Geometry, in which the Author, in order to give proof of his universal Science, explains the most abstruse Topics he could choose, and does so in such a way that even persons who have never studied can understand them" (Cottingham, et al)

6. Both the *Optics* and the *Geometry* made major contributions, the latter especially via van Schooten's Latin editions, with commentary (greatly expanding the text), of 1649 and 1659
   a. *Optics* includes the law of refraction, which (like others) he appears to have discovered independently of Snel
      (1) With this law, a theory of geometric optics covering shapes of lenses -- introducing real science into the design of telescopes
      (2) Identifies and explains spherical aberration (mistakenly attributing chromatic aberration to the same thing) and indicates lens shapes for eliminating it
   b. *Geometry* extends classical geometry in ways that legitimate the use of algebraic methods to solve problems
      (1) A primary step, together with the work of Fermat, in forming what we call analytical geometry
      (2) Though not a reduction of geometry to algebra (just the opposite) and no Cartesian coordinates in it
      (3) Rather, it expands the notion of geometric construction beyond compass and straight edge, and then "reduces" algebra to this expanded geometry, thereby legitimating it
      (4) Huygens studied Cartesian geometry under van Schooten in Leyden, and Newton's reading of van Schooten's second edition contributed greatly to his early advances in math, including the calculus -- arguably as much as anything else did
   c. *Meteorology* covers phenomena like lightning, storms, and clouds, but now probably best known for Descartes' account of rainbows (Eighth Discourse)
7. The works that made Descartes most famous were published in the 1640's, appearing initially in Latin, but with authorized translations into French
   a. *Meditations on First Philosophy*, *with Objections and Replies* in 1641 (2nd ed, 1642); French translation, 1647
   b. *Principia Philosophiae* -- the *Principles of Philosophy* in 1644; French translation, 1647
   c. *Passions of the Soul* in 1649, and working on *Description of the Human Body*, which would have complemented the *Principles*, at the time of his death

B. Descartes' Intellectual Mission
1. While Descartes, as much as Mersenne and Gassendi, was part of an anti-Scholastic movement within Catholicism, he never rejected its goal of a unified, comprehensive philosophy
   a. His concept of education remained that of obtaining a world view, tied to Catholicism
   b. The fault lay not in the goal of Scholasticism, but in the Aristotelian philosophy underpinning it

2. Descartes grew up at a time when skepticism, as articulated in the late 16th century most forcefully by Montaigne, was in full flower
    a. Montaigne's version, an extension of Sextus Empiricus' Pyrrhonism, offered persuasive arguments against all knowledge claims
    b. Descartes appears to have seen his mission in part as one of saving the world -- in particular the Catholic world -- from skepticism
    c. Aligning him at least in spirit with Mersenne's *The Truth of the Sciences* of 1625
3. As a consequence, one demand he placed on himself was to find a method of knowing that is secure from skepticism
    a. How to achieve absolutely secure knowledge, once and for all, including (perhaps with qualifications) knowledge of the sensible world around us
    b. Notice here the contrast with Kepler and Galileo, both of whom were concerned with securing knowledge in certain limited domains, but felt no need to take on the general problem
4. The second demand Descartes placed on himself was to formulate a new, comprehensive, unified philosophy to replace Scholasticism
    a. A total new curriculum for universities -- something he was definitely aiming at
    b. (Galileo too was pushing a new curriculum, but confined largely to natural philosophy)
    c. A total world view, akin in its unity and extent to the teachings of St. Thomas Aquinas
5. One can therefore think of Descartes as emulating Aristotle, who had managed to cover virtually everything known in his philosophical writings
    a. On Descartes' view, it seems, Aristotle had the right conception of what needs to be done, but adopted wrong methods
    b. This time Descartes was going to do it right, in the process ending skepticism and its consequences forever
6. However grandiose this may seem, such a vision was not entirely unique to Descartes at the time
    a. Bacon, Hobbes, Spinoza, and Leibniz were certainly on a similar track, at least up to a point
    b. Indeed, it was a natural response to the state of the intellectual world at the time
    c. The more modest views about our capacities for knowledge that were expressed by Galileo, and subsequently by Gassendi and his followers -- especially the willingness to live with ignorance -- were atypical

C. The Scope and Goals of Cartesian Science
1. Descartes is often said to have wanted to reduce all empirical science to geometry; but this is worse than uninformative
    a. He always distinguished between the domain of mathematics -- the realm of pure possibility -- and the domain of empirical science -- the realm of the actual
    b. Thus the absence of geometry in his *Principia* is not necessarily a sign of its incompleteness

2. For our purposes it is better to think of Cartesian science as a response to skeptical arguments against the possibility of knowledge of the empirical world
    a. The argument from illusion is the most important of these arguments
    b. The challenge it poses is how to distinguish conclusively between veridical and non-veridical perception, and hence how to distinguish veridical perceptual judgments from others
3. Descartes accordingly finds himself obliged to present not just an account of the world around us, but continuous with it an account of perception
    a. The geometry of perspective of Desargues (also part of Mersenne's circle) provides an example of how to put illusion in its place, as are accounts of refraction and of how the eye works
    b. The account of the world and our perception of it should allow inferences from perception either to the real cause, explaining illusion away, or to an identification of what additional information is needed to get to the real cause
    c. Perception itself is a corporeal process (at least up to a point) and hence ought to be a unified, continuous part of any science of the material world
4. So far as I know, this was a novel idea: a single, unified, comprehensive empirical science covering all the material world, including epistemological foundations characterizing veridical perception
    a. Physics, mechanics, optics, etc.; chemistry (e.g. fire), etc.; biology; and physiological psychology, etc.
    b. The overall science able to reconstruct truth out of the vagaries of appearance
    c. The ultimate evidence for the science: save the phenomena, as perceived, while identifying the single reality yielding the vagaries in them, yet staying within the mechanical philosophy
5. One consequence of this program is that Descartes' books within science tend to occur in pairs
    a. *Le Monde* and *Treatise on Man*; *Principia* and the uncompleted *Description of the Human Body*
    b. The *Optics* also exhibits signs of this preoccupation, covering both the physics of lenses and visual perception

D. The Historical Significance of Cartesian Science
1. Even the briefest encounter with the 300 pages of Descartes' *Principia* is enough to reveal that his empirical science consists almost entirely of falsehoods
    a. Unlike everything else we have been reading, it makes virtually no specific lasting contributions to science
    b. Obvious question: why am I having you read garbage
2. Reason: his *Principia* was profoundly influential; whether they agreed with it or not, it was a background in common that everyone else we will be studying shared (until roughly 1780)
    a. Huygens and Newton, in particular, were both strongly affected by it in their youth
    b. But even 120 years later, 80 years after Newton's *Principia*, the greatest figure of that time, Euler, was still insisting on Cartesian-like vortices in astronomy

c. As Voltaire's famous letter of 1728, "On Descartes and Newton," attests, the views of Descartes' *Principia* swept Continental Europe

3. Reason: Descartes was Newton's antagonist -- his *Principia* was written to respond to and to refute Descartes'
   a. Not just to show that Descartes' scientific theories were false, in particular the vortex theory
   b. But also to show that Descartes' whole way of doing science was a mistake, and a different method was needed, as illustrated by Newton's *Principia*
   c. One cannot understand Newton's *Principia* without Descartes' *Principia*
4. Reason: though Newton never openly admits it, many aspects of Descartes' thinking had a profound influence on him
   a. Descartes' way of conceptualizing motion was the principal source of Newton's way -- this in contrast to e.g. Galileo's
   b. Hence to understand how Newton envisaged certain problems, we often need to consider how they would have been formulated within Descartes' framework
   c. (Much the same is true of Huygens, who also rebelled, though not so categorically, against Cartesian science)
5. Reason: Cartesian science was the main source of resistance to Newton's *Principia*, both the knee-jerk and the sustained resistance, explaining why it provoked a 100 year controversy
   a. To understand the conflict over gravitation in the 18th century, one must understand the contrasting conceptions of science offered by Descartes and Newton
   b. This not just a conceptual conflict, but also a conflict about how to achieve empirical knowledge at all
   c. In other words, a conflict about evidential reasoning, and not just about action at a distance
6. Reason: Descartes' conception of science, for better or worse, is still with us, although often hidden somewhat from view
   a. This raises the question, why is this conception of science so compelling, especially in the face of Newton's critiques of it and the now obviously absurd substantive science it led to
   b. What really is wrong with this conception of science? -- this is a question we want to answer by the end of the course

III. Descartes' "Mechanical Philosophy"

A. The Mechanical Philosophy: Two Schools

1. Descartes was the leader of one school of the movement known as the "mechanical philosophy" that came to dominate 17th century natural philosophy
   a. Descartes' chief rival, Gassendi, became the principal leader of the other school, which, through his influence on Boyle, flourished in England in the second half of the century
   b. Mersenne largely neutral between the two

c. Both schools were a response not just to Aristotelian natural philosophy, but also to Renaissance Naturalism, as illustrated (at its best) by Gilbert's *De Magnete*

2. The thread common to the two was a critique of Aristotelian and Naturalistic explanation as pseudo-explanation
   a. Both of these movements were criticized for positing qualities in objects that only appear to explain, such as heaviness to explain falling and lightness to explain things that rise, as criticized by Galileo
   b. The Naturalists openly acknowledge mysterious qualities, like the special vital spirit in iron producing magnetic phenomena
   c. Moliere's famous satire of "multiplying" qualities -- the dormitive power in opium that causes sleep, with no grasp of the mechanism at all -- probably reflected the influence of the discussion group Mersenne initiated and Gassendi continued after Mersenne died
3. The paradigm of explanation for the mechanical philosophy was the mechanical clock, in which everything could be accounted for in terms of one part in motion, pushing another
   a. Once started, the clock runs through contact of gear to gear, with a spring initiating the motion
   b. Every mechanism is totally comprehensible: no open questions, like how is this able to do that?
4. The only legitimate attributes in explanations are ones universal to all matter, such as occupying space, moving in time, encountering other matter, and producing change of motion through contact
   a. So, for example, if iron has a special magnetical quality, that must be explained in terms of the matter composing it and generic properties of this matter, such as shape
   b. Different shapes, for example, can produce different effects, but the generic category of shape is universal to all matter

      "All the properties which we clearly perceive in it are reducible to the sole fact that it is divisible and its parts movable; and that it is therefore capable of all the dispositions which we perceive can result from the movement of its parts" Part II, Article 23

5. One of the requirements of the mechanical philosophy was no action at a distance, for no explanation could be offered for how such action was effected
   a. E.g. Galileo's critique of Kepler's tidal theory
   b. Any appeal to action at a distance a pseudo-explanation, substituting a mere word for understanding, with the consequence of creating only an illusion of understanding
   c. A corollary: all talk of “attraction” suspect, along with appeals to “virtues” and “powers” that continued to appear throughout the literature in Engand
6. The two different schools of mechanical philosophy split over the question whether a vacuum can exist in nature
   a. Cartesian school: plenists
   b. Other schools: atomists (Corpuscularеanism)

B. Descartes on the Vacuum and Atomism

1. Descartes held that the very concept of a vacuum is incoherent, and hence no vacuum is even possible in nature
    a. In the tradition of Aristotle, who argued, e.g., that two things separated by a vacuum are separated by nothing at all
    b. Descartes' approach contrasts with those who consider the issue, do vacuums exist, an empirical question to be resolved by experiments
2. The key premise in Descartes' argument is that the essence of any corporeal (i.e. material) object is extension, where 'essence' means what it is for that sort of object to exist
    a. His argument in the *Principia* and *Meditations* to exclude all other quantities turns on the claim that we can conceive bodies without color etc., but not bodies that do not occupy space (see II, 4)
    b. For him that leaves not even solidity, but only extension; not everyone agreed with this
3. But then the very idea of a vacuum is contradictory, for empty space extended and hence is a body
    a. Anything that is extended is a substance, namely corporeal substance -- (II, 16)
    b. To oppose this argument, one must argue that corporeal objects have some further essential attribute, for only then can one distinguish between empty space and such objects
4. {Galileo, by contrast, considered the issue an empirical one, and endeavored to devise experiments that would distinguish
    a. In 1644 his protegé Torricelli (1608-1647) created the barometer, following his suggestion
    b. In the late 1640's Pascal (1623-1662) conducted compelling experiments using the barometer to show that vacuums exist, which he reviewed face-to-face with Descartes in 1647-48
    c. Boyle followed these with a battery of experiments over the next dozen years
    d. Even so, there were holdouts against the vacuum well into the 18th century -- e.g. Leibniz}
5. Descartes does take the trouble to explain the concept of empty space, viz. as a conceptualization in which dimensions and shape are abstracted away from specific bodies
    a. But this doesn't alter the substantial reality
    b. Indeed, space and place are just relative anyway (II, 13) -- there is no external receptacle
    c. And, at least considered geometrically, motion too is relative

C. The Plenist World View, Versus Ours

1. On the Cartesian world view, then, matter is everywhere: air, liquid, and solid all material, so that differences lie only in such things as sizes, shapes, and movement of parts
    a. Further unseen particles, as defended in II, 7:

        "it is less consistent with reason to imagine something unintelligible, in order to appear to explain rarefaction by a merely verbal device, than it is to conclude, from the fact that bodies become rarefied, that they contain pores or interstices which grow larger and that some new body approaches to fill these pores; even though we may not perceive this new body through any of our senses"

b. As we shall see, Descartes has unseen particles of more than one type, with the smallest indefinitely small by virtue of infinite divisibility

2. A fluid mechanical world view, with the universe filled completely -- i.e. total continuity of contact for all matter, completely continuous, and infinitely divisible
   a. No smallest particles and hence no atoms (II, 34)
   b. Motion does not occur via bodies transferring into empty space, but via closed circuits (II, 33)
3. Gassendi, by contrast, offers a world view, derivative from Lucretius's *De Rerum Natura*, in which atoms ("corpuscles") move around in a vacuum, striking one another
   a. An immense void filled with atoms in motion, touching one another and impacting on one another, with no forces acting at a distance among them
   b. {Galileo was inclined in this direction, though he felt less need for a comprehensive world view}
4. Both of these world views should be contrasted with the one we inherited from Newton, which involves atoms in a void, but with forces at a distance among them
   a. Atoms or corpuscles the basic units of matter, endowed with a small number of fundamental forces, attracting and repelling
   b. This view violates the mechanical philosophy: how do these atoms attract and repel one another from a distance?
5. Cartesian plenism is likely to seem crazy, but this primarily a comment on the difference between the way we conceptualize things and the way it requires
   a. Nothing intrinsically incoherent in this view
   b. With time we could learn to think this way -- indeed, in fluid mechanics we often do
   c. Kuhn's central point applies here: to understand and hence to see why a discarded view in science was once so compelling, we need to look at it from within, and not from without

D. Descartes on Magnetic Phenomena
1. The most obvious challenge confronting the mechanical philosophy was the phenomenon of magnetism, as described phenomenologically in Gilbert's *De Magnete*
   a. He argued that it has a special immaterial quality that enables it to act at a distance
   b. Intellectual honesty demanded an account, which Descartes offers at some length in Part IV
2. Descartes lists 34 qualitative phenomena identified by Gilbert, many of them found through "experiment" -- i.e. intervention -- (IV, 145)
   a. Phenomena involving "magnetic force" -- i.e. "virtutis"
   b. Include all the usual ones: North and South poles, magnetic earth, alignment, attraction, repulsion, declination, etc.
   c. Descartes then claims that all 34 follow from simple compositional feature of the solid matter peculiar to iron