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THREE BASIC CONCEPTS IN TEACHING THE ATOM: INFINITY, VOID AND ARCHE

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ABSTRACT
In this study the concepts of arche (essence), infinity and void that are rooted in the atomist thoughts of ancient Greek philosophers have been explained using easily applicable scientific activities. The activities were carried out with a study group of (N=73) participants consisting of science teacher candidates. Worksheets were used to carry out and evaluate the activities and the qualitative data obtained were evaluated. It was concluded as a result of the study that questioning the continuity of matter, comprehending matter as void and arche are important in understanding the concept of atom and nature and that macro world is not a copy of the micro world meaning that it should be perceived differently. In addition to the results, the study also suggests a different approach that makes it easier to teach the concept of atom via introductory activities developed with inspiration from the work of antique period philosopher Lucretius entitled De Rerum Natura.
Keywords: Atom, Infinity, Void, Arche, Scientific Activity.

INTRODUCTION

Modern atomism was built on the foundation of profound and systematic thoughts that have been discussed for thousands of years. However, in current science education, the portion of these thoughts that correspond to approximately the first 2000 years of their progress is almost not discussed at all. This is true despite the fact that modern atomism is founded on the atomic philosophy of Antiquity, which should not be considered an obstacle to today's learning but rather a philosophical guide. It has been for this reason that the concept of the atom, as in today's world, has progressed through inquiry in every period of history. It is important therefore to question the teaching of the concept of the atom in science education and to create a need for learning about the atom.

In the first era of ancient history, the ideas that led to the atom arose from the discussion of *arche* (ἀρχή), the element or principle that was thought to lie at the root of the universe. At the beginning of the 6th century BC, Thales of Miletus postulated that water was *arche* (Capelle, 2006, 54). Later, Anaximander described *arche* as *apeiron* (ἄπειρον), or infinity/the unlimited (Capelle, 2006, 61). Contrary to this view, a generation later, Anaximander's student Anaximenes of Miletus (585-528 BC) set forth that everything was created by the concentration and subsequent rarification of air in a certain way. After ideas about *arche* matured in Miletus, in the period following, Zeno of Elea, the teacher of Leucippus, opened up the *principle of divisibility* for discussion based on the concept of *infinity*. Indeed, Leucippus refuted the idea of *infinite division*, claiming that matter could not be divided endlessly and bringing forth the concept of the existence of an indivisible *arche* (*arche atomos*). Leucippus defended the idea that the most fundamental particles making up the mass of an object

(*arche atomos*) had no void inside and that infinite division would only continue until the arche was reached (Capelle, 2006, 216-217). Thus, the many behaviors of matter in the macro and micro dimension became imaginable in terms of the concepts of void and atoms. The concept of the void was to become very controversial in later periods. In fact, Aristotle (384-322 BC) perceived the concept of the void in the context of the ancient world's view of the atom not as progress but as a philosophical obstacle in the development of the concept and a teaching that should be refuted. On the other hand, a small segment of the population was to debate atomism in every era. For example, about 120 years after Leucippus and Democritus, Epicurus (341-270 BC) was to make the idea of the atom the foundation of the philosophy of matter, his thoughts to be later adopted by Roman philosophers such as Titus Lucretius Carus (*ca.* 99-55 BC), Marcus Tullius Cicero (106-43 BC) and Lucius Annaeus Seneca (4 B.C. – AD 65). Even many centuries later, similar thoughts were set forth in 1582 by the Italian researcher Giordeno Bruno, who said that "the division of everything in nature ends with an indivisible particle."

As described above, today's concept of the atom has been shaped from the discussions of certain thoughts over a period of thousands of years. These thoughts are almost never discussed in the contemporary teaching of the concept of the atom. It is frequently mentioned in the literature in the field that the failure to learn about such precursor ideas often results in learning difficulties and misconceptions. As philosophers of Antiquity turned to nature with their senses, the students of today also try to reach knowledge about the atom with their senses. This has a significant impact on the views of students about existence, matter and atomism. Students will frequently confuse the properties of a single atom with the macroscopic properties of matter (Harrison & Treagust, 1996) and perceive the fundamental particles that make up matter as a whole in the macro dimension (Renström, Anderson & Marton, 1990). In a study conducted with 30 Italian elementary school students, Albanese & Vicentini (1997) found that the students deduced from the word "atom," which in both Ancient Greek and Latin means "indivisible" (*atomos/atomus*), that an atom was an indivisible particle of matter. On the other hand, some students claimed that matter could ultimately be divided "until nothing was left (Yeğnidemir, 2000)." Although the literature qualifies both of these thoughts as misconceptions, the two ideas constitute alternative ways that students learn about the philosophy of the atom. The difference here is that students perceive matter to be either continuous or impermanent. That the students think that matter can be divided until infinity shows that their understanding is that matter is continuous. Novick and Nussbaum (1981) report in their research that students in every age group think of matter as continuous. The idea that matter is divisible brings the concepts of space and arche up for discussion. When Leucippus in Antiquity set forth the concept that atoms (*arche atomos*) had the qualities of being solid and full, he was suggesting their physical existence and the eternal (eter-ether-esir) existence of the void in which they moved (Capelle, 2006, 216). Today, students generally think that there is matter between atoms (Griffths and Preston, 1992). Novick and Nussbaum (1978) interviewed 154 students about the gas state of matter, stressing the importance of knowing the concept of the void when trying to understand the structure of the atom.

As can be seen from the studies mentioned above, student misconceptions about the idea of the atom derive from the difficulties they experience in perceiving the concepts of arche, void and infinity. This is why we can now turn to look back into the works of Antiquity, a time when these concepts puzzled the minds of the philosophers who were trying to understand how the universe had been created. The students of today experience similar uncertainties. In this context, the goal of the present study was to develop some introductory activities by using certain selected threshold thoughts on the atom stemming from Antiquity in order to inspire inquiry and prepare students for an integrated learning experience about the atom.

MATERIALS AND METHODS

The study group

The research on the introductory activities for teaching the atom was conducted with a study group (N=73) of pre-service science teachers.

Data collection instruments

The worksheets developed for each activity were used as data collection instruments. The data consisted of the written answers to the questions on the worksheet that the three researchers interpreted through encoding using content analysis.

Activities used in the research

The "soap activity" was selected to discuss the concepts of *infinity* and *arche* while the "syringe activity" was used to discuss the concept of *void*.

The Soap Activity

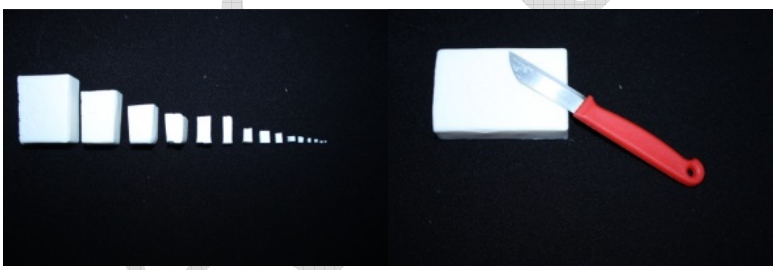

Figure 1. Images of the soap activity.

The purpose of the activity was to lead the students into perceiving infinity or finiteness by making use of the truth claimed by Leucippus and Democritus that the atom was solid and indivisible. The activity was inspired by *De Rerum Natura*, the masterpiece of Titus Lucretius Carus; a similar observation was made by Baine (2007) to explain how the notion of the atom came about. As can be seen in Figure 1, the pre-service teachers were asked to keep dividing a piece of soap into its smallest particle. Meanwhile, the students were guided into inquiring into and discussing the questions asked on the worksheet prepared for the activity. For example, the question, "*When you continue to divide, will all the particles in the end still be soap?*" may guide the students to question the concept of infinity by considering the notions of continuity and discontinuity. Similarly, with the question, "*If you could continue to divide, would there be a point at which you would have to stop?*" the students were led to discuss what the next parts of the activity would be, whether they could continue on like this into infinity, or whether they would have to stop at some point. Thus, the students were encouraged to discover and assign meaning to the concept of *arche* by themselves based on the concept of *infinity*. It is important that the teacher read the related part of the Lucretius' poem *De Rerum Natura* (Lucr. I, 267-424) before the activity.

The Syringe Activity

As summarized in the introduction to our study, the discussion of the *void* with respect to matter holds an important place in the thought process leading to the concept of the atom. To make this concept comprehensible, the activity seen in (Figure 2) was carried out. In this activity, students were given a syringe and an eraser and asked to press the syringe down on the eraser. Many of us use this exercise of observation frequently in our classrooms to prove the existence of air, pressure and similar elements (Nussbaum, 2005). The fundamental aim in choosing this observation as an introductory activity in this research, however, was to use an effective element of observation to lead students to inquire about the atom and ask questions in the context of the concepts of *void* and *arche* and in parallel to the historical development of atomism. Discussions can be subsequently initiated about the worksheet questions developed for the activity regarding the nature of the void and space between the particles that make up air. For example, in the introduction to the activity, Zeno's teachings about the void in Antiquity and the emerging paradoxes provide considerable motivation for pre-service teachers. In addition, questions were posed on "*How can the phenomenon observed with the syringe be associated with a fish swimming in water, our moving about in the air, water trickling down into the deep through the rocks*," which were inspired by *De Rerum Natura* and carried the intention of explaining the void and *arche* using examples straight out of nature. These two activities were developed to motivate and prepare pre-service teachers prior to their 11-week course on the atom. The support of science educators, a classical philologist, physicists and philosophy academics was enlisted in the development of the two activities and in evaluating them in terms of scope and content. Thus, the difficulties today's students face in learning about the atom were evaluated in the light of historical data, leading to the development of the two introductory activities described above, which are recommended for teaching the threshold concepts of infinity, void and arche. The degree to which students were able to perceive the fundamental ideas treated in each activity and whether or not the activities fulfilled their aim was examined with qualitative analysis of the open-ended questions asked of the pre-service teachers. In this analysis, the three science educator researchers analyzed each answer under the different codes assigned.

Figure 2. Images from the observation activity on the concept of void.

RESULTS AND DISCUSSION

In the soap activity, the pre-service teachers discussed the concepts of *infinity* and *arche* in the context of matter and existence. Table 1 displays the answers and response percentages related to the worksheet question asked of the pre-service teachers, *"When you continue to divide, will all the particles in the end still be soap?"*

Table 1. Answers given by the pre-service teachers to the question, "When you continue to divide, will all the particles in the end still be soap?"

Answers	% values
Soap is still soap however much we divide it.	82
When we continue to divide, at one point, the soap will no longer be soap.	18

In considering the answers given by the pre-service teachers in the light of the thoughts of major philosophers in history, we see that 82% of the pre-service teachers' thoughts were exactly like those of the ancient philosopher Zeno: *"Soap is still soap however much we divide it."* The other 12% believe, like Leucippus, that *"When we continue to divide, at one point, the soap will no longer be soap."* It would be a mistake at this point to question which thought is more accurate because each of these thoughts was correct and meaningful in different eras. It can also be said that individuals exhibiting each of these thoughts may be at different levels in their own development. The main idea to be gleaned from these results is that a large percentage of pre-service teachers have an understanding of continuity and infinity. In fact, the main goal of the activity is to encourage inquiry about the concept of infinity and for this reason, there is no right or wrong answer. The fundamental philosophy behind this is that there is no absolute clarity in the nature of science. Similarly, at no time or in no subject has there ever been clarity about the nature of atomism.

The answers to the worksheet question, "*If you could continue to divide, would there be a point at which you would have to stop?*" are shown in Table 2.

Table 2. Answers to the question, "If you could continue to divide, would there be a point at which you would have to stop?"

Answers		% values
Yes, there would be.	Division of matter can continue until the limits of science on a micro dimension or until the limits of the area in which the experiment is being performed.	19
	Matter can be divided until a cut-off point is determined.	7
	Matter can be divided until the atom is reached.	26
	Matter can be divided until the smallest particle is reached.	17
No, there would not be.	There is no end to the act of division and division may occur infinitely.	31

Lucretius, the source of inspiration for the activity, speaks of infinity in this way:

" Moreover, were there not a minimum,
The smallest bodies would have infinites,
Since then a half-of-half could still be halved,
With limitless division less and less.
Then what the difference 'twixt the sum and least?
None: for however infinite the sum,
Yet even the smallest would consist the same
Of infinite parts" (Lucr. I, 616-620).

As Lucretius describes, students attribute the smallest element, in other words, *arche*, to different phenomena. Beyond having the students in Table 2 inquire about the accuracy of the phenomena, the aim here was to lead students into forming a questioning thought pattern. Indeed, in the historical development of the atom, *arche* has sometimes been attributed to water and sometimes to air, other times being qualified as an atom, while today, with the discovery of the 6 subatomic particles, the concept is almost entirely attributed to infinity.

In the *Void Activity*, the pre-service teachers observed the air pressed into the syringe; the aim here was to open the void, which was the explanation for the exercise, to discussion. The views on the explanation of the phenomena of the void and the *arche* related to the question, "*How can the phenomenon observed with the syringe be associated with a fish swimming in water, our moving about in the air, water trickling down into the deep through the rocks?*" can be seen in Table 3.

Table 3. Answers the pre-service teachers gave to the question, "How can the phenomenon observed with the syringe be associated with a fish swimming in water, our moving about in the air, water trickling down into the deep through the rocks"

Answers	% values
There are spaces between atoms and these spaces are the source of movement.	21
It is caused by the space.	35
The free movement of the liquid and gas molecules causes movement.	4
It is caused by the pressure.	19
There is no association.	21

As seen in Table 3, in the second activity performed with the pre-service teachers, although different ways of expressing it were used, the large majority of the respondents made the association between the movement in the syringe and the spaces between the atoms. When the works of Antiquity are examined, it can be seen that it is stated that *corpora* (main bodies) move arbitrarily towards all directions in *spatium* (space), that they come together, arrange themselves and then become untied. The solid state, weight, density and softness of objects were associated with how scant or how plentiful i*nanis* (void) were between the atoms (Eyüpoğlu, 2001, 21-22). The concept of the void is therefore important for students in being able to make sense out of phenomena in nature.

CONCLUSION

Three concepts (*infinity, void* and *arche*) of atomism have been discussed for 2000 years throughout history and continue to interest us today. All of the ideas that were set forth in this process were concepts that deserved inquiry in terms of understanding the concept of the atom. Although the various ideas do not completely mesh with the concepts accepted in today's atomism, they are still important because they contributed to making the concept of atom become meaningful. It is for this reason that the goal of our activities was to provide pre-service teachers an introductory activity that would lead them to make inquiries about the ideas concerning the concept of the atom. These two activities, which integrate the views of Antiquity with today's inquiry-based educational philosophy, were instrumental in our implementing a successful introductory class. The researchers did not evaluate any of the responses as being either right or wrong. The aim of our efforts was to add a different dimension to the students' system of inquiry, arouse curiosity about the atom, and ensure that the questions raised by the students in learning about the concept of the atom were answered. These thoughts are all part of the constructivist and inquiry-based philosophy of education. The introductory activities were performed in the short classroom period of one hour and succeeded in motivating the pre-service teachers and preparing them for learning about the atom. The concepts discussed during the course of the activities will provide pre-service teachers with guidance and more knowledge on Brownian motion, cathode rays, the flame test and other experiments performed in the fields of physics and chemistry. During the activities, the pre-service teachers generally expressed an association between the concepts *infinity, space* and *arche*. The two activities the researchers developed thus have the potential of providing support to new quests and implementations needed in today's system of education.

FURTHER IMPLICATIONS

The basic approach of the research in terms of teaching encompasses inquiry and observation. The place observation occupies in science education has been discussed over the years but it is a fact that exemplary applications are needed to ensure that concept are understood. In concepts such as the atom, there is a need for more research in this context.

The activities developed can be examined by curriculum development experts and considered as introductory material that may be included in textbooks, as well as in science fairs, science camps and other educational organized events.

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