Comparing Historical and Intuitive Explanations of Motion: Does "Naive Physics" Have a Structure?

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ABSTRACT

Are students' explanations of motion generated by an underlying structure? We address this question by exploring striking parallels between intuitive explanations and those offered by medieval scholastics. Using the historical record, it is possible to reconstruct an inferential structure that generates medieval explanations. We posit a parallel structure for intuitive explanations.

INTRODUCTION

There is an extensive literature that establishes that intuitive explanations of motion differ fundamentally from Newtonian explanations (cf. Caramazza, McCloskey, & Green, 1981; Clement, 1982; Halloun & Hestenes, 1985; McCloskey, 1983; McDermott, 1984; and Viennot, 1979). The literature also shows that students exit physics classes with their intuitive beliefs pretty much intact, even though some of them may have learned to manipulate the mathematical formalism of Newtonian physics. Thus it is clear that our strategies for teaching physics need to be re-evaluated.

Among the prerequisites for developing more successful instructional strategies are the following: First, we need to know, at a deeper level of analysis than exists at present, just what are the intuitive beliefs and concepts, whether these form a structure, and if so, what kind; second, we need to characterize the differences between an intuitive representation of physical phenomena and a scientific representation; and, third, we need to understand the methods through which a scientific representation can be constructed. In this paper we focus on the first prerequisite.

There are substantial data on student predictions and explanations of projectile motion and free fall (cf. Caramazza et al., 1981; Halloun & Hestenes, 1985; McCloskey, 1983; McDermott, 1984; and Viennot, 1979). The interpretation of these data is the subject of some controversy. In particular, researchers disagree over whether there is an underlying structure that generates intuitive explanations. McCloskey (1983) has been the strongest advocate of structure, claiming that these explanations are generated from an intuitive theory of motion, whereas di Sessa (1987) represents the most radical position on the side opposing structure. For him, intuitive knowledge of physical phenomena is piecemeal and fragmented.

Our approach to the question of the nature and structure of the content of "naive physics" is to explore the intriguing parallels between historical pre-Newtonian explanations of motion and those used in our "everyday" modes of thought. Although many researchers have pointed out parallels, most of the literature is vague about their nature and what we can hope to learn from them. We propose that, if there actually is a significant degree of recapitulation of the content of historical pre-scientific representations in intuitive representations, knowledge of the historical structures and of the reasoning processes through which these were replaced by scientific representations will provide a valuable resource for enhancing our understanding of "restructuring" in science learning.

METHOD

In our larger study, we examine medieval explanations of projectile motion and free fall and formulate the beliefs that underlie these explanations (Nersessian & Resnick, 1989). We then reconstruct relevant portions of the medieval inference structure, comprising presuppositions, observations, and beliefs, that generates their explanations. Additionally, we extract the medieval categories and conceptual structure for these domains. This analysis makes use of the extensive record of arguments and discussions by medieval scholars concerning motion (Clagett, 1959).

In a parallel analysis, we take summaries of student protocols found in the literature on "naive physics" and extract what seem to be widespread beliefs underlying intuitive explanations of projectile motion and free fall. As shown in Table 1, these turn out to be quite similar to the medieval beliefs. We thus attempt to construct an inferential structure--comparable to the medieval structure--comprising presuppositions, observations, and beliefs, that could produce their explanations. Finally, we abstract the underlying categories and conceptual structure for these domains. The postulated inferential structure provides a competence model for intuitive reasoning about motion; that is, we claim that, if pushed, students will either generate the structure or agree with it and will generate novel statements consistent with it.

Constructing a belief structure for intuitive explanations is more difficult than for the medieval case. Students have rarely been asked to explicate in detail the assumptions underlying their explanations of projectile motion and free fall, and they have not been probed deeply for the meanings they attach to words they repeatedly use in their

explanations, such as energy, force, gravity, momentum. Thus, we have had to make inferences about what they mean and how they could be reasoning. We made the minimal assumptions we thought could be supported by what is reported in the literature. Although our reconstructions of the historical and the intuitive structures are independent, we did use the historical analysis as a guide to abstracting the intuitive categories and presuppositions.

We have been able to construct structures constraining all the medieval beliefs and the intuitive beliefs in Table 1. Since only a small part of the analysis can be presented here, we concentrate on the categories and structures pertaining to the intuitive belief that has most intrigued researchers, IB 3: continuing motion is sustained by a stored force and its medieval correlate, MB3: motion is sustained by impetus.

MEDIEVAL BELIEFS
MB 1: ALL MOTION REQUIRES A CAUSAL EXPLANATION

The medieval categories and presuppositions are in essence Aristotelian. The division between heavenly and earthly motion is central. The motion of heavenly bodies is eternal and presents no problem. All earthly or "local" motion is a process of change that bodies undergo, much like that of an acorn growing into a tree. All changes require a causal explanation; thus all local motion requires a causal explanation. The category of "motion" is opposed to that of "rest," which is the state bodies are in naturally. No explanation is needed for why objects remain at rest.

MB 2: MOTION IS CAUSED BY A MOVER

Things either move by themselves (for example, by falling) or they are moved by an external agent (that pushes, pulls, etc.). Medievals reasoned that, in the latter case, the motive power comes from the agent, and in the former case it must come from something internal to the object. In both cases the motion comes from the activity or power of the source, that is, from what was called a mover.

MB 3: CONTINUING MOTION IS SUSTAINED BY IMPETUS

Two local motions, "violent" (e.g., projectile) and free fall, presented problems for medieval theorists. First, objects in free fall speed up as they fall, and there is no satisfactory explanation in Aristotelian theory as to why this should happen. Second, objects in violent motion do not immediately fall downward when they are detached from their source of motion but continue in motion for a finite duration. Medievals argued that for violent motion to continue some of the power the agent imparts to the body must be stored in it. They called this stored power impetus. Early medievals believed that impetus would dissipate on its own, but in the final versions of the theory, Buridan claimed that impetus would keep a body in motion forever if it were not interfered with. The theory also explained the increasing speed of free fall by postulating that falling bodies acquired impetus from their heaviness.

Figure 1 shows the belief structure of medieval impetus theory. The structure consists

of:

1. presuppositions: enclosed in ellipses
2. pervasive observations: enclosed in hexagons
3. beliefs: enclosed in rectangles.

Figure 3 shows the relevant portion of the medieval conceptual structure. The concept map consists of:

1. concept nodes: names enclosed in ellipses
2. links between concepts:
   a. kind links: straight lines, labelled "K"
   b. property links: lines ending in arrows, labelled "Pr"
   c. relation links: lines ending in arrows, labelled "R" or with a particular relation.

INTUITIVE BELIEFS

In explicating these beliefs, it will be useful to give some indication of how they compare with the medieval and the Newtonian beliefs. Additionally, Table 2 compares the intuitive categories with the medieval and the Newtonian categories.

IB 1: ALL MOTION REQUIRES A CAUSAL EXPLANATION

This is perhaps the most fundamental of intuitive beliefs. As in historical pre-inertial thought, "motion," in the intuitive conceptual system, seems to be categorized as a kind change. "Rest" is not a well-developed category in intuitive thinking but does seem to oppose "motion," as in the medieval case. Why something remains at rest does not require explanation. However, the types of explanations students offer of motion indicate that, like other changes, all motions require a causal explanation. This parallels the medieval view and stands in contrast to the Newtonian view that motion is a state and only changes of state (i.e., accelerated motion) require an explanation.

IB 2: MOTION IS CAUSED BY "FORCE"

This, together with IB 3, is the most frequently noted intuitive belief, "motion implies force." What is usually not noted is that "motion" and "force" have meanings quite different from the meanings they have in Newtonian mechanics. For intuitive physics, "motion" is a process, not a state, and "force" is either a causal agent or a property of the object, and not a functional quantity (i.e., a relation between objects). Projectile motion is caused by some external agent ("force"), while for self-propelled motion, the agent can be a "motor" of some sort. The problem case is where motion continues after the object has separated from the agent.

IB 3: CONTINUING MOTION IS SUSTAINED BY A STORED "FORCE"

Students explain motion that continues after detachment by using such words as energy,

inertia, impetus, oomph. From their patterns of responses, we hypothesize that all of these terms make reference to an invisible force stored inside moving objects. This stored-up force is a property of the object, imparted to it by the agent. Thus, these words correspond most closely with the medieval notion of "impetus" and not to the modern notions of "energy" and "inertia."

Further, virtually all students claimed that in the absence of an external "force" objects will "run out of steam" and come to rest. This indicates that they expect the stored force to get used up as motion continues. It is unclear whether students believe friction plays a role here, or the force dissipates on its own.

Figure 2 shows the postulated intuitive belief structure. Figure 4 maps the intuitive conceptual structure.

CONCLUSIONS

We have been able to construct an intuitive belief structure, with its associated conceptual structure, that parallels an actual historical structure. The similarities between the intuitive and the medieval categories, conceptual structure, and belief structure are striking. This lends plausibility to our hypothesis that the postulated structure is capable of generating frequent intuitive explanations of certain kinds of motion. We also hypothesize that, given all the pertinent data for a situation, the seemingly inconsistent explanations that students occasionally give will prove to be consistent with the structure. We plan to test these hypotheses by implementing the structure in a computer model and by designing studies to test its empirical consequences.

Our structure provides an alternative to the major proposals in the literature. We agree with di Sessa that intuitive thinking is not developed sufficiently to constitute a theory. However, intuitive thinking about motion can still have a structure in that there is entailment and consistency among the beliefs.

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WIDESPREAD INTUITIVE BELIEFS		MEDIEVAL BELIEFS	
IB 1:	ALL MOTION REQUIRES A CAUSAL EXPLANATION	MB 1:	ALL MOTION REQUIRES A CAUSAL EXPLANATION
IB 2:	MOTION IS CAUSED BY "FORCE"	MB 2:	MOTION IS CAUSED BY A MOVER
IB 3:	CONTINUING MOTION IS SUSTAINED BY A STORED "FORCE"	MB 3:	CONTINUING MOTION IS SUSTAINED BY IMPETUS
IB 4:	ACTIVE AND PASSIVE MOTIONS DIFFER	MB 4:	CARRYING DOES NOT CONVEY IMPETUS
IB 5:	DOWNWARD MOTION IS NATURAL	MB 5:	DOWNWARD MOTION IS NATURAL
IB 6:	HEAVIER OBJECTS FALL FASTER	MB 6:	HEAVIER OBJECTS FALL FASTER

Table 1

CATEGORIZATIONS

MEDIEVAL	INTUITIVE	NEWTONIAN
MOTION: PROCESS	MOTION: PROCESS	MOTION: STATE
REST: STATE	REST: STATE	REST: STATE
MOVER:	"FORCE":	FORCE: RELATION
EXTERNAL: AGENT	EXTERNAL: AGENT	
INTERNAL: PROPERTY	STORED UP: PROPERTY	
HEAVINESS: PROPERTY	HEAVINESS: PROPERTY	GRAVITY: RELATION
		MASS: PROPERTY
		WEIGHT: RELATION
SPEED: PROPERTY	SPEED: PROPERTY	SPEED: RELATION
		VELOCITY: RELATION
		ACCELERATION: RELATION

TABLE 2

MEDIEVAL BELIEF STRUCTURE

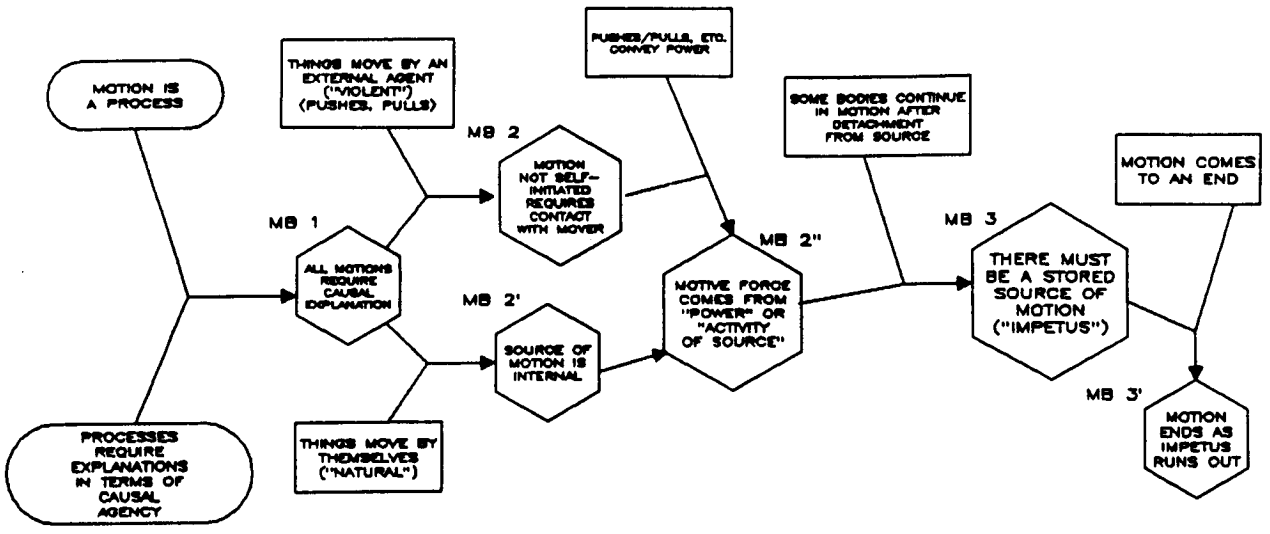

Figure 1

INTUITIVE BELIEF STRUCTURE

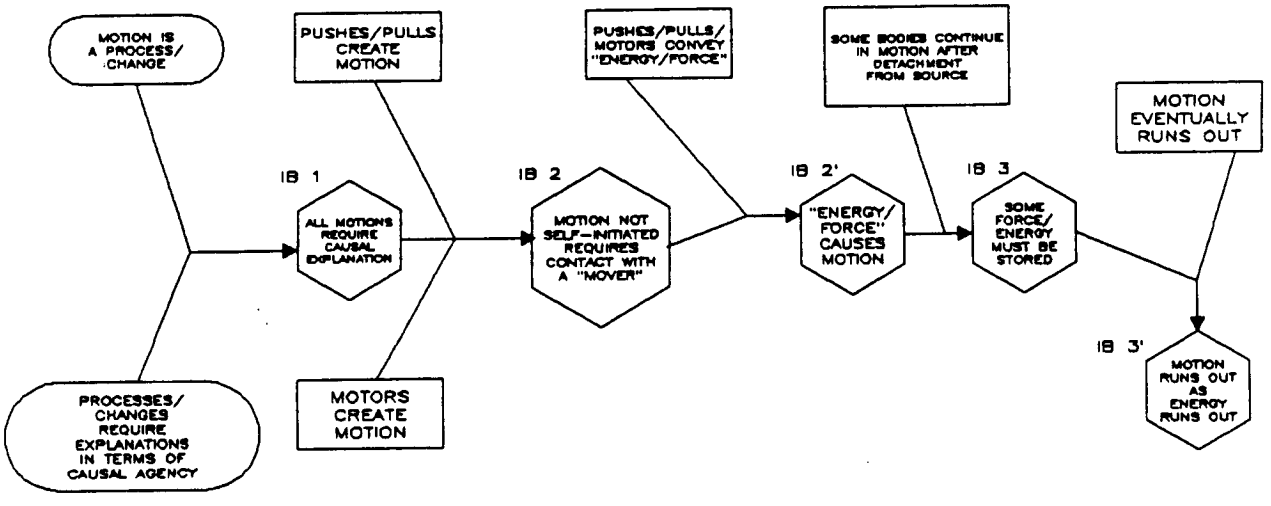

Figure 2

PARTIAL CONCEPTUAL STRUCTURE OF MEDIEVAL THEORY OF MOTION

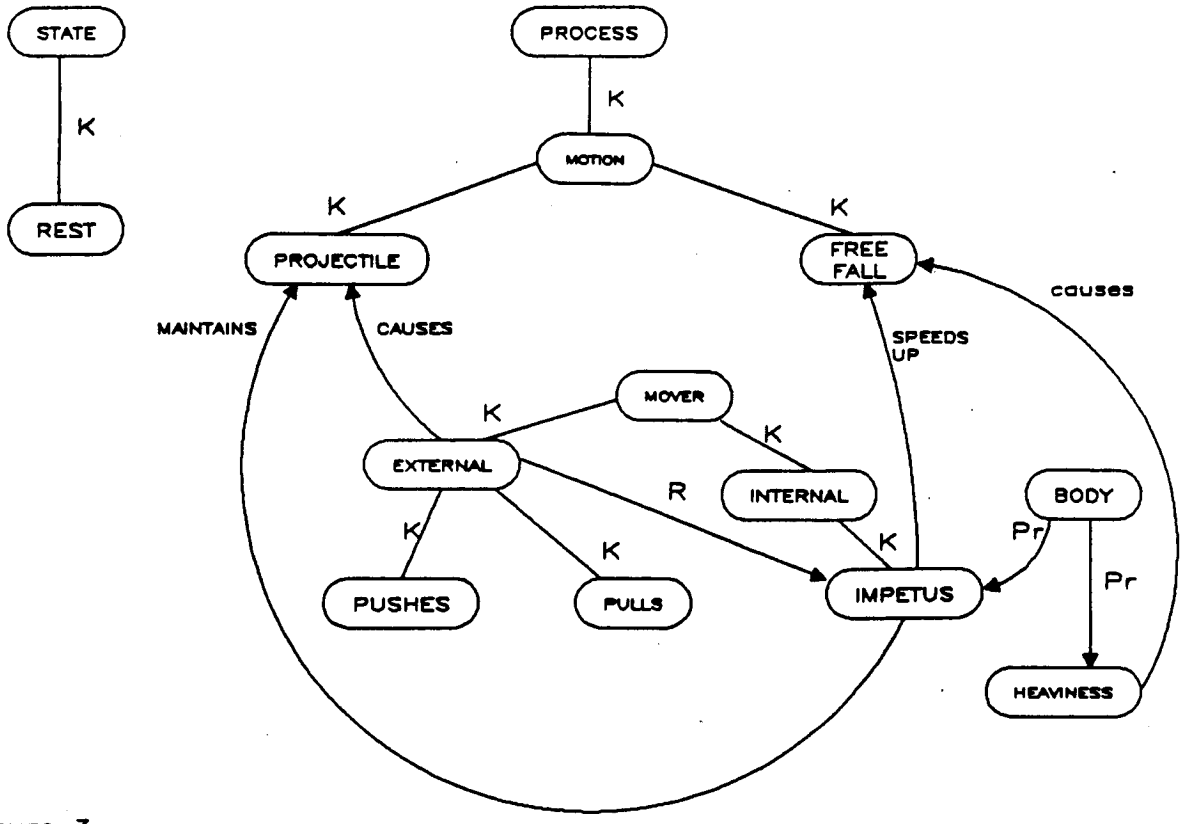

Figure 3

PARTIAL CONCEPTUAL STRUCTURE OF INTUITIVE PHYSICS

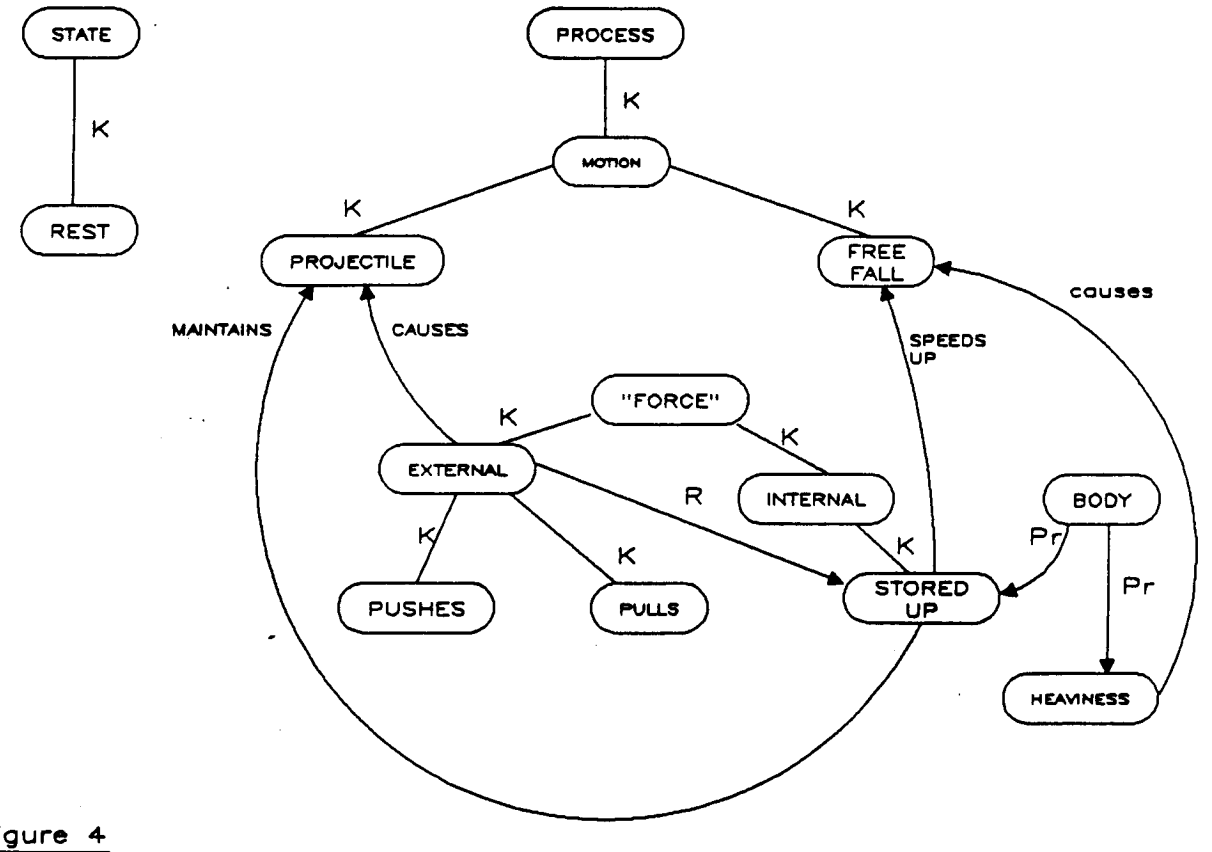

Figure 4