and their avoidance by talking about Newton's central 'discovery' or construct--universal gratitation. In Newton's *Principia*, the most famous and important scientific book ever published -- (*The Mathematical Principles of natural philosophy* in its English title) -- the central concept that makes the whole book work is this conception of universal gravitation. I will give you an idea of what it means in a very simple case. (fig. 1) We are not dealing with anything like the real universe, but a simple universe which consists of infinite empty space and two point masses (two mathematical points that have mass). Newton's concept of gravitation, expressed mathematically, states that in this situation, Mass 1 and Mass 2 will attract each other with equal and opposite forces, with a force which is measured by this expression:

> The force is given by multiplying the masses of the two bodies together, and then dividing the result by the square of the distance between the two bodies.

Obviously if the bodies are far apart, the force is going to become weak but it never becomes nothing. Even at huge galatic distances there is some force there, no matter how small.

Now let us look at this theory with the jaundiced eye of a mechanical philosopher, a Robert Boyle type. Newton is saying that in the real universe, every particle or corpuscle attracts, and is attracted by, every other particle or corpuscle. The atoms that are in the centre of some distant star are at this minute exerting a gravitational attraction on every atom in your body and vice versa. Newton's universal gravitation meant every piece of matter attracts every other piece of matter according to his formula. This force operates across empty space and there is no intervening mechanism to cause or convey that force. You could say "how does that atom in that star attract the atoms that my body is made out of?" And Newton's answer is "They just attract each other!" There is no 'mechanical' mechanism in between. There is nothing like what which a modern physist would call a gravitational field. There is no special state, or action or mechanism in the space in between -- there is just *attraction at a distance*. If someone using a nuclear reactor on a planet surrounding that same distant star had just now created an atom of uranium or plutonium, the moment that atom came into existence (according to Newton) it began to attract every atom in this room and vice versa. That is the implication of Newton's viewpoint. So the gravitational action is *instantaneous* and *at a distance* acting across empty space.

Newton's viewpoint is very strange from a mechanical philosopher's standpoint. For instance, a mechanical philosopher like Descartes or Boyle would say "what is the mechanism? What causes this attraction? How do you explain this phenomena? Newton's explanation is "That is how you explain it", "There is attraction at a distance." This idea would also be extremely weird and incorrect from a 20th century post-Einstein and post-James Clark Maxwell standpoint. From the standpoint of modern physics, actions do not propagate themselves instantaneously. Nothing can propagate itself faster than the speed of light, and that star I am talking about might be a hundred thousand light-years away from here. So it would take electro-magnetic radiation a hundred thousand years to reach us. But Newton's theory states that atoms on a star and on Earth, *instantaneously* attract each other over empty space. All atoms are in instantaneous spontaneous simultaneous communication with each other by attraction, according to the mathematical expression of the law of universal gravitation.

Newton's view is not acceptable from a 20th century standpoint, but it was also not acceptable from a 17th century mechanical philosopher's standpoint, because they wanted particles or atoms moving around to cause these actions, by pushes, pulls or pressures. And, there is another consideration for the mechanical philosophers, for they believe that all actions take place through the collision or pressure of corpuscles. If Descartes wanted to explain how bodies fall to the Earth, he would say the following: (and of course this is implausible) "we do not feel it or see it but there is a vortex of very fine corpuscles which spins around the Earth, which causes a centrifugal tendency. In this 'local vortex' the gravity corpuscles spin and this piece of matter, being more dense than the surrounding air corpuscles, it gets pushed down".

Basically, in this kind of mechanist explanation, the chunk of matter is pushed down by the particles in the gravity-causing vortex acting by impact on its *surface*. Newton's gravity, by contrast, is not a surface phenomenon, for it is not a collision between particles, but a phenomena that penetrates to the very core of every body (every chunk of matter). Here is a modern way of explaining this: Newton's gravitational force 'X-rays' every piece of matter and operates to the very core of every piece of matter. Why? Because gravitational force operates according to the amount of matter that a body has, not the surface area! The gravitational force is acting upon the complete inner quantity of matter.

So we have a force;
(1) that has no mechanical explanation
(2) that acts instantaneously all over the universe and
(3) that penetrates to the very core of every piece of matter.

The gravitational force emanating from the atoms in your body is right now attracting the body of the Sun and vice versa. Your gravitational forces, the ones emanating from the atoms that make up your body, are attracting the Sun in proportion to the mass of the Sun. That is not a mechanistic philosopher's concept because mechanistic interactions can only occur through the collision or pressure of corpuscles, not by these spiritual powers that 'X-ray' the bulk of the pieces of matter.

This concept was viewed as strange from a Cartesian or mid 17th century Mechanistic perspective, but it is a conception that, put to work mathematically by Newton, is just about the truest thing that has ever been claimed in science--if true means being very powerful at solving problems, making predictions, and addressing a wide range of phenomena, for the time being: (where "For the time being" means from about 1680 to about 1900, which is a long time for a theory to survive). If there ever was a successful paradigm that went on from strength to strength, solving problems and puzzles, it was Newton's physics. Kuhn's model of a successful paradigm has a lot to do with the history of Newtonian physics and its overthrow in the 20th century.

Let's consider just how successful this conception was at the time, after 1687. We have Newton's law of gravitation and to it we must add his three other laws of motion. The First is the Law of Inertia: a body in motion in a straight line at a constant speed will remain in that motion, in that line, at a constant speed unless acted upon by an outside force. Third Law is that to every action corresponds an equal and opposite reaction: you shoot a rifle, you get an action out of the barrel of the gun, but you also get a kick in the shoulder which is the equal and opposite momentum; or in the law of gravitation the two masses exert equal and opposite forces upon each other. The Second Law is: Force equals mass, times acceleration, which means if you apply force to a body accelerates.

If you use Newton's conception of universal gravitation and his three laws of motion and if you could imagine a particle or planet moving around another larger particle or planet, you can deduce Kepler's laws of planetary motion. That is, Kepler's laws, which Kepler struggled and bumbled along for years to get, simply fall out in Newton's physics. But they fall out in a slightly qualified way, because if you accept Newton then you see that Kepler's laws hold broadly, but cannot be exact. Kepler's work in celestial physics becomes a special case of Newton's theory. But there is more. Newton can ask what happens if you have a big, round mass like the Earth and a minute mass very near the surface of the Earth. You do the mathematics and find out that if you drop such a smaller mass, it accelerates toward the surface of the much bigger one in the exact proportion that Galileo gave in 1638. So, Galileo's physics of falling bodies also becomes a special case of Newton's new physics of gravitation. **Kepler's laws of the heavens for a Copernican system and Galileo's laws for falling bodies on Earth became a special applications of, and derivation from, Newton's physics**. From this baby description of "Newton's synthesis" of Galileo and Kepler, you can feel some of the power of what is going on in Newton's work. Newton was working with Galileo and Kepler's life-long struggles. Galileo did not have time to do celestial mechanics, he was so busy trying to figure out his terrestial mechanics. Kepler did not have time for terrestial mechanics because he was so busy trying to figure out how the Sun pushes the planets around.

So Newton accepts Galileo's and Kepler's laws as special cases which now follow within his deeper theory of universal gravitation. If you accept their laws, explained his way, you can give a model for the Copernican system: you can take all the available astronomical data, feed it into the system of Kepler's laws and get a Newtonian explanation via gravity of the motions of the planets around the Sun. It worked excellently, except for a couple of anomalies (some aspects of the motion of the Moon and the motion of Mercury). But in general, Newton has a physics that puts Copernicanism on the map. Now do not get me wrong. The Copernican system had already been accepted--it would be an historical mistake to believe that it is Newton's physics that makes everyone believe in Copernicus' theories. They were already Copernicans -- Newton is just stating he has worked out the whole picture and he deserves a lot of credit for that. (Cf fig. 2: Newton's synthesis)

Newton is also able to explain other important classical problems. For instance, the tides. Newton takes the tides as a great puzzle for which he can show he has a solution, thus demonstrating the power of his theory. The Earth and Moon attract each other; the Earth and Sun attract each other; the waters of the seas on the Earth are sloshing around on the surface of the Earth. You can apply Newton's universal gravitation to this, provided you have to use a lot of simplifying approximations, but the basic phenomenon of the tides lies in the relationship amongst the Moon, Earth and Sun's gravitational interactions.

There are other notable triumphs in the *Principia* such as Newton's prediction of the shape of the Earth. Newton states that the Earth cannot be a sphere, because if the gravitation is correct then the Earth has to be a little fat around its equator than the poles. In the 18th century (I suppose this is a Kuhnian normal science carried to extremes) the Parisian Academy of Sciences sent one expedition to South America and another to Lapland to measure a unit of distance on the surface of the Earth and to their satisfaction they confirmed that Newon was correct. (Of course in the 20th century we have learnt that the Earth is more pear-shaped, being fatter in the southern hemisphere in general, but you need other theories to explain this.)

It therefore seemed that just about anything and everything could be explained by Newtonian physics. For example, the curious wobble of the Earth on its axis. The general story is that the Earth's axis keeps its same orientation as the Earth goes around the Sun, but we know that the Earth's axis wobbles slowly, completing one revolution every 25,000 years or so and that is what causes what was known by the Ancients as 'precession of the equinoxes'. The Ancients thought this phenomena had something to do with the sphere of the fixed stars shaking and wobbling slowly. Copernicus had to assume that it was the the Earth's axis that wobbles; but, why does it wobble? Newton finally had an answer. Newton treated the Earth like a top that was beginning to fall over; he gave the Earth the dynamics of a top and he analysed it, explaining the necessity of its slow axial wobbling.

So much for the broad outline of how Newton applied the idea of gravitation and his laws of motion. His 'paradigm' had a long term great future. During the 18th and 19th centuries physicists applied Newton's ideas about force acting at a distance and his laws of motion and his modes of mathematical analysis to the problems of studying other supposed forces: the force of electricity; force of magnetism; certain types of chemical forces of attraction and repulsion. Hence, we have paradigm extension and in 19th century physics before Maxwell or Einstein, this is what we see. Newton's theories were highly successful although based upon the highly weird concept of universal gravitation, a concept that presumably did not fall out of nature into our laps but which was made, constructed.

This smmary leaves us with three questions :

> (1) How did Newton construe the concept of gravity, in particular what kind of question is gravity the answer to?
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> (2) Why was Newton so weird a natural philosopher? He was weird for the late 17th century because he was not a mechanist in that he theorises things as such gravity which are non-mechanical forces that control corpuscles and cause phenomena.
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> (3) Given that Newton operated within a weird natural philosophy that was almost a throw-back to the magicians and neo-Platonists, how did he, within his worldview, construct gravitation?

The first thing we to do to address Newton on gravity is to make a comparison between what Newton thought and what the mechanists thought. (fig. 3) In the mechanist system, God made corpuscles and atoms and they have very few properties: size, shape, motion and impeneterability. God also laid down some laws of nature according to which atoms move and collide. The motion or impact of corpuscles, according to those laws causes phenomena to occur.

Newton, for his part, believed that there are various immaterial causes in the universe, causal agents that do not consist in corpuscles or mechanistic interaction, because they actually cause the corpuscular interaction. They are not themselves produced by corpuscular interaction. So, there are certain immaterial causal agents such as gravity, magnetism, electricity, chemical force. God created not only corpuscles but also these agents--the higher spiritual level above corpuscles. Gravity, as an agency, acts in a law-like manner according to a beautiful symmetrical mathematical equation. These agents, acting according to laws, cause motions of particles, and those motions cause phenomena. The closest thing to this idea, that we have seen is in Kepler's theories shaped by his neo-Platonic natural philosophy. Neither Kepler or Newton pursued the magical manipulation of nature implied by such a neo-Platonic metaphysics, so they are actually quite similar. Therefore, Newton is a kind of conceptual throw-back, looking back as he does to Kepler and to other neo-Platonists.

Finally, there is one other key point to remember as we proceed: Newtonian gravity is not a natural phenomenon: gravity is a conceptual construct. We have an Einsteinian physics that does not entertain gravitational force in the Newtonian form. For Einstein, bodies do not attract. Bodies move towards each other according to the shortest space-time trajectory because massive bodies distort spacetime in their locales. Nothing is attracting everything else.

So gravitation was not there waiting in nature for Newton to discover it. What I want to suggest to you is that Newton was the first person to *construct* universal gravitation as a theoertical concept and as a mathematical expression. One way to investigate the genesis of new concepts or theories is this: Consider a concept or construct as the answer to a question, even though the question may not have necessarily been explicitly stated. So, what is the question to which Newton's conception of universal gravitation is the answer? I think it was, in effect: **What immaterial (spiritual) causal agency explains the motions of the planets and the fall of bodies on the Earth?** This is the question to which universal gravitation is the answer. You have to have that type of question to get Newton's concept. And that question assumes a host of related background ideas, assumptions and aims, including: a belief in causal agencies and a belief that terrestial and celestial physics can be tied together into one theory.

Let us look at some of the major thinks that we have met in this text and ask if they have the same question in the same, as it were ecological-theoretical space. First consider Aristotle. Could you ask Aristotle "What is the immaterial causal agency acting mathematically that explains both motions of the planets and falling bodies on the Earth"? No, for he would say it was a ridiculous question, because in the 'heavens' there is celestial matter which moves in a circular motion and on Earth, in the centre, you have heavy stuff which falls by its nature to the centre of the Earth. Terrestial concepts and celestial concepts are totally different.

How about Copernicus. What moves the planets according to Copernicus? (Remembering that Earth is a planet now). Copernicus does not say very much, for he is embarrassed that the Earth has to move, because he cannot really explain the phenomenon. Historians now think he believed in celestial spheres, just as did Aristotle and the medievals. Now, where the Earth's celestial sphere is attached to the Earth to move it around is a mystery, which is why Copernicus does not talk about it. And, furthermore, for Copernisus, Why do things drop straight down on the Earth? Again he has a problem, but not the solution. Newton's question was just not in the realm of possiblity for Copernicus--he had other agendas to pursue and difficulties to face.

How about Kepler? Well, we know that he is a Copernican and he had a natural philosophy similar to one Newton later constructs. Kepler thought that there were many spiritual powers in nature e.g.: the Sun gives off light which is spiritual power obeying nice mathematical laws of propagation, intensity, reflection and refraction. And we also know that for Kepler the Sun gives off other, different, spiritual spokes of power that move the planets. The laws of planetary motion are the laws of action of that spiritual power, which is akin to Newton's conceptualisation, but still Kepler's celestial mechanics is prior to and different from Newton's. Moreover Kepler tries to explain local gravity -- the fall of bodies -- but he does not link that problem to the issue of the motion of the planets around the Sun. Kepler calls this gravity, which for him is a low-level spiritual force by which pieces of Earth attract each other. For Kepler, this low level spiritual force is quite different from the grand powerful planet moving force coming out of the Sun. Light, magnetism, gravity, planet-moving forces are all different spiritual forces with their own spheres and laws of action. Kepler uses the word gravity, but uses gravity in a different connotation in only one area where Newton later uses the term.

Finally, our mechanical philosophers, Descartes and the rest. For them, there is an infinite universe and each of the star systems has an individual vortex of fine corpuscles going around its central 'Sun'. It is almost like Kepler without the spiritual forces. There is a material whirlpool pushing the planets around not a spiritual force. As for the fall of bodies to the Earth -- the Earth has a small vortex which it carries around with it and heavy bodies move down because of a relative lack of centrifical force compared to the vortex particles. Interestingly, the moon is also moved around the earth because it is trapped in this local vortex--the entire package, earth-moon-local vortex swirls around the sun in the solar vortex---hmm? So, what are we going to say about Descartes who describes both local gravity and planetary motion mechanically through whirlpools, although he has two different whirlpools to explain two different phenomena -- planetary motion and gravity. Well, unlike Newton, he has got 'mechanisms' not funny immaterial forces (he would have denied such things exist). Moreover, Descartes has no way he can mathematize the two questions. In short he was not asking Newton's question.

In short, you can't ask Newton's question outside of a kind of post-mechanist but neo-Platonic natural philosophy, and, given that, Newton's question is unique to him: **What one, single spiritual force explains simultaneously the motion of the planets and the falling of bodies on the Earth?** So we next have to ask why he had that question, and that assumption about spiritual forces and agencies. This turns out to depend upon the form of his fundamental commitments in natural philosophy and those commitments in turn have biographical, institutional, social, religious and political factors shaping them. We have to look at those in the next Chapter, before tracing the path of research and speculation that led Newton to his strange and fruitful construct.

Figure 1

$$\boxed{F = \frac{m1 \times m2}{R^2}}$$

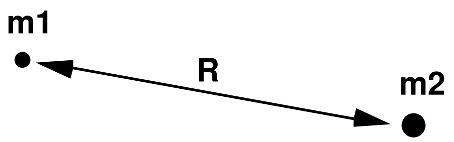

Figure 2 Newton's Synthesis: *Principia* (1687)

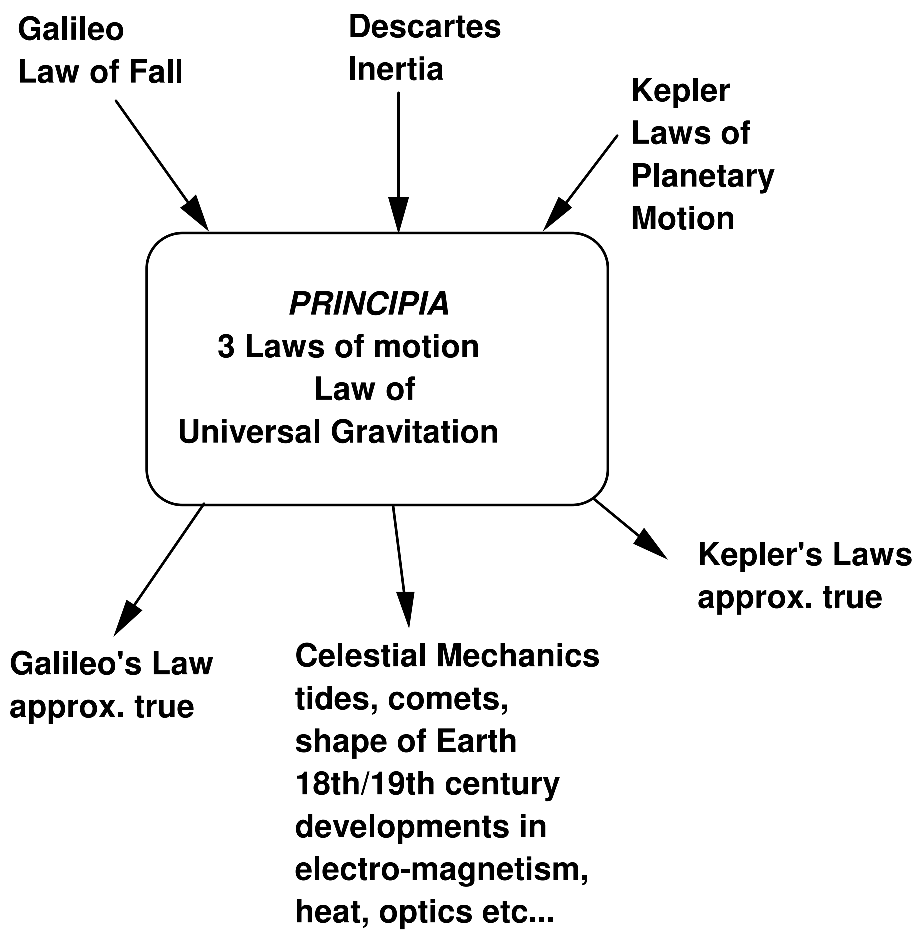

Figure 3