Naive Materialistic Belief: An Underlying Epistemological Commitment

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A considerable amount of research has been done in mechanics which identified students' alternative frameworks in physics (Clement 1982, Viennot 1979, McDermott 1984). A few studies have also focused on students' beliefs in electricity, energy, heat and light. These studies show, in general, that many "misconceptions" can be traced to students' prescientific beliefs about the world. Furthermore, such beliefs appear to be fragmented, incoherent, built in pieces (Di Sessa, 1984), and context bound (McClosky, Caramazza & Green, 1980; McDermott, 1984; Reif, 1987). Hence, this set of beliefs has a limited power of explanation, and of course, differs from the scientific theories held by the scientific community.

Although naive explanations for a given phenomenon appear to be very context sensitive, it seems possible that there is an underlying implicit set of epistemological commitments that are respected in the various specific explanations. Nersessian and Resnick (1988) have outlined such a set of underlying commitments for the domain of mechanics. These commitments include the presuppositions that motion requires an explanation, (because it represents a change in state), and that an adequate explanation of motion must be framed in terms of mechanisms in which agents act physically on objects (rather than in terms of relations among theoretical constructs, as in Newtonian physics). These presuppositions were shared by pre-Newtonian physicists, and the local explanations constructed by today's naive subjects seem to share key features with those of Aristotelian and impetus theorists.

In this paper we explore another basic commitment--*a naive materialistic belief*--held by students, as well as by some adults, that can explain many of the students' beliefs as reported in the research on alternative frameworks in physics. The following example illustrates what we mean by a materialistic belief. In every day expressions, when we say that something is an illusion we usually mean that it is not real. We consider a moving car seen in a hologram to be an illusion, or unreal, even though we see it as if it was real. The reason that we refer to the moving car in the hologram as "not real" is that it is not made of what we call in everyday life "real material". An examination of students' explanations concerning light, electrical circuits, heat, energy, and force, suggest that they conceive of these entities in terms of the properties and behavior of "real material". Thus, we propose that a basic materialistic conception may underlie students' beliefs and understandings about a number of physical concepts.

Materialistic Interpretation of Light

Our hypothesis of naive materialistic commitments arose while working with adult physics students and teachers on concepts of lights. We begin by reporting this work and then examine other research on alternative frameworks in different domains for evidence of materialistic commitments.

Conceptual beliefs about light have been investigated by Anderson and Karqvist (1981), Jung (1981), and La-Rosa (1984). The main focus of that work was on sight, the propagation of light through space, and issues in optical geometrics, but little details were provided about what students think that light is. Anderson and Karqvist (1981) report that students believe that "something" (either rays of light emanating from the eyes, images, or "something which goes backwards and forwards between the eye and the book") enables vision. But these investigators did not deal with the question of *what a student means when he uses the word light, or ray, or other such terms.*

In our work (Reiner, 1987), we interviewed 12 senior physics students and physics teachers about light phenomena related to every-day situation. All of the subjects had learned the appropriate physics to answer the questions, but the findings showed that their interpretations about light phenomena reflected materialistic commitment. Each subject was asked 4 questions: two questions concerned common everyday phenomena (the disturbance on T.V resulting from a lightning, and rotation of the radiometer); the other two questions were those commonly asked in physics classes (interference and defraction patterns of light). Analyses of the students' explanations showed that the the notion of massive "particles of light" played a basic role in explaining both the every-day phenomena and the physics class types of questions. For example, the rotation of the radiometer was explained by most of them as a result of the force or momentum transferred from the massive particles of light to the black plates of the radiometer.

It is not clear whether the source of this kind of materialistic conception arose from physics instruction or it might be rooted in a naive, preinstructional view. In order to examine this, we interviewed a new sample of bright, 17-year-old Technion-bound students who have not had the theory of light before. 31 out of 32 students showed a materialistic belief. Of the various specific beliefs expressed, three were dominant:

1. 22% of the students believed that light was produced by a hot body, which radiates a kind of material--a fluid or a stream of tiny particles--that can fill the air. Colors of light, according to this belief, results from the combination of two fluids that have different colors.
2. 18% of the students believed that a hot body emits particles of different sizes. Each size has its own color. It is easy to change a particle's color from white to any other color, but very difficult to change another color to white-- the same way that a white fluid will get a darker color if mixed with a darker fluid. It is interesting to note that this is very similar to Newton's theory of light--a point that reminds us that materialistic views were dominant in physics until quite late in the field's development.
3. 22% of the students believed that a chemical reaction causes the emission of light particles, which then have the ability to fill space. Many of these students noted that particles could be slowed down by the air (friction?) , and that is the reason that after a certain distance the particles stop, which explains why the light (such as from a candle) only goes a certain distance.

These results suggest that our initial sample of 12 senior physics students and teachers did not gain the materialistic belief from books or any other forms of formal instruction. Instead, they appear to have retained a naive materialistic way of thinking which is fundamental to pre-instructed but bright 17-year-olds. Thus, both the naive 17-year-old students and the senior physics students and teachers have "materialized" light in two possible ways:

1. Light itself is considered to be a type of material--either small balls, or a stream of flowing continuous substance;
2. Light is a property of an object, for example, an object shines, so that light does not exist if the hot object, or the reacting materials in a chemical reaction, do not exist.

Materialistic Conception of Electrical Circuits

Maichle (1981) found that more than 80% of the students in secondary school level conceive of electric current as a kind of substance with the properties of quantity, storability and consumability. Even at the university level, 40% of the students agree to such statements. As might be expected, most of these students confuse the terms of voltage and current (Cohen, Eylon, & Ganiel 1983; Maichle, 1981). They use the term electricity for both current and voltage. Sometimes voltage is used to mean the storage of current. In this case, both current and voltage are materialized. According to students, "electrical material" is used up by the bulb, or other electrical devices, and hence there should be less current "after" the device "uses" it. The "misconception" of storability and consumability is a result of looking at electrical current as if it was a material which is stored in the battery. The material flows as long as there is "plenty of it" in the battery, that is, until the battery is "empty". This view is confirmed by Reiner's (1987) finding that high school students studying electricity believe that electrons have to "arrive" at the bulb in order to make the bulb shine, and that the propagation of the electro-magnetic field is equated with the flow of electrons in the wire.

Osborn and Gilbert (1987) found similar conceptions both among 18-year-old students studying A-level physics (the highest physics level in Britain) and 7-13-year-olds who had received no formal teaching in physics. The fact that both the naive and the 18-years-old students, who have a relatively good background in physics, refer to the battery as a storage of material which is the cause of current, implies that the materialistic framework appears to be resistant to teaching.

To summarize, students appear to materialize electricity in two ways: they think of electricity as if it was a material which can flow from one place (such as the battery) to another (such as the bulb); and furthermore, this material has the properties of being consumable and storable.

Materialistic Interpretation of Heat

Erickson and Tiberghein (1985) claimed that students imply that heat is substantive in nature, and describe it as something that can be stored in objects, transferred from one object to another, and travel from one location in an object to another. They also claim that every day expressions like "Close the window to keep the heat inside" (and the cold outside) or expressions heard in classrooms such as: "heat is gained or lost", "travels along a metal rod", indicate that it seems to be natural to describe heat as a type of materialistic substance which can cause predictable changes in other objects. A "caloric" conception of heat, in which heat is referred to as a fluid that has no mass has also been found among students by several researchers (Albert, 1978; Erickson, 1980; Tiberghien, 1980; Shayer & Wylam, 1981).

To summarize, from these findings, we suggest that heat has been materialized by students in two ways: Heat is viewed as a kind of material (e.g., a fluid) which can travel from one place to another; and furthermore, like electricity, heat can be stored in materials, and takes on the shape of the object in which the heat is stored in the same way that gas takes on the shape of the container in which it is stored.

Materialistic Interpretation of Energy

Duit (1981) reported that for the overwhelming majority of students, the term energy in every day language has the meaning of a general kind of fuel to be used by motors and machines. Energy can be stored and consumed. To gain further insight into the meaning of the word for students, they were asked to give examples of energy. The results show that 51% of the students refer to the concept of energy as "things". According to this research, energy is not seen by the majority of students as an independent entity, but rather as a property of material bodies.

We again suggest that energy is materialized in two ways: first, energy is a kind of fuel, and second, energy is a property of an object, and exists only if an object exists.

Materialistic Interpretation of Forces

If naive students have a commitment to materialistic explanations, they should have difficulties in explaining motion in the absence of an external contact force. This is indeed the case. For example, Clement (1982) reported that students believe that the motion of a body implies that a force was exerted on it. In the case of a coin tossed up in the air, they think that "the coin has a force". This force, according to Clement's students, is believed to be decreasing during the coin's motion upwards, until the gravitational force overtakes the "coin's force", and then the coin will reverse it's direction and fall down. Minstrell (1982) also reported that his students' notion of a moving body is one that "has a force in itself". Gunstone and Watts (1985) also reported that forces are explained as having to do with living things. Students talk for instance about "an object trying to fight it's way upwards against the will of gravity", which is very similar to Clement's results. In all three of these cases, force is viewed as a *property of an object*. The force does not exist unless the object exists. Force in this sense has no meaning independently of a materialistic object.

If force is viewed as a property of an object, then, force from a distance poses a special problem for students. Although students use the term gravity, they do not understand that it can cause objects to fall. Instead, weight, and "falling down", are both perceived as two different properties of a materialistic body (Vicentini, 1983). "Falling down" is explained by the naive belief that a body falls because it 'wants' to be in it's natural place, which is "down". Vicentini-Missoni (1981) stated it as the "first law" formulated by students:"All heavy objects fall down, if nothing sustains them". This issue has been investigated by Nusbaum and Novak as well (19xx). They asked students to predict the motion of a body through a hole dug through the earth. Most of the students answered that the dropped stone will "fall down" through the center of the earth, and "fall down", out of the earth. The notion of gravity as a force directed to the center does not exist, and the motion of the stone is not related to the gravitational force towards the center, but rather is referred to as a property of the body. According to this belief, every materialistic object has the property of "falling down". The force from distance does not exist per se, unless it is related to a materialistic body. Thus both weight and the force driving objects to fall are transferred into *properties of a body*.

Another way of materializing force is by transfering the force into a contact force between the body and the air. Driver (1985) reported that some students believe that in the outer space there is no gravity because there is no air.Vicentino and Missoni (1981) reported that adults explain gravitation as : " The force of gravity is due to the air pressure". In this case the force from distance is transferred into a force of contact between two materialistic bodies. This is not a very new belief; Gassendi, a 17-th century scientist, conjecturing about the existence of a vacuum, remarked that no forces and no motion will be possible in the vacuum because of the absence of contact among bodies that could produce a force.

To summarize, we suggest that forces have been materialized in two ways: It is a property of an object, and a force is a contact between two (or more) materialistic bodies.

Conclusion

We have shown that a basic materialistic commitment underlies some of students' conception of key physics concepts. This materialistic commitment has 3 characteristics:

1. The entity itself is a kind of material (e.g., light is a massive particle or a kind of a fluid; electrical energy is equated with material fluid; and heat is caloric material);
2. The entity can be stored in material. There exist other objects whose role is to store the entity (e.g., light is stored in materials such as in the air which explains why reason we have light after sunset; electrical current is stored in the battery; and heat is stored in material objects; and force is captured in the body);
3. The entity exists only as a property of a materialistic object (e.g., light is a property of a hot body, or materials that react chemically; energy is a property of an object--the body has energy; gravitational force--falling down--is a property of a body; a moving body has force in itself, "Force of falling" is a result of the contact of two materials: air and the falling object);

The analyses reported here characterize the ways students conceptualize numerous physics concepts (light, electricity, heat, energy, and force) in terms of a basic underlying materialistic interpretation. The pervasiness and apparent robustness of such a fundamental conception across different physics concepts raise three important issues. First, if such a conception is so fundamental to the way we understand these concepts, how readily can instruction modify such a view. That is, what kind of instructional methods needs to be designed that can undermine such a basic epistomological commitment and produce conceptual change. Second, because such a materialistic view appears to be so inherent in students conception of the physical world, it seems to engender similar interpretations to related entities and concepts. For instance, students apply their conception of the properties of electrical current to the flow of energy in a wire. It is not clear how we can terminate the propagation of this kind of materialistic misconceptions. Finally, this research questions the validity of instructional approaches which use materialistic models as analogical tools. For example, do mental models of electricity such as flowing waters or teeming crowds distort our understanding of electricity by sustaining the materialistic view. Additional research is needed to address these issues.

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