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Teaching about Vacuum and Particles, Why, When, and How: A research report

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INTRODUCTION

Most curricula in many countries introduce the idea that matter is formed from particles, to students when they are approximately 13-14 years of age. The reasoning for studying the subject in this age is the assumption that the cognitive development of younger students is not yet ripe enough to handle such "abstract" ideas, while older children already need the particulate model as applied in more advanced subjects as physics, chemistry and in biology.

For approximately 15 years, there has been a growing awareness among science educators of the difficulties that students experience in studying the particulate model and applying it in different scientific areas. Many research studies have shown that students develop various misconceptions regarding the particulate structure of matter and the interactions between particles in physical, chemical and biological phenomena (see the reviews of Nussbaum, 1985; Andersson, 1990). Misconceptions among students in various scientific fields are recognized today as a general and basic phenomenon requiring theoretical revisions in the psychology of learning and in teaching strategies.

In a recent international conference[1] devoted wholely to the issue of relating micro to macro in science education, a number of researchers reported on their projects, in which they applied their unique approaches to teaching particulate theory. All of these projects began in the eighties, as a result of an awareness of the difficulties of teaching the subject as mentioned above. Each researcher presented his own rationale.

The rationales were developed from considerations drawn from various areas, such as the history and philosophy of science, psychology, as well as from didactic principles and educational practice. Each rationale was based upon different combinations and different degrees of emphasis of those considerations.

It is important to remember that although two people may recognize that considerations should be drawn from a certain area, the specific considerations drawn by each of them, as well as the conclusions which each one reaches, may not necessarily be identical, and may even contradict each other. A brief review of some of these reports would be worthwhile in this introduction.

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[1]in Utrecht, The Netherlands, 1990.

Millar (1990)[2] presents mostly psycho-didactic and practical considerations. He recommends that science be taught "from everyday contexts to scientific concepts". He promotes distributing the introduction of ideas of the particulate model across the general program in science, for ages 14-16. He further promotes the concept of introducing parts of particulate-kinetic theory - but only in places in the curriculum which can contribute to an additional understanding, and not as instruction in discrete subjects. He opposes the teaching of the theory in its entirety as a single educational unit. Millar recommends the introduction of particular ideas, in the first stage, when it is necessary to explain the behavior of solids. He strongly recommends postponing the use of particulate model of gases for a later stage. His arguments are that research findings have shown that children have difficulties understanding that *gas* is *matter*, and that it is comprised of constantly moving particles in a vacuum. From a psycho-didactic point of view, he recommended that students be convinced of the existence of particles which so tiny that they are imperceptible. He used a method which he called *ostention* - "showing" - rather than by abstract discussions about the behavior of imperceptible particles. For example, they bring the student from the macroscopic world to the microscopic, by studying threads of clothing with a magnifying glass, and only then do they continue to the ultra-microscopic level of particles.

Meheut and Chomat (1990)[3] presented considerations resulting from the identification of a basic aspects of atomistic theory, i.e., the conceptualization of particles as invariant constituents of matter (which themselves never change), while the empty spaces between the particles and the motion of the particles are variable factors of matter (appearing in different magnitudes in different circumstances). They demonstrate that these dinstinctions existed among the first Greek atomists. Their historical and content analysis did not extend much beyond this, and the historical difficulties and misgivings were not discussed in the rationale which they presented. In their instruction, as opposed to Millar's recommendation, the experiments dealt entirely with air and other gaseous behavior; they have demonstrations of pressure and change in volume as well as the diffusion of two gases in each other. The decision to begin with gases results from the assumption that the attempt to explain the behavior of gases will bring about the identification of variables of space and motion. They criticize Piaget's analysis of the development of "atomism" among children because his definition of an "atomistic view" is superficial, and does not include all of the essential

[2]His project has produced a textbook - *Salter's Science* (1989). York: University of York, Science Education Group.
[3]From LIRESPT, Universite Paris 7

attributes of the scientific model. They feel that even if a child thinks about particles in the Piagetian manner, he would have no reason or need to see those small pieces of matter as invariant. They present the children with phenomena and expect them to construct a particulate theory which would explain that which is observed. However, the very idea of the existence of invariant particles was not elicited from the students, but was presented from the outset in given propositions.

Johnstone (1990)[4] describes an experiment in instructing the particulate model to children aged 13-14. It is based upon the psychological constructivist approach, which converged with the constructivist approach in the philosophy of science. Their teaching scheme includes three phases of instruction as proposed by Driver and Oldham (1986)-

An elicitation phase: In which students are provided with opportunities to put forward their own ideas and to consider the ideas of their peers.

A restructuring phase: In which the teacher introduces activities which interact with students' prior ideas, and which encourages students to move their thinking towards the school science review program.

A review phase: In which students are asked to reflect on the ways in which their ideas have changed.

They began the first phase of their project by asking the students to compare the characteristics of gases, liquids, and solids, and to propose a theory which would explain the differences.

Johnstone indicates that many students showed in the first phase that concepts such as atoms and molecules are familiar to them from elementary school or from television programs. However, they soon showed all of the familiar misconceptions shown in the research literature.

The last phase of the teaching scheme was to have been meta-learning, a kind of lesson in epistemology, in which the students reflected upon their experiences during their initial phases of instruction. Thus, the activities during this phase were related more to the philosophy of knowledge than to the particulate model. According to the report, some students had difficulty connecting prior learning with this reflective activity.

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[4]CLIS, Children Learning in Science Project. (R. Driver - director). University of Leeds, UK.

Despite the fact that Johnstone mentions Driver's proposal (1989) that a strategy for promoting conceptual change in science classrooms "needs to be investigated in the context of particular domains of knowledge", her report did not have a focussed attempt to analyze the source of the specific problems of this area of particulate theory. It seems that their effort focussed more on creating a general constructivist trend, without a clear innovation in the specific contextual area.

de Vos, 1990[5] integrates a psychological and content-oriented analysis in a relatively highly-developed manner. He also integrates references to the distant and recent history of the atomistic theory. In content-oriented analysis, he shows how the definitions of textbooks are imprecise and how they contribute to the formation of misconceptions. He emphasizes how important it is to identify and formulate which qualities which are known on the *macroscopic* level are to be used to explain the *microscopic* world, and which ones should be avoided. He identifies certain misconceptions from the history of science and describes the intuitive processes which apparently influenced those scientists. He emphasizes that it would be quite natural for the intuition of the modern student to operate in the same way.

In a fine analysis, he identifies five characteristics of the macroscopic world, and stipulates that they are the only ones which can be used in the particulate theory. These five unique qualities are *mass, space, time, mechanical energy* and *electric charge*. de Vos indicates that these five elements are really seen as quite structured and simple for instruction, yet "..would it be obvious to students why the elements from which a corpuscular model is to be built, should be mass, space, time, energy and electric charge? Or would they prefer to choose, say, colour, taste, toxicity, temperature or malleability?"

Despite the fact that the rationale of de Vos seems to the present author as richer and more comprehensive than that of all of the others, its considerations do not yet hint how they influenced their teaching unit. At any rate, the last section of his article, describing their strategy in general, is worthy of note:

> "In science lessons at lower secondary school level, it is not very important which corpuscular model a child learns. It is much more important to preserve something of the uncertainty and the tentativeness which are characteristic of models...It means that children should experience

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[5]Vos, W de (1989), *Chemie in Duizend Vragen (Chemistry in a Thousand Questions)*. Utrecht: The University of Utrecht.

how it feels to work with ideas without being sure whether they are correct or not. Working with models is not just an intellectual affair, but also an emotional one. It requires creativity as much as discipline, and it may lead to frustration as well as to satisfaction. This way of learning to work with models is encouraged if the teacher does not present corpuscular models as facts discovered by famous scientists, but instead asks students about their own ideas, stimulating them to discuss these and test their consequences in suitable experiments."

Sources for our Rationale for the Teaching of the Particulate Model

The rationale of our[6] teaching strategy is heavily based on implications drawn from analyses of (1) the historical development of the particulate model; (2) current basic issues in the philosophy of science; and (3) current views in cognitive psychology. The analysis and the implications will be presented according to these source areas.

(1) ***The historical development of the particulate model.***

We do assume that each conception in science presents the student with cognitive difficulties which are unique to the nature of the subject. For in designing effective teaching one must first identify the difficulties. One important way of identifying these difficulties in advance is by identifying and analyzing the cognitive difficulties which the scientists of the past faced during the course of the historical development of relevant scientific ideas. This paper has <u>no</u> intention of arguing that the development of the scientific understanding of the student precisely recapitulates the historical pattern. The argument is that if the basic cognitive difficulty which appeared in the history of particulate theory is indeed so significant, that there is reason to be concerned that it would also appear today among our students. Despite the fact that the survey and analysis of the historical processes demand extensive room, we feel that the matter is worth doing for the reader who is seriously interested in the matter.

We do not know how the first Greek atomists arrived at their brilliant ideas and we are amazed that the first ones forming the bases of theory, Leucippus (450 BCE) and Democritus (410 BCE), propounded nearly all of the essentials of the atomistic theory: (a) the material is constructed of separate particles, which are full, indivisible corpuscles[7] and they comprise together the mass of material; (b) The particles exist within an absolute vacuum; (c) The particles move freely and continously within the vacuum and interact with each other. (d) The interaction of the particles creates the macroscopic changes which we see. The interactions include situations of *association* (condensation, solidification, and the creation of new compounds) as well as *disassociation* (breaking down of the existing compounds by

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[6]The use of the plural form (the editorial we) includes my close colleague, Dr. Shimshon Novick, with whom I started this project. He unfortunately passed away in 1983.

[7]Even today, when we know about subatomic particles, the basic idea remains that we always arrive in our research to particles which in this stage of the research are for us indivisible.

attack from outside) and situations of *creating pressure* such as with gas.

The Greek sources quoted in Sumbursky's Anthology (1965) indicate that

> "Democritus thinks that the nature of the perceptual things consist of small particles infinite in number. For these he postulates another space of infinite size. He designates space by the term `the void', `Nothingness' and `the infinite', and each of the particles by the terms `the something', `the solid' and `the being'. He thinks the particles are so small as to be imperceptible to us, and take all kinds of shapes and all kinds of forms and differences of size. Out of them, like out of elements, he now lets combine and originate the visible and perceptible bodies. They move in confusion in the void..., and while in motion they collide and become interlocked in entanglement of a kind which causes them to be juxtaposed and in proximity to one another without actually forming any real unity whatsoever.... The cause of the continuance of aggregations of particles for some period of time, he says, is their fitting into one another in bondage - for some of them are uneven, others barbed, some concave and some convex.... He thinks they hold together and continue to do so until the time when some stronger force coming from the environment disrupts and disperses them in different directions." (p.55).

Democritus' atomistic concept postulates the existence of vacuum as necessary to allow movement of particles, and thus also allows interaction and changes. It is worth noting that the atomistic view is a *reductionistic* and *mechanistic* model for understanding reality. The model is *reductionistic*, because it reduces the number of components and factors relating to all complex phenomena to an interaction of the simplest microscopic particles. The model is *mechanistic*, because he assumes that these basic particles move, bump into each other, and rebound according to mechanistic laws. This model is therefore causal rather than teleological. This mechanistic model was applied by the atomists, such as Epicurus (350 BCE), in all areas of existence, including cosmology, physiology and mental processes in man. Reductionism combined with mechanism is the characteristic of all of our natural sciences. The acquisition of this approach is a meta-goal of science education.

Each of the four basic essentials of the model mentioned in the previous page are combined and strengthened by the existence of the other factors. Change in matter means a change in the arrangement of the particles, which requires the existence of movement, which in turn requires the existence of vacuum in order to occur. As a result, the existence of vacuum is a the most substantial part of the entire model. This idea is expressed in the original writings of Epicurus:

> "the atoms are in continual motion through all eternity. Some of them rebound to a considerable distance from each other, while others merely oscillate in one place when they chance to have got entangled or to be enclosed by a mass of other atoms shaped for entangling.
>
> "This is because each atom is separated from the rest by a void, which is incapable of offering any resistance to the rebound; while it is the solidity of the atom which makes it rebound after a collision, however short the distance to which it rebounds, when it finds itself imprisoned in a mass of entangling atoms." (ibid p.84).

Apparently, just after the generation of Democritus and Leucippus there was a debate between those who agreed with and those who opposed atomism. The head of the opposing faction was Aristotle (350 BCE). The main aspect of the debate of Aristotle was not the actual possibility of the existence of the minuscule imperceptible particles, but rather the possibility of the existence of a vacuum.

The concept of the vacuum created the major philosophical obstacle, and therefore it faced most of the effort of refutation (although there were other arguments against the notion of the indivisibility of elementary particles). Aristotle gives a long series of philosophical-physical arguments why the existence of a vacuum is not substantially possible.[8] For the duration of an entire lengthy series of arguments Aristotle attempts to reverse the arguments of the atomists' arguments and to argue that the existence of a vacuum is not essential for the existence of movement, but rather the existence of the vacuum would actually *prevent* movement or would create movement which would have no specific direction. Two exemplary arguments in

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[8]I do not want to enter into the roots of the argument relating to the opposing arguments of the concept of the "space". Whereas the atomists (such as *Democritus* and *Newton* conceive of space as an infinite vacuum into which bodies are placed, *Aristotle* conceives of space as one of the basic concepts of the bodies themselves. Therefore, space and matter are indivisible, and therefore the world, which has spatial dimensions, is *full* of *continuous* matter.

the original formulation as proposed by Aristotle are presented here:

> "...not a single thing can be moved if there *is* a void; for as with those who for a like reason say the earth is at rest, so, too, in the void things must be at rest; for there is no place to which things can move more or less than to another; since the void insofar as it is void admits no difference..."
>
> "Further, in point of fact, things that are thrown move though that which gave them the impulse is not touching them, either by reason of mutual replacement, as some maintain, or because the air that has been pushed pushes them with a movement quicker than the natural locomotion of the projectile wherewith it moves to its proper place. But in the void none of these things can take place, nor can anything be moved save as that which is carried is moved." (*ibid.*, p.71).

Greek atomism remained strong among its supporters for about five hundred years. In the first century BCE it is described in vivid detail in the great poem of the Roman poet Lucretius (*ibid.*, p. 88 and it is also the basis for scientific and technological experiments in the behavior of the air performed by Hero of Alexandria (60 CE) (See Toulmin and Goodfield, 1962, p.222).

However, in the middle ages it was clearly rejected, and Aristotle's position apparently took hold firmly. His philosophy was adopted in nearly all areas of thought and science, both by the Christian Church and by many Arab philosophers. Regarding the notion of vacuum, it was accepted for the duration of the Middle Ages that vacuum is implausible and that "Nature abhors a vacuum".

In the beginning of the 17th Century, a clear return to atomism began. It rested to some degree on experiments, but was rooted in speculative philosophical considerations. Toulmin and Goodfield (1962) in their historical survey argued that Galileo (1564-1642)

> "adopted atomism for general philosophical reasons: It was the intellectual instrument by which he hoped to bring matter theory within the field of mathematics (*ibid.*, p.194)..."A truly scientific account of behavior of things should therefore refer only to shapes and motions - mathematically analyzable properties, which Galileo called the \`primary' qualities of things. Characteristics such as colour and warmth, by contrast, had no place in scientific theory: such \`secondary' qualities were no more than by-products of the interaction between our bodies and the atoms of the outside world (*ibid.*, p.194-5).

> "Galileo was happy to follow Democritus in most respects, differing from him only in the central importance he attached to mathematics (*ibid*., p.196) ... (He) and his pupils began to experiment on the physical properties of elastic (i.e., compressible or gaseous) fluids - notably, on the air of the atmosphere. This choice of starting-point was no accident. *Atomism had always appeared most plausible when applied to the physics of gases*, and Hero of Alexandria's treatise on the subject was familiar both to Galileo in Italy and a generation later, to Robert Boyle in England." (*ibid*., p.196) [emphasis mine, J.N.].

The experiments carried out by the student of Galileo, Toricelli (1608-1655) on the air in the atmosphere brought about the invention of the first barometer. The barometer, which demonstrated the natural formation of a vacuum at the top of the pipe, and subsequently, Toricelli's explanation of air pressure, created a wave of excitement which spread among the European scientists.

It was clear that Toricelli's experiments challenged Aristotle's claim that "Nature abhors a vacuum". Pascal (1623-1662) continued Toricelli's experiments and showed that the column of mercury in the barometer is shorter when measured on the top of hills, since it left more vacuum at the top of the glass tube. These breakthrough experiments with the barometer resulted in a situation in which atomism was more receptive and which therefore could be brought to the center of scientific thinking after 2000 years of opposition. It should be pointed out that despite this great jump forward, no effort had yet been made to clarify the "true" form of corpuscles or atoms, but rather of the very existence of vacuum and of its being an important part of the world of matter.

Pascal is interesting here:

> "It is not difficult to demonstrate...that nature does not abhor a vacuum at all. This manner of speaking is improper, since created nature .. is not animated, and can have no passions.... [Nature] is supremely indifferent to a vacuum, since it never does anything either to seek or to avoid it" (Sambursky, p.261-2).

This article of Pascal concludes with a pathos emphasizing the stormy depth of the historic argument over vacuum.

> "Does Nature abhor a vacuum more in the highlands than in the lowlands? In damp weather more than in fine? Is not its abhorrence the same on a steeple, in an attic, and in the yard? Let all the disciples of Aristotle collect the profoundest writing of their

> master and of his commentators in order to account for these things [the barometer's changes] by abhorrence of vacuum if they can. If they can not, let them learn that experiment is the true master that one must follow in physics; that the experiment made on the mountains has overthrown the universal belief in nature's abhorrence of a vacuum, and given the world the knowledge, never to be lost, that nature has no abhorrence of a vacuum, nor does anything to avoid it; and that the weight of the mass of the air is the true cause of all effects hitherto ascribed to that imaginary cause" (*ibid.*, p.263).

Boyle (1627-1691) continued the line of research of Toricelli and Pascal and carried out experiments on "the spring of air". In his summary, Boyle writes:

> "the notion I speak of is that there is a spring or elastic power in the air we live in." (*ibid.*, p.281)..."this notion may perhaps be somewhat further explained, by conceiving the air near the earth to be such a heap of little bodies, lying one upon the other as may be resembled to *a fleece of wool* [J.N.]. For this ... consists of many slender and flexible hairs; each of which may indeed, like a little spring, be easily bent or rolled up; but will also, like a spring be still endeavouring to stretch itself out again." (*ibid* p.282).

Thus, as we see, Boyle did not explain the springiness of air by a kinetic model with invisible corpuscles bumping into each other and into the walls. Even his particles are not necessarily ball-shaped, as we have gotten used to thinking of them. He is prepared to compare them to a fleece of wool. Why, if such is the case, is his model worthy of being considered atomistic?

It is indeed atomistic, since he assumes a vacuum area similar to the "empty" space which surrounds and impenetrates the wool, and also because he assumes that the matter of the air *is not* continuous, but composed of discrete particles. Note the following statements made by Boyle:

> "This power of self-dilation is somewhat more conspicuous in a dry sponge compressed, than in a fleece of wool. But yet we rather chose to employ the latter [the wool model] on this occasion, because it *is not*, like a sponge, *an entire body*, but a number of slender and flexible bodies, loosely complicated, as the air itself seems to be (*ibid.*, p.282).

It may be assumed that Boyle, who considered himself to be an empiricist, did not want in this article (1660) to make too much of a strong statement or to return to the model of Democrates in its entirety (separate atoms moving and interacting within an infinite vacuum). He adopted the atomistic model only insofar as experiments "compelled" him to do so. Thus, it is certain that the empty space contains discrete particles crowding together under pressure. The less bold explanation seemed to be that each particle behaves like a spring. Kinetics, which was part of the Democrates' model, did not seem compelled from within the experiment, and therefore he took pains not to use it at this stage. However, we find that Boyle had a full kinetic model from his writings in 1666 (Toulmin and Goodfield, p.201).[9]

Boyle recognized that there is an alternative, Cartesian explanation to his experiments with the air, and yet he preferred the atomistic explanation because of its simplicity (Sambursky, p.283).

Toulmin and Goodfield summarize these historical stages as follows:

> "The basic appeal of atomism to seventeenth century corpuscular philosophers remained general and philosophical: their experimental work on air did not, by itself, provide compelling evidence of the truth of the atomic doctrines. It carried conviction only to the convinced. (p.199).

Atomism, in its physical view, before the modern chemical period, reached the peak of its development with Newton (16--) who added the concept of the existence of attracting and repelling forces among the particles. By using this idea, Newton explained physical and chemical concepts such as cohesion, capillary attraction, absorption of water vapor by hygroscopes, the warming of a mixture in a salt solution with water, or with the reaction of acids upon different material. Despite the fact that the promotion of Newton's atomic theory was very significant, the very transfer of his concept from the macro world of magnetism and gravitation to the micro world of atomic interaction, brought Newton to propose also a *misconception* which remained in force until the beginning of the nineteenth century.

Newton's general assumption regarding the attractive forces among atoms is accepted and the basis of our understanding today of matter. However, Newton continued another assumption regarding the forces of *repulsion* between gaseous atoms (which act for a large distance) which create

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[9]It is interesting that kinetics, which is responsible for the flexibility and springiness of the air, was missing from Boyle's first explanation, but it appeared in the opposing concept of Descartes. However, Cartesian movement differed from the linear displacement concept proposed by Democritus, because the former espoused a rotation of bodies moved by a continuously whirling celestial fluid - ether - which was assumed to fill the entire universe.

the springiness of air which Boyle described. Dalton (1766-1844) retained this misconception and argued that the forces of repulsion exist only between atoms of the same gas and do not exist between atoms of different gases. In this way, Dalton explained how it is possible to achieve homogenic diffusion of two gases with each other, rather than achieving two separate layers.

The noting of this misconception here emphasizes the point that the scientists' return to Democritus' model began from the acceptance of the existence of vacuum, while it took additional time to convince others of the movement of particles.

We propose several implications from the historical review discussed above:

i. *Instruction by philosophical discussions*. Historical analysis shows that experiments by themselves cannot convince everybody by themselves of the correctness of a theoretical explanation. Also the very knowledge and understanding of theory is no guarantee of the adoption by a person who studies it. Aristotle and Descartes were would have received a high mark if they had been tested on the details of the arguments of the atomists, but nonetheless Aristotle and Descartes absolutely rejected the atomic theory. Therefore we see no way to bypass the basic philosophical discussion regarding the quality of matter. Only as a result of a philosophical discussion is it possible to achieve a true and significant level of convincing.

ii. *Beginning by explicit and elaborate discussion of the concept of vacuum*. The main philosophical aspect which presents innovative material in the atomic theory is the fact that vacuum is a significant part in physical existence. Only if there is a vacuum could matter be non-continuous, and thus particulate. Only if there is a vacuum is there a possibility of a movement of particles which can be described in Newtonian mechanics. The "correct" form of the particles and the kinetic concept are less important or primary. The quality of instruction will be tested by its ability to create a true philosophical discussion of concepts of vacuum.

iii. *Entering into the particulate model by an investigation of the behavior of gases, mainly air*. Since it was demonstrated historically that the gas phase calls for the idea of the existence of vacuum and thus *ipso facto* particulate matter, more than a phase of liquid and a solid, it is worth beginning also with students from an investigation of the air.

iv. *A study of the particulate model is a lengthy process of conceptual change*. The history of science has shown in various areas that a conceptual change is a lengthy process accompanied by coping with different types of misconceptions and it includes alternating stages of advance and retreat. It is not reasonable to expect our students to internalize the subject in a meaningful manner while studying it for several weeks. The educational process which applies Points (1) through (3) above has to be given time, and it must be developed in a spiral fashion over the course of several years of study.

(2) ***Implications from the philosophy of science.***
A previous article (Nussbaum, 1989) pointed out the possible significance of the philosophy of science on the teaching of science in schools. That article presented these matters in detail while this paper will present only a brief summary, with references to that source.

The broad trend predominating today in philosophy is constructivism, which replaced the two classical trends - empiricism and rationalism. The two traditional trends believed in absolute knowledge, while the current trend emphasizes the building of knowledge by a person, as well as the fact that the basis of science is a process of revised constructs and reconstructions of models for the existential structure. The main issue which separating constructivist philosophers is whether there is (and whether it is proper that there be) clear criteria for abandoning an older theory and the adoption of another theory. From Popper it is clear that scientists abandon a theory when a critical experiment refutes it. Kuhn argues, quite uncompromisingly, that the inclusive theories, or paradigms, are not necessarily replaced because of a critical experiment, but to a great extent because of social and psychological reasons which affect the individual scientist and the community of scientists. Lakatos (196-) and Toulmin (1972) take intermediate stands, both of them emphasizing that it is not a critical experiment which creates a conceptual change. Lakatos argues that the abandonment of a theory occurs not with a conflict between the theory and a new experiment, but only whit an open conflict between this theory and an alternative theory. A theory is abandoned only when its proponents gradually realize the advantages of an alternative theory and the disadvantages of continuing to reconsider of their own theory. Toulmin emphasizes the gradual and evolutionary change in the meaning of the concepts. These two philosophers emphasize that the conceptual change among the community of scientists is not a purely intellectual process but rather includes a process of social negotiation.

This writer is more convinced by the philosophical approaches espoused by Lakatos and Toulmin, and believes that during the course of conceptual change in the classroom, the process must include negotiations among the alternative models, as a main part of the instructional strategy. The teacher guiding the process must be patient and tolerant, and to be prepared not only for slow progress among some of the students, but also for a possible retreat among some of them.

(3) ***Implications from the area of cognitive psychology***

The writings of various people in cognitive psychology, beginning in the Sixties, shows a psychological concept reminiscent in its principles of the constructivist concept in the philosophy of science. After studying the convergence of the current concepts in philosophy and psychology, those involved in teaching science began to speak of a constructive approach to education (Driver, 1985; Novak, 1988). From a certain point of view, also Piagetian theory is constructivist, but Piaget's intellectual construction of reality is created only through logical operations. Since the development in stages of logical operations is an immanent component of Piaget, it results that a young child cannot study abstract concepts. Logic has lost a great deal of its centrality when conceptualizing the essence of science among recent philosophers (Brown, 1988). In addition, various psychologists have challenged the centrality of logic as the primary criterion determining the quality of thought (Donaldson, 1979) and Piaget's gradual development model.

With certain variations many psychologist agree today that the thought of the child is affected by their existing context-oriented and context-dependent concepts.

Writings such as Matthews (1984) and others have shown that very young children are capable of true philosophical discussions. It has become clear from these projects that it is not the age of the children which is a limiting factor for their ability to philosophize. It is rather the ability of the adult guiding the discussion to stimulate them and to assist them to draw out their hidden potential.

According to these considerations, we have hypothesized that philosophical discussions can be carried out regarding the particulate model of matter also with children of a relatively young age - and younger than the age that the subject is generally taught in schools. If it could be studied at an earlier age then it would certainly be worthwhile, as noted in the previous section indicating that the conceptual change is an extended process.

Our argument is that because the subject is not introduced until age 13-14 and up, and that furthermore it is introduced in insufficient methods, we find that high school students still cannot operate with the particulate model in a meaningful manner in advance subjects such as chemistry and biology.

In some of our previous articles (Nussbaum & Novick, 1981,1982) we attempted to apply the considerations which we brought above for instructing the subject to students aged 13-14, and we found that the strategy which we proposed was very successful.

The present research presented an attempt to investigate whether it was possible by means of some modifications to teach the subjects to students aged 9 (third graders).

Structure of the instructional unit

Since we cannot expand on the process of education which includes 30 propositions, the structure will be described following in the form of expressions or questions. In most of the classes each expression or question will be accompanied by experimental activities.

Generating concepts and primary factual knowledge regarding air and pure gases	J Is air matter? Air takes up room; air carries out activities. J Various gases, such as carbon dioxide and oxygen, are colorless and clear. How can carbon dioxide be identified? How is oxygen identified? Air is a mixture of carbon dioxide, oxygen, and nitrogen.
Preparation for the cognitive need for vacuum	J If we had magic eyeglasses, how would air remaining in a closed flask look after part of it was pumped out. From what place within the flask would air be missing after it was pumped out? J Why is air compressible whereas water is not compressible?
Preparation of an "analogy" for the following discussion	J Air behaves like a spring or like a sponge. Given a block of iron, steel wool, a steel spring, a rubber stopper, and foam rubber, which is compressible? Which is not? The structure of the material, rather than the material itself, determines whether it will be compressible. Steel wool, a spring, and a rubber sponge have empty spaces in them, and this is why they are compressible.
"Feeling" the applicability of the new model	J Are there empty spaces in the air surrounding us? What can explain the compressibility of air? Air is made of particles in a vacuum - the teacher's preferred proposal.
Debating the plausibility of natural vacuum	J Given acetone, alcohol, and water - which has the strongest smell? Which evaporates and disappears first? Where are the acetone particles which left the liquid? How are the acetone particles distributed in the air?

Supporting experience	J Acetone, alcohol and water: Which was has the strongest smell? Which one evaporates and disappears first? Where are the acetone particles which left the liquid? How are the particles of acetone distributed in the air?
Debating animism vs. mechanism. Smell is a substance.	J Do the acetone particles "want" to reach our noses? J "Smell" is a substance which changed from a liquid (or solid) form to a gaseous form. Smell is vapors. Vapors are caseous matter. Water vapor has no smell. Where are the naphthalene particles which evaporated?
Temperature and particles kinetics animism vs. mechanism	J A flattened plastic bottle with some liquid acetone expands when heated. What did the heating do to the particles of acetone in the bottle? What did the particles of gaseous acetone do to the walls of the bottle? J The connection between the heating and the movement of particles J The rising of a bubble of soap which seals off the mouth of the test tube - by heating the air in the test tube. J The lowering of that bubble by cooling of the test tube. J What is the particulate explanation? Do particles escape from the heat? What pushes the bubble harder - the air inside or the air outside?

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