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The Scientific Revolution: Different Answers for Different Question

In the modern day, we go through a specific process to conduct science: the scientific method. We make observations, do background research on questions that arise, construct a hypothesis, do an experiment, analyze our results, and share our findings. To hear about this process growing up, one might believe that this is the only way science has ever been conducted. If one looks back at the history of physics, however, one sees that there have been multiple ways of investigating the universe. In Aristotle's time, scientists were not even called scientists, they were called "natural philosophers," and their interaction with the world made this name the obvious choice. To develop explanations for phenomena, they observed the world and made sense of it through theories. The addition of experiments to test these theories sparked the scientific revolution.

To study the revolution, class "C123: The Copernican Revolution" conducted two main experiments, one to investigate an Aristotelian theory and one to investigate a Galilean theory. These figures, Aristotle as a natural philosopher and Galileo as a scientist, were two of the main characters of the revolution. Their fundamentally different approaches provided two different explanations for the same phenomenon. By analyzing their methods, however, we see the merit of both styles.

Aristotle lived from 384 BCE to 322 BCE. He attempted to make sense of the chaotic world around him by developing theories based on his experiences and observations (Grant 59). He observed that certain objects, namely earthier or "heavier" substances, tended to fall toward the center of the earth and less heavy bodies, such as water and fire, tended to move upward toward the sky. He also observed that the stars in the sky moved in a fixed pattern. Based on these observations, he imagined the universe was composed of different spheres, with earth at the center. The imperfect, ever-changing terrestrial sphere could be broken down into an earth, water, air, and fire sphere. The perfect celestial sphere, outside of the terrestrial sphere, contained the sun and all of the fixed stars. The moon, in the lunar sphere, separated the terrestrial and celestial spheres. Each sphere had its own "unmoved mover" which was able to move something without moving itself. The celestial "prime mover", or God, was the immaterial mover who moved the celestial sphere (67 Grant).

Within the terrestrial sphere, Aristotle categorized movements into natural and violent motion. The first, natural, is caused by bodies, which are composed of different elements, moving into the sphere of the element which they most contain. For instance, rain falls in order to reach the water sphere. Stones roll downhill toward the earth sphere. Embers fly up toward the fire sphere (59 Grant). Humans also have free will and are thus able to fill a bucket with water and throw it into the air. This action is violent motion: acting upon an object in a way to take it out of its natural place. Once the object loses contact with the agitator, the air swoops in behind the object, filling in the space and pushing it forward until its weight becomes too much and it falls toward its natural sphere.

Aristotle spent his years building this universal view which answered the question: "Why?" For this reason, our experiment to study Aristotle's worldview centered not on the meticulous details of what was happening, but on the broad explanations. Resistance seemed to be a major factor, so we focused on his $V=F/R$ equation, where V is the velocity of the object, F is the motive force, and R is the resistance of the body and the external medium (Grant 62). We dropped three different balls through three different mediums in a graduated cylinder and measured the time of fall. The earthiest medium, honey, most resisted the movement of the balls, since this medium was already close to the natural sphere of the earthy balls. Dropping the balls through air gave the least resistance, as the balls quickly found their way to the bottom of the cylinder, which was closest to the earth. From just this brief explanation one can see how Aristotle conceptualized motion. He treated resistance as an integral piece of the puzzle to explain why motion occurs. He thought of motion as interplay between the tendency of the ball to be in its natural place and the composition of the medium. For a more complete breakdown of our process and the outcomes, refer to our attached laboratory write-ups.

While Aristotle was a natural philosopher who contemplated and observed, not experimented, we can still compare our methods in this experiment to his attitudes. Aristotle tended to take one look and then to contemplate this observation until he had a theory to fit it, without going back again and again to double check his data points. Thus, that was not the point of our experiment either. He was not overly concerned with quantitative results, but rather the explanation for the observations. When we witnessed the motion of the balls, we were led to ask what elements were contained in them to make them move in this way. We noticed an increase of resistance to the falls of the balls as the external medium increased its earthiness, since the ball was already in its natural place. Movement requires no external cause; it is the actuality of potentiality by an object going to its natural place (C&R 126). In our experiment, we analyzed the fall of the ball holistically, rather than in piece-by-piece increments. Paralleling Aristotle's' philosophy, we spent more time thinking about why our results occurred the way they did, than drawing up graphs and analyzing them mathematically (Drake 8).

This is, however, is exactly what Galileo would have done. Galileo was a scientist who lived from 1564 CE-1542 CE. He became interested in mathematics during his university years and began to apply these studies to explain observable occurrences (Drake 15). To help with his careful mapping of the night sky, he developed the toy telescope into an unprecedented tool for astronomers. With this tool he was able to observe the moon's imperfections closely, disproving the Aristotelian ideal of a perfect celestial sphere. His talents of careful observation led him to notice and track the rotation of Jupiter's moons every night for nearly three months (Drake 56). To him, this evidence dispelled other's arguments against a heliocentric universe, in which they argued that it was nonsensical for everything to move around the sun but the moon to move around the earth. It turns out there are more moons out there rotating around other planets! Most considerable to the experiment we enacted, Galileo proposed that falling objects are composed of two separate motions, a horizontal velocity, which does not change, and a vertical velocity, which changes in proportion to time (Grant 166). To test this acceleration, he carried out his famous incline-plane experiment, which we, as a class, replicated.

Freefall is difficult to study, so Galileo and our class "diluted" the acceleration by releasing a ball down an incline plane. The horizontal velocity should be the same regardless, while the vertical velocity would remain comparable, since the track has fairly uniform resistance. We took five measurements each of a released ball falling from 200 cm, 190 cm, 180 cm, etc., all the way down, in increments of ten or twenty, to 10 cm from the end. Staying true to Galileo's period in history, we used a water clock to time each fall. Then we plotted this data on a distance-time graph. Since it was unclear whether the graph was parabolic or exponential, we squared the time and plotted these values. The straight line formed by this data showed that the original data was parabolic and that the speed of a falling object is directly proportional to the time it takes to fall. For a complete explanation of the reasoning behind our methods, reference our attached lab sheet.

Galileo's work centered on answering: "How?" Resistance was not important to him because it focused on: "Why?" Rather than time the full length of a fall through various resistances, as we did in the Aristotelian experiment, we took precise measurements at exact distances all the way down the path of a falling object in order to find the exact behavior of the fall. A Galilean approach is more quantitative than philosophical. We spent most of our time gathering data and then graphing and manipulating these points. "A straight line is constant acceleration," was more important to us that why that acceleration occurred in the first place.

Aristotle's viewpoints remained largely unchanged for more than a thousand years because people were unable to let go of his original biases which shaped his observations. Even if he was wrong, the theories stuck and simply gained hundreds of small alterations, as contradicting observations were made. Galileo was willing to start afresh, to experiment and observe again and again until he was sure he had an accurate description of the natural world. While Galileo may not have known what gravity was, he was able to describe the increase ofvelocity at a set rate (C&N 140).

One may be tempted to view the Galilean approach as the superior method. After all, other scientists proposed ideas about uniform acceleration, about heliocentric universes, but he was the first to bring together all of these definitions and ideas, test them tediously, and bring them together into an ordered whole to explain much more accurately how the world works. Indeed, his methods are more useful than Aristotle's in many situations. If we want to predict an ever-changing condition, such as the weather, we cannot approach it completely theoretically from our arm chairs. There has to be a way to go into the field and research many variables of the weather. However, there comes a time when technology has not yet caught up with our ideas and we are unable to conduct experiments. Sometimes we must take a breather to stretch our imaginations, take on the role of a natural philosopher, and think of all the possible ways the world could be.

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Citations

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