b. Transformation from experiments in which recalcitrant results come to be viewed as fundamental

c. In other words, Galileo's own path to the theory in *Two New Sciences* largely hidden from view there, but does involve a substantial reconceptualization, a la Kuhn

d. Most important element of reconceptualization: motion in the absence of a resisting medium versus motion in its presence; further element: equal increments in time, not space}

D. Galileo's Approach: An "Idealized" Science

1. Galileo sees one notable weakness in the argument that weight is not a pertinent variable: effects of weight may be attributable to resistance over large distances, but what about over small ones

a. I.e. sees limitations of experiments used so far:

"The experiment made with two moveables, as different as possible in weight, made to fall from a height in order to observe whether they are of equal speed, labors under certain difficulties....In a small height it may be doubtful whether there is really no difference [in speeds], or whether there is a difference but it is unobservable." [128]

b. Note: same type of problem as with stellar parallax: distinguishing between no effect at all and an effect too small to measure adequately

c. Solution: devise an experiment which would reveal any such small differences through their cumulative effect

"...one might many times repeat descents from small heights, and accumulate many of those minimal differences of time that might intervene between the arrival of the heavy body at the terminus and that of the light one, so that added together in this way they would make up a time not only observable, but easily observable." [128]

2. Experiment uses two balls, one of cork and one of lead, at the end of 5 braccia pendulums

a. Resistance affects the height of the light pendulum more, but time of descent remains the same for both, for they stay perfectly in phase with one another (over 100 cycles) [p. 128]

b. Key point: lead and cork bobs pass equal arcs in equal times, and hence in equal speeds

c. Since period independent of initial height and of speed, have grounds for arguing that period, unlike velocity, not affected by resistance at all -- i.e. separate two mechanisms and then confirm that weight shows up only in the second one

3. {Claims made by Galileo about circular pendula in "The First Day" a peculiar mixture of right and wrong, with many of the wrong ones, including this one; Meresenne had denied the isochronism of circular pendulums in print in the mid-1630s, before *Two New Sciences* appeared

a. Small arc circular pendula are isochronous, and their periods are proportional to the square roots of their lengths, to high accuracy even with air resistance

b. But large arc circular pendula are decidedly not isochronous, as is evident in trivial experiments, insofar as, for small values of $k^2 = \sin^2(\theta_0/2)$

$$P = 2*pi*\sqrt{(\ell/g)}[1 + (1/2)\, k^2 + (1*3/2*4)\, k^4 + (1*3*5/2*4*6)\, k^6 + ...]$$

c. In absence of resistance, period more than 1/6 longer for 90 deg initial half arc, 7 percent longer for 60 deg, and 4 percent for 45 deg than for 5 deg -- readily detectable in a careful experiment after 20 cycles (see table in Appendix)

d. Galileo had presented the experiment in a letter to his mentor dal Monte in 1602, which confirms that he did do it, making the isochronism claim all the more mysterious (Bertoloni Meli, p. 70)}

4. Nevertheless, Galileo does have grounds for adopting, at least as a working hypothesis, the thesis that the detailed motion of falling objects results from two distinct physical mechanisms!
   a. The mechanism of fall itself, and the consequent mechanism of medium resistance to fall
   b. Weight (and shape and surface roughness) become pertinent in the case of observed falling objects only through the second of these, and can be ignored in an account of the first
   c. First then depends only on height of fall so far as questions like 'What speed is acquired?' and 'When does falling object reach various intermediate points?' are concerned
5. Such an account is going to comprise an idealized science in its making claims about what would happen in the absence of any resistant medium -- i.e. in a vacuum
   a. Whether a vacuum was possible even in principle was disputed at the time, though Galileo, in keeping with his corpuscularеanism -- i.e. atomism -- thought so
   b. Hence maybe better to say, in the limit as resistance of medium becomes negligible
6. A radically new approach, raising obvious question: how to assess whether it is right, other than through the long term success of the science predicated on it?

E. The Evidential Challenge Facing the Science

1. Important to see how radical this approach is: Galileo is proposing to offer not a theory that will approximate observation reasonably well, but a theory that will be exactly true of a situation that at that time could not be observed, for the simple reason that it could not be made to occur
   a. In contrast to e.g. Ptolemy, who could defend his account as approximating observation reasonably well, Galileo can be taken to be making a much stronger claim of exact truth
   b. And relative to this claim, how well the account does approximate observation becomes, in some respects, beside the point, vs. how well it would in the absence of a resisting medium
2. Three distinct grounds can be offered for adopting this approach of ignoring one mechanism involved in the actual process and focusing exclusively on the other, even though it cannot be isolated in fact
   a. A theory of the dominant or principal mechanism is possible, and it is needed in order to make the empirical investigation of the other mechanism tractable: divide and conquer
   b. Experiments yielding observations of evidential value are possible, provided only that the confounding effects of the other mechanisms be largely eliminated
   c. No theory of the other mechanism is possible at all, so that a science becomes possible only through such a move -- Galileo

3. The obvious difficulty with adopting this sort of approach at the outset is that it tends to undercut the very possibility of developing evidence for the theory through comparing precise measurements with precise predictions
    a. Of course, in Galileo's case could not easily make precise measurements at the time anyway, because of the time scale of the phenomena
    b. But even if he could, discrepancies between prediction and experiment would not as such have been grounds for falsification or revision
4. Kepler's situation, by contrast, is that he first develops an account, then finds small residual discrepancies, putting him into position to argue that various higher-order mechanisms are at work
    a. For Kepler the question of discrepancies between observation and theory is central to the entire evidence process!
    b. For Galileo, it cannot be once he stipulates that exact agreement with observation not the goal
5. The challenge of developing an idealized science of the sort Galileo is proposing, then, is to find other ways of bringing evidence to bear on the theory
    a. Ways that will allow distinctions to be drawn between errors in the theory and confounding effects from other mechanisms -- this is the key concern
    b. Challenge doubly difficult in Galileo's case since the observations themselves were often so difficult to make
6. And, of course, the danger lurking in the wings is a science that is immune not just to falsification, but to progressive refinement on the basis of empirical evidence
    a. A non-empirical, philosophical theory all over again, though mathematically motivated
    b. Ultimately justified on grounds of elegance etc.
7. The move to such an idealized theory made here by Galileo will not be the last time in the history of science that such a move is made; indeed Truesdell claimed it has been dominant in mechanics
    a. Whenever it is made, the evidence problem becomes complicated in special ways
    b. Want to look carefully this week and next at how Galileo and his contemporaries tried to deal with it and problems related to it

II. "The Third Day": Some Conceptual Obstacles

A. Galileo's Conceptualization of Motion

1. Galileo faced another difficulty that anyone must face at the beginning of a new science: no reason at all to think that the concepts and distinctions with which you initially describe the phenomena are effective, and not systematically misleading
    a. By 'concepts' here, I primarily mean sets of distinctions and the basis for making them -- e.g. his weight versus heaviness (see Drake glossary)
    b. He was acutely aware that Aristotle's concepts had proved an impediment -- e.g. lightness as a correlative property of heaviness -- and hence he had profound reason for concern