A History of Science classroom experience: Teaching the movement concept

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Abstract
We have used the History of Science to introduce movement ideas and concepts from Aristotle to Copernicus, Brahe, Kepler and Galileo, aiming to help students to surmount their difficulties and to review misconceptions originated in the common sense. Those author's basic texts started the discussion and a small list of questions was worked out. After getting the student's comprehension of Aristotle, Brahe, Kepler, Copernicus and Galileo's ideas, they have been tested, so as to guarantee their understanding of the nature of Science, its evolutional character and the full meaning of the expression Modern Science. Following this, we introduced Galileo's inclined plane experiment, in which we are able to study linear uniform movements and free fall accelerated movements. This activity had two phases: first we repeated the procedures used in Galileo's time, and secondly we have used a microcomputer and LOGO to acquire data and draw graphs and tables. Students were then induced to (re)negotiate the meanings, including now the experimentally observed facts. We discussed the accuracy and precision of measurement processes, and students manifested doubts about Galileo's interpretation of the results. At this moment, the data acquisition process became an influential aspect to guarantee the confidence in the physical interpretation of the experiment. Our theoretical base was the social-interactionist constructivism to pedagogical activities allied to History of Science to introduce and negotiate the meaning of movement. We believe the student's conceptual profiles were enriched and the evolution of the movement concepts was clarified for them.

Keywords: History of Science, Physics Education, teaching methods.

Resumo
Nós usamos a História da Ciência para introduzir as idéias e conceitos sobre movimento desde Aristóteles até Copérnico, Brahe, Kepler e Galileu com o objetivo de ajudar aos estudantes a vencer suas dificuldades e a rever suas concepções espontâneas decorrentes do senso comum. A discussão foi iniciada a partir dos textos básicos destes autores e um pequeno número de questões propostas aos estudantes a respeito destes textos. Após nos certificarmos que os estudantes haviam entendido os conceitos básicos propostos por estes autores, nós os testamos a respeito de seu entendimento sobre a natureza da Ciência, seu caráter evolutivo e o significado da expressão Ciência Moderna. A seguir nós introduzimos o plano inclinado de Galileu; um experimento que permite estudar o movimento linear uniforme e o movimento de queda livre. Esta atividade foi realizada em duas fases: primeiro nós reproduzimos os procedimentos de medição como no tempo de Galileu e a seguir nós utilizamos um microcomputador e o sistema LOGO para a aquisição de dados e a feitura de gráficos e tabelas. Os estudantes foram então estimulados a (re) negociar os significados incluindo os dados obtidos na atividade experimental. A acurácia e a precisão dos processos de medição foram então questionadas na comparação entre os resultados obtidos com régua e relógio e os resultados obtidos usando o computador. Neste ponto os estudantes manifestaram dúvidas se com os instrumentos de medida da época de Galileu era possível obter resultados capazes de permitir a interpretação que o mesmo propôs. Para os estudantes, o processo de aquisição de dados tornou-se fundamental para garantir a confiança nas interpretações dos resultados do experimento. Os fundamentos teóricos utilizados foram o construtivismo social-interacionista para as atividades didático-pedagógicas aliado à História da Ciência para introduzir os significados relativos ao conceito de movimento que deveriam ser (re) negociados pelos estudantes. Nós acreditamos que os perfis conceituais dos estudantes foram enriquecidos e a evolução dos conceitos de movimento tornou-se clara para eles.

Palavras chave: História da Ciência, Ensino de Física, Métodos de Ensino, conceito de movimento.

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I. INTRODUCTION

Students consider Physics as a set of codes and mathematical formulas to be memorized and studies, which in most cases are completely out of their life experiences. In general, they are not able to make a connection between the Physics they study and the world around themselves. The schoolteacher's attitudes are the most important factors influencing the students' success or failure in basic levels of education. M. R. Mathews, in the foreword of Asia-Pacific Forum on Science Learning and Teaching [1] agree with the students. He hopes that "History of Science could contribute to overcome the sea of meaninglessness which one commentator said has engulfed science classrooms where formula and equations are recited but few people know what they mean". On the other hand Trindade and Fiolhais, [2] advocate:

"*The teacher must provide more effective learning resources to help students to overcome the difficulties, seeking, where possible, to update their pedagogical resources, because gaps in learning complex and few intuitive concepts may occur more frequently if they are only presented in verbal and textual forms*" [2].

The points of view advocated by Mathews and Fiolhais & Trindade are the starting point for this work: considering that the teacher task is increasing the learning chances of their students, we have chosen a set of teaching and learning resources supported by a specific theoretical framework. To build an educational methodology to teach movement concepts in general and the principle of inertia, we had been using Galileo's inclined plane and the History of Science. This construction has been tested, implemented and evaluated with first year students of the Agricultural Technician School Nilo Peçanha at Universidade Federal Fluminense (University Federal Fluminense) in Pinheiral City – RJ, Brazil, during the years of 2005 and 2006. Students in this level are in the same level that high school 10th year. They did not have a Physics class yet, only Biology and Chemistry and a generalist Science class where they were exposed to some qualitative concepts about movement. However, in their Science and Geography classes mention is done about Copernican ideas and Earth's motions. Students from three classes were organized in groups of four or five. Individual activities were not stimulated. The discussion and evaluation of divergent views with meaning negotiation were considered essential items in the assessment of the success of the activity.

First, we spent three classes in a normal classroom. Students received a History of Science based text and a questionnaire developed by the teachers to introduce movement ideas. We have used this material to support the discussion and the student's construction of mental models. This material was also used as a diagnosis tool of previous knowledge and student's areas of proximal development [3, 4]. At the end of the activity the students should report a group consensual point of view about the discussed ideas.

In a second phase, we spent three more classes with the students organized in the same work groups in the Physics laboratory to perform the inclined plane experiment. The main targets are to measure, test and compare the models and conclusions produced in the first three classes with the data produced in the lab. At first students performed a manual measurement, *i.e*. with a stopwatch and a ruler. In this process the time spent between to see an event and take an action is a determinant factor in the results confidence. In the second step students made a computer assisted measurement using the game port of a personal computer and LOGO [5, 6, 7, 8].

History of Science and the laboratory were used as tools for pedagogical action over students. On one hand we use the historical discussion of the concepts of movement in the sky and on the Earth's surface to make a diagnosis of student's previous knowledge and provoke social interaction; on the other hand we helped then to make mental models concerning movement. The laboratory results were used to test effectively the pedagogical model's confidence *i.e*. if the previous knowledge presented in History of Science activities was changed in new knowledge based in these results. We hope that student's smooth cognitive conflicts between historical facts and lab activity results had permitted accommodation and assimilation related to the understanding of movement abstract concepts, both in heavens and in the gravitational field of Earth. Additionally, computer assisted data were compared with those acquired in a manual process. This comparison led a discussion on the validity of the findings obtained manually. Did quality of those data are equivalent or not to data obtained by automatic collection. At this point, the students made a harsh criticism to the results interpretation considering manual data collection and the methods of data collection available at Galileo's time. They also said they do not believe that Galileo had made measurements to support his conclusions using only the water clocks of his time. We hope to be able to accomplish the best teacher definition we know:

"*The teacher's first responsibility in a Vigotskian approach is to select a focus for attention that is both culturally significant and intellectually challenging, and to engender a sense of ownership of the problem and a commitment to addressing and solving it. The second responsibility is to provide the necessary resources and conditions for students to engage in the learning task and to ascertain, through observation and dialogue with the students, the limits of the group's unaided ability to clarify or solve the problem. The third responsibility is to provide whatever support, encouragement, advice, criticism and expertise is contingently appropriate to enable the group to achieve what they could not manage alone. By working on joint activities within the student's zone of proximal development the teacher enables them to complete the task-in-hand and to appropriate the knowledge and other cultural resources that will thereafter enable them to proceed unaided*" [9].

II. THEORETICAL EMBASEMENT

We have adopted a qualitative approach in our work. This approach have been increasingly used in educational research, as people believe in a dynamic relationship between the real world and the subject, *i.e.* an inseparable constraint between the objective world and the subjectivity of the individual that can not be translated into numbers. Qualitative research involves direct and prolonged contact between the researcher and the environment where the problems occur, which is being investigated by the labor-intensive field [10]. According to Bogdan and Biklen, [11],

"*Qualitative research involves the collection of descriptive data, obtained by direct contact between the researcher and the situation studied, emphasizing more the process than the product. This approach is indicated for phenomena that are influenced by their context. Thus, the data collected are predominantly descriptive, rich in descriptions of people, situations, comments and events and include transcripts of interviews, photographs, drawings and statements of many kinds of documents. In these studies, there is always an attempt to capture the participant's perspective, i.e. how the individuals interact with the targeted issues, considering the different points of view, which allow illuminating the situations and internal dynamics, usually inaccessible to external observers. Researchers do not seek evidence to prove a priori hypotheses or questions, which does not imply the absence of a theoretical framework to guide the data collection and analysis*."

On the other hand, a pedagogical framework is needed. Piaget and Vigotskii theories are the choice to deal with learning and teaching Physics. In the following text their theories are presented and used to justify our procedures. We know that constructivism is under serious criticisms [12, 13, 14, 15, 16, 17, 18, 19]. However, our epistemological choice based on Piaget's thought [20] where independence between subject and reality is stated, seems to be confirmed by Wong and Hodson results [21] related to how scientists think:

"*All the scientists echoed this commitment to the belief that the universe is both rational and understandable; without such faith, they said, scientific inquiry and attempts to build theories would be pointless. Inevitably, discussion moved to the question of whether science is realist or instrumentalist. Is scientific knowledge a true description of the world or it is merely a convenient (and possibly fictional) construction for gaining a measure of control and predictive capability? Although the high-energy physicist sees a role for instrumentalist models (In some cases, scientists just construct models and say that if these models are taken, as true, then interesting things would happen), his overall position is a realist one. His view that entities such as electrons are real because "we're able to move individual electrons around" is essentially that is propounded by Hacking [22]. Indeed, all our scientists subscribed to the view that the predictive power and technological applicability of current scientific theories can be taken as strong evidence that in many respects we are getting closer to the truth about the universe. They seem to be saying that while a detailed explanatory structure it may still be somewhat tentative and subject to elaboration and modification, the specific entities postulated within that theory have a real existence* [21]."

A. Piagetian thought

Piaget's theories are based in the interaction processes between the individual and the object of his/her knowledge. The object of knowledge is the movement and History of Science/lab instruments are mediators that bring the subjects near it. Cognitive development in Piaget's broader vision represents a relationship between equilibrium and disequilibrium, in which each successive level of equilibrium reflects the addition and reorganization of cognitive elements through the acquisition of better quality new knowledge. In Piaget's view, the cognitive development of all individuals is through assimilation, which means the use of a cognitive structure already formed, and accommodation, a process that involves the modification of structures already developed to address a new situation. The individual builds mental assimilation schemas to address the reality using mediators to interact with the object to be known. For Piaget, whole assimilation schemas are built up and the whole approach to reality involves an assimilation schema. The individual searches to assimilate ideas, concepts and so on using the possibilities of understanding built by him. If the individual is unable to assimilate the new situation, there occurs the phenomenon named by Piaget as accommodation. In this process individuals change their previously established concepts and hypotheses to fit new facts, concepts, ideas, etc. and to produce new schemes of assimilation.

"*There is no accommodation without schemes of assimilation: accommodation is the schemes of assimilation restructured. The equilibrium between assimilation and accommodation is the fit to the situation. Experiences fitted lead then to new patterns of assimilation and a new state of equilibrium is reached*" [23].

To fit Piagetian thoughts the teacher should develop the content and the teaching materials as tools that serve for the natural development of the student. The teacher needs to take into account that learning is a process built internally, and this is dependent on the level of development of the subject and the mediators used to approach the knowledge. Social interaction and instruments favor a cognitive reorganization. At this point Piaget and Vigotskii agree [24, 4]. The choice of content and approach, with emphasis in historical process from Aristotle's ideas on the motion and Galileo's lab experiments, reinforce this agreement.

The students preliminary ideas generally agree with Aristotle's ideas, *i.e*. students agree when Aristotle says that an external agent is needed to maintain any movement. Student's previous conceptions were in agreement with historical beliefs [20]. Our hope is that History of Science help students to build assimilation schemas. A cognitive conflict is established when the results of measurements made on the inclined plane are compared to models built in the first three classes based on the History of Science, and to the previous knowledge brought by students. Students need new assimilation schemas to learn new concepts overcoming misconceptions and broadening student's conceptual profile [25, 26] to include the principle of inertia and Newtonian movement ideas. We hope that the cognitive conflict could be smoothness by History of Science activities before lab.

History of Science activities should help students to broad their conceptual profile. The more extended the conceptual profile more weak the cognitive conflict. The comparison between historical beliefs and lab results will give them a nature of science view.

B. Vigotskii's thought

The theory of Vigotskii is based on the premise that to understand the cognitive development of the individual we must consider the social and cultural context in which it is inserted. Cognitive development is strongly influenced by social environment. "*In our point of view, the real course of thought development does not go from the individual to society but from society to the individual*" [3, 4]. In this case, social relations are transformed into higher mental functions (thinking, language) through the mediation of tools and symbols. The instrument is used to make anything and the symbol is something that has meaning. The symbol may be of three types:

a) Indicators that have a relation of cause and effect to what it are meant;

b) Icons, pictures or drawings of what they mean and;

c) Symbolic that has an abstract relationship with what it means.

Cognitive development occurs through the internalization of tools and systems of symbols [23]. In our context, History of Science and the tools of interaction will provide the system of symbols by the lab activities. To analyze school learning, Vigotskii supposes two levels of development. The first one is called real development zone and is related to cycles of development already completed by the individual. All activity that children can perform alone without any external help is usually accepted as indicator of their development. According to Vigotskii's research, the activities that a child can perform with external help are more indicative of their stage of development than those she can achieve alone.

Analysis of children's behavior that share the same development level but present different learning performances under the guidance of a teacher have demonstrated this conclusion by showing that they don't have the same mental age. It could be because its conceptual profile related to the subject to be learned is narrower than the other children are. The children development level under the teacher's guidance is the potential development zone, the distance between the real development zone and the potential development zone is the proximal development zone. The difference in the ability to learn a given concept between children in the same mental development stage was considered by Vigotskii as of fundamental importance and a measurement of the mental functions still maturing in their minds [3].

The education oriented to children's real development zones is not efficient. For teaching to be good, according to Vigotskii, it should be oriented to cognitive development of the learner. In this case, the proximal development zone is where the learning occurs, mediated by social interactions with teachers, peers and so on. To learn, the individual redefines the boundaries of that area. The teacher's role, according to this theory, is to be the mediator; the more capable partner, that by interacting with the students has the task of making them share the same meanings. Previous concepts and scientific concepts can coexist simultaneously in the student's minds: according to the circumstances, they use one or the other. This process does not show a resistance to conceptual changes, but the existence of a cognitive changing process, a step in the construction of a new cognitive structure. At this point Mortimer and Vigotskii agree. The different methods of data acquisition, the evolution of the Physics concepts and the comparison of the results obtained in human society different ages can create conditions for a more effective learning of Physical concepts. The classroom and the lab have become a privileged space for social interactions and historical discussions.

We have used historic tools and symbols, text and images (photos, illustrations), which did offer to the student the opportunity to interact with the object, facilitating the establishment of relations, the knowledge construction and the diagnostic of development zones. To facilitate and encourage social interactions between students in the classroom, we propose that during the class the activities were conducted in groups of 4 or 5 students, under guidance of the teacher.

Thus, the individuals will own the signs that are used in a specific social context when they interact with the social environment. Through this interaction, signs make sense and meanings can be compared with those shared inside the group. The process can be started by a History of Science narrative and continued in the lab. History of Science allows one to determine the potential and real development zones of the students. Of course, their misconceptions and previous knowledge can be determined too. In our context History of Science play a trigger role of interaction between the students and the laboratory play an instrumental role mediating the interaction between students and their object of knowledge. History of Science mediates the meaning construction and lab made the technical mediation to acquire data [27].

The final meaning will be the result of social interaction. At this point, we should return to the criticisms of constructivism: If the final meaning was gotten by social interaction only, any conclusion or theory, which students consensually arrive, is a good conclusion or theory. In Science a good theory is able to provide accurate descriptions and good predictions *i.e.,* good conclusions or theories should bring a system's description, tell us what will happen in a future specific situation and explain what did happen in the system past evolution. Reality there should be independent. We hope our students could be closer to the Newtonian thought about movement than before to interact with History of Science and Lab technical mediation.

III. METHODOLOGY

Historically, two world models evolved from the Greek formulations until the seventeenth century and each step of this evolution lead to a correction of these concepts, presenting an increasing level of sophistication in their ability to explain the world. These adjustments are supported by a growing philosophical and technological complexity [27].

We can also place these transformations in a Piagetian context: the changes that led to the profiles formation can be considered as a series of balances and imbalances requiring the construction of new patterns of assimilation, which allow the accommodation of new knowledge in the individual's cognitive structure. We can infer from the historical evolution how to disrupt the student's cognitive structures by a series of balances and imbalances, and how the historical process of knowledge production can be used in the classroom teaching-learning process [20].

Vigotskii's thought can also be used in the analysis of social and linguistic mediations that allowed this conceptual development. Moreover, the student's world experience should mediate him/her relationship with the historical development of ideas. An example of this mediation can be seen in the student's responses when presented to the Ptolemaic system of the world: rejection and misunderstanding. The students' reasoning based on the grounds of that they already had seen in elementary school and on television, is that the Copernican system is correct.

How should we relate Bachelard's concept of technological mediation to Vigotskii's socio-linguistic mediation? Accordingly, we advocate that technological mediation allow one to obtain information on the object to be known, as the sociolinguistics mediation will permit negotiation of the meanings contained in this information. The limits of this process are defined by what should be a good theory.

A. Classes description

We have worked with first year three agro technician high school class: class 101, 102 and 103 into Agricultural Technician School Nilo Peçanha at Universidade Federal Fluminense (University Federal Fluminense) in Pinheiral City – RJ, Brazil. Students in those classes have 100 minutes a week in Biology, Chemistry, Physics and lab practices.

The class 101 was composed by 29 students and was divided in six groups with 5 students each except group VI with 4 students. All groups at class 101 had participated in the discussions on the topics covered in handouts. Some students agreed with the points raised. Those who disagreed with these points had started a debate about the meaning of physical concepts related to movement: common sense concepts, technical concepts and scientific concepts. These concepts and other social influences had to be negotiated between students groups and between students and teacher [4].

The class 102 was composed by 21 students and was divided in 4 groups, 3 groups with 5 students and group IV with 6 students. Groups I, II and III had always been involved in the class work. These groups had participated effectively in all discussions proposed. Group IV had to be convinced to work out their tasks. This group looked apathetic, disinterested, and unpleasant. Its behavior started to interfere in other group's performance and the teachers need to draw attention and require commitment of their members.

The class 103 was composed by 21 students and was divided in 5 groups: group I and group II with 5 students each, groups III and V with 4 students each and group IV with 3 students. All groups in this class were involved in the class work. These groups had participated in classroom discussions as much as the class 101 groups. At least one student showed interest in doing all the work alone, which was not allowed, because the different students and group's views should be shared and a common view had to be negotiated [3, 4]. However the questions after lab were answered individually.

Three descriptive texts were distributed between the students. In these texts, the thoughts of Aristotle, Ptolemy, Copernicus, Brahe, Kepler and Galileo were presented and a short questionnaire at the end of each text was proposed. The texts were worked out in a sequence of three weeks and the students answered the questionnaire with their own point of view. In the next phase, students took three laboratory classes to carry out the Galileo's inclined plane teaching experience. The experience was carried out in two steps: a manual measure with a stopwatch and a ruler, and a computer based measure.

To compare measures and lab results with questionnaires answers was the students' task. At this stage, student's beliefs on historical results and understanding of movement were very large. However, they had developed many doubts about Galileo's procedures after their own manual measures be done. The comparison of low accuracy students' first manual measures with the measures made with water clocks by Galileo convinced the students that the interpretation of results and conclusions supported by them and defended by Galileo might not be possible to obtain in 17th century. At this point students were presented to Settle's 1961 paper [28]. According to the author, Galileo's experiment, as described in Dialogues Concerning Two New Sciences, are precise enough to prove the direct proportionality between distances and squared times. Students had used texts by [29, 30, 31] to get in contact with Aristotle, Ptolemy, Copernicus, Brahe, Kepler and Galileo's ideas. The questionnaires answered by the students after the discussion of the movement concepts in the History of Science follow below:

A.1. Questions for discussion – first class

1- List and describe the points where you agree with Aristotle.

2- List and describe the points where you disagree with Aristotle.

3- According to Aristotle, heavier bodies should fall faster, as they seek their natural place with more urgency than light bodies. Do you agree? Why?

4- Following Aristotle's Mechanics, Ptolemy developed a cosmological system in which the Earth was the center of the universe and was at rest. Do you agree with Ptolemy?

5- According to Ptolemy, "to throw a stone right up, I noticed that this always returns to us. If the earth moves to the east, the stone inevitably fall to the west of us". It is not what is observed. Do you agree? Why?

A.2. Questions for discussion – second class

1- The heliocentric system proposed by Copernicus contradicted Aristotle's Mechanics without giving an alternative. Why was it accepted as truth?
2- What do you think about Kepler's 1st law?
3- Kepler's 3rd law is a mathematical law. So we can conclude that "discover the hidden mathematical laws governing the universe from the apparent observed data chaos" became the goal of modern science. Do you agree? Why?
4- Do you agree with the four steps proposed by Galileo to support modern science?

A.3. Questions for discussion – third class

1- Did Galileo's pendulum show experimental evidence that two bodies of different weights fall together if left in the same time?
2- Galileo made important observations with a simple telescope. What do you think of the three points mentioned in the text? Do they prove that Copernicus heliocentric theory is correct?
3- Using an inclined plane Galileo did experiments to prove that the falling speed was not constant and was independent of the body's mass. What should be measured to achieve this goal?
4- What do you think about the concept of inertia proposed by Galileo? Why?

B. Experimental procedure

This class was held into the didactic lab in the day reserved to Interdisciplinary Laboratory [32]. The first three groups in each class performed the inclined plane experiment. The teacher started the lesson saying that the aim was to compare Galileo's ideas and results with the Aristotle's ideas. They had studied in the earlier Physics class and presented the material available to perform the experiment: a PVC pipe with some holes, a ruler, a scale, a stopwatch and some marbles that can be the mouse one or the ping-pong one.

Still questioning what should be measured and how to carry out the measurements to verify the Galileo's statements. The students could repeat the experience as often as they felt necessary and recorded the data obtained in tables and graphs. Students spent fifteen minutes reading the final text provided by the teacher (where there was a brief description of the experiment performed by Galileo) and discussing the questions suggested by the teacher, to start the experiment. All groups agreed, after discussion, that they should measure the mass of the ball, the distance between the holes in PVC pipe and the time spend for the ball through two holes, which were fixed with a distance of 20 cm between. None of the groups proposed measure and perform the same experiment with different balls, *i.e*. balls of different weights and sizes. All groups performed the first experiment with the PVC pipe inclined, supported on the notebooks. After that they did the measurements with the PVC pipe in a horizontal position, to make a comparison and to verify if both speeds were constant (as Aristotle said) or different, with increasing velocity in the inclined plane, as Galileo believed.

All groups had great difficulty in performing the measurements of time, as the intervals are very short between two consecutive holes. Each group adopted different strategies to accomplish the task. The groups set up the tables to record the measured values of the position and time. After getting data, the students were encouraged to construct graphs and tables for our review. Next lesson the experiment was repeated with computer aided data collection and the construction of graphs and tables was made in real time. Both results were compared and question about difficulties that Galileo and his predecessors must have had to obtain data to allow a reliable interpretation has been raised.

B.1. Questions for discussion - after lab

1- Explain the Aristotle's conceptions of movement.
2- Explain the geocentric system proposed by Ptolemy. Why he survived so many centuries?
3- Copernicus proposed the heliocentric system contrary to the views of Aristotle. Look for an argument (or experience) that the Earth is at rest.
4- Name two observations made by Galileo to prove the Copernicus theory.
5- What are the changes introduced by the Kepler 1st law? How important are these changes?
6- What are the changes introduced by the Kepler 2nd law? How important are these changes?
7- Using an inclined plane Galileo did experiments to prove that the falling speed was not constant and not dependent on body mass. What should be measured to achieve these goals?
8- Galileo, through a thought experiment, proposed that if a boat is moving straight and uniform and a stone is dropped from the top of the mast, where should it fall? For Galileo the rock fall at the foot of the mast (ii) while the Aristotelians maintained that it falls behind the foot of the mast (i). Who was right, Galileo or the Aristotelians?
9- According to Aristotle, "rest in the natural place is the final stage of all earthly bodies and to move a body, will always be necessary for a violent action. When the cause (force) is finished, the body must stop. Do you agree with this statement, why?

IV. RESULTS

In this session, we present the student's answers to proposed questions before and after lab activities. At the same time we analyze the two sets of answers and their relations with our theoretical basis.

A. Answers before lab

A.1. First class – Ptolemy and Aristotle's mechanics

In this first lesson the students were presented to Aristotle's ideas on motion over earth's surface and in heavens for discussion in small groups. The Ptolemy geostatic model was also presented. During the activity various groups interrupted the reading on text specific points; these points correspond to the emergence of doubts and differences between them. In most cases, the presence of the teacher was requested to clarify these questions. After much discussion, the main questions were pacified. The students began to answer the questionnaire where the responses that the group agreed should be written.

In the following we will analyze the student's responses for the first question: all groups in the three classes, agreed with the Aristotelian definition of motion. According to Aristotle, there were two distinct kinds of movement: natural produced by internal causes and the violent, produced by external causes and are opposed to natural movements. Natural movements, in turn, were also two kinds: radial descendants or ascendants, to earthly bodies and uniformly around a circle to the heavenly bodies. The violent movements are those that oppose the natural movements and are always caused by external actions. So, if you throw a stone up, it will move away from its natural place, but once the action is exhausted, it will start the fall, seeking its natural place. The final state of all earthly bodies is the rest on their natural place. To move a body, it will always be necessary a violent action (force). For Aristotle, there isn't inertia, it ceased the movement cause (force), and the body will stop.

The group VI of the class 101 was the only exception and said:

"*We don't agree with Aristotle's theories because we couldn't find logic in his definitions*."

For this group, Aristotle's definitions are very different they had studied about movement in the elementary school science class. They didn't agree with them.

The group II of class 101 and group III of class 103, also agreed with the idea that a body moves to find its natural place in the universe. They had included the four elements water, earth, fire and air also cited by the groups V of classes 101 and 103. Only the groups IV of classes 101 and 102 agreed with the Aristotle's statement "heavier bodies should fall more quickly, since it most urgently seeks their natural place." We can see that the Aristotelian conceptions of the movements are still present in almost all groups. We should note that in groups IV of classes 101 and 102 these conceptions are more strongly established because these groups had accepted that heavier bodies should fall faster than lighter because of urgency to reach its natural place.

Regarding the second question, all groups disagreed with the Aristotle's statement:

"*A body can only take one movement at a time, so that a projectile that is thrown inclined up has a straight path upward until the initial action is exhausted, then when the body will fall down*."

All groups disagreed with th stating that:

"*This is not the movement of a ball when it is kicked up*," in soccer games for example.

Group I of class 101 disagreed that to move a body we need for violent action,

"*Because natural movements are possible as well as a body that is already in motion continue in motion unless an opposing force acts on it, causing it to stop*."

Again this group disagrees with Aristotle. They had already learned about the law of inertia, because this issue has been studied previously in elementary school.

Only the group III of class 101 disagreed that the Earth is the center of the universe, saying:

"*Aristotle thought the earth was the center of the universe and everything was attracted here, but we know that is the opposite, that is, the Earth is not the center of the universe and what makes objects fall is gravity. And for us the sun is the center*."

Groups IV of the three classes have clashed,

"*When he says that there isn't inertia he contradicts himself. In addition to not knowing the two forms of inertia*."

The group V of class 101 also disagreed on that point, saying:

"*The existence of inertia: for a body in MRU that has zero natural force, will remain in motion until to be stopped by an external agent*."

Concerning the third question this group also disagreed with the point:

"*The heavier body falls first, because it depends on its volume and not on its mass*."

Groups I, II and IV of the class 101, I and II of 102, I, II and III of 103, agree that:

"*Heavier bodies should fall more quickly, because it most urgently seeks its natural place*."

The group I:

"*Because a heavy body is denser than air so it gets speed and goes so fast to its natural place*."

The group II states:

"*Because the heavy bodies the tendency is to get faster its natural place*."

The group IV:

"*Because the more weight the object has, the faster it tends to fall. This is because the more weight it has more speed it gains to fall*."

Groups III and VI of the class 101 disagree that "*heavier bodies should fall more quickly, because it most urgently seeks its natural place*."

"*Because gravity exerts different forces at the same speed and because the gravitational force exerts the same force on bodies of different weights*."

Groups V of class 101, III of 102 and V of 103, also disagree, but for another reason:

"*It depends on the volume not on the mass that body has*."

These last five groups do not have clearly defined the concepts of force, gravity and weight, indicating that these groups need to be worked to clarify these concepts. It is important to report that in the midst of a discussion between the teacher and the two groups on this issue, a student of the group V of class 101 rose, and taking a sheet of paper and a notebook said,

"*Which one comes first to the ground when dropped from the same height at the same time?*"

Then she puts the paper over the notebook, raised both and released, and everyone found that the paper and the notebook fell together, *i.e*. bodies of different masses had fallen from the same height at the same time.

The answer to the fourth question was a unanimous vote to deny the geostatic system of Ptolemy, because they had already studied the Heliostatic Copernicus system in elementary school. Groups I, II, IV and V of 101 and 103 classes, say that:

"*The sun is the center of the solar system where Earth is in continuous rotation and translation*."

Group III of class 101 disagrees with Ptolemy:

"*Because he thought that any object thrown up should fall back to the center of the universe. We do not think so, because we know that this action is the result of the force exerted by gravity on the object and because we also know that planet Earth is not at rest, but moving*."

The group VI of class 101 disagrees:

"*Ptolemy's thought was pointless because he did not know if the universe was finite or infinite, and the earth moves constantly even we feel these movements.*"

This group did not specify what they meant by "no logic" and not justified in saying that "we feel these movements," which probably means some conceptual confusion.

In the fifth question of the first hand out groups I, II, IV and VI of the class 101 disagreed with the proposed ideas. The other two groups in this class agreed. In classes 102 and 103, groups I, II and III disagreed with the argument in question, and groups IV in both classes and group V of class 103 agreed. The argument used to disagree is:

"*Because no matter the side on which the earth moves. it tends to return to its natural place*."

In other words, they had used Aristotle own ideas to challenge Ptolemy. The groups III and V of class 101, groups IV of class 102 and 103 and group V of class 103 agreed with the ideas in the last issue on the first hand out. They argue that:

"*Because, according to this idea of Ptolemy, when we throw the stone up, while it was moving vertically, the Earth would move to the east and the rock would fall to the west. The stone relatively to space would be in the same place, but in relation to the Earth it would have changed its place*."

All groups disagreed that "*you can only have one kind of movement at a time*". It seems to show a further imbalance in their conception of movement. To contribute to this discussion, the teacher asked:

"*a coin was thrown up in a bus moving with constant velocity, would it fall into the hands of those who thrown up? Or would it fall behind him?*"

Again, the discussions had intensified, with some students agreeing that:

"*the currency would fall into player own hands and some students saying that if it were a ball of paper it would fall behind, because it is very light and the wind can throw it back.*"

A.2. Second class - the heavens revolution: Copernicus, Brahe and Kepler

In the second class we had worked the contributions of Nicholaus Copernicus (1473 - 1543), Tycho Brahe (1546 - 1601) and Johannes Kepler (1571 - 1630). The students were separated into groups, the same as the first class and had received a handout distributed by the teacher to begin reading. As the groups had progressed in reading, the discussions were also intensified, requiring the teacher's presence to guide, organize, or add some detail. In the next step, the students tried to find a consensus to respond, in writing, the questions posed at the handout's end.

Looking at the first question posed we had revised that as studied in the previous lecture Ptolemy had developed a geostatic cosmological system based on Aristotle's ideas about celestial motions. Copernicus on the other hand proposed a heliostatic cosmological system. However without physics that supported his ideas. There were several advantages of Copernicus' model over that of Ptolemy:

1- It could predict planetary positions to within 2°, the same as that of Ptolemy.

2- The relative motion between them and the Earth explained retrograde motion of planets.

3- Distances between planets and the Sun could be accurately determined in units of the Earth-Sun distance (*i.e*. Astronomical Units).

4- Orbital periods could be accurately determined.

5- It explained the difference between the inferior planets (Mercury and Venus) that were always observed close to the Sun and the superior ones (Mars, Jupiter and Saturn).

6- It preserved the concept of uniform circular motion without the need for equants.

7- It preserved Aristotle's concept of real spheres nestled inside one another.

8- Unlike Ptolemy's model, it did not require the Moon to change in size.

Copernicus' model also had several problems that contributed to its failure in immediately supplant Ptolemy's model:

1- No annual stellar parallax could be detected. Copernicus explained this, as because the stars were a vast distance hence any parallax would be very small and difficult to detect.

2- It required a moving Earth, This would contradict Aristotelian physics and Copernicus presented no new laws of motion to replace Aristotle.

3- By removing the Earth from its natural place, it was philosophically and theologically unacceptable to many scholars.

4- It was no more accurate than Ptolemy's in predicting planetary positions was.

5- It was actually more complicated then Ptolemy's model. In his efforts to avoid, the equant but retain uniform circular motion he had to introduce more devices to fit his observations.

So Copernicus wrote [29]:

"*Mercury runs with 7 circles in total, Venus runs with 5 and the Earth runs with 3, around the Earth the moon with her 4,* *and finally Mars, Jupiter and Saturn with 5 each. So in the universe 34 epicycles are enough, with which is explained the whole structure of the world and the dance of the planets. At rest, however, in the midst of all this is the Sun. Who would place the lamp in another or better place than this, which it can illuminate everything at the same time?*"

Although we need more circles to describe the system developed by Copernicus, the students perceived it as simpler as and easier to use than Ptolemy's system. The groups' replies on this issue had reinforced the ease and simplicity of this system over the previous. Few differences had occurred between the answers. Groups III and IV of the classes 101 and 102, and the groups I, IV and V of the class 103, said that:

"*People tend to believe in the heliocentric system proposed by Copernicus because it was simpler to understand than Ptolemy and Aristotle's system. And also its use was easier.*"

Groups I and II of classes 101 and 102 and the groups II and III of class of 103, said that:

"*Copernicus showed that his theory was useful and appropriate and easier to use, where the Earth would move around the Sun, which remains at rest. However, it did not solve the three basic problems of heliocentrism: to show that the Earth moves, to develop a not Aristotelian Mechanics and to establish a theory of gravity*."

The group VI of class 101 has responded foolishly different:

"*Basically it can be considered true. Because he didn't believe that the epicycles exist. He had created a theory that contradicted the Aristotle's theory, however at that time he could not prove it because there were no scientific experiments*."

Therefore, no group showed a response that corresponds to the system developed by Copernicus, showing only the simplicity and ease of use of this system in relation to Ptolemy's system.

The second question, on the first Kepler's Law, all groups agreed, because:

"*it proved that the orbit was not a perfect circle, but an ellipse having two focus where one of them was the sun and the other was empty, breaking the Aristotle's theory*;"

"*Because the idea of a perfect universe it was denied. It was believed that the trajectory of the planets was in a perfect circle, but this belief was changed in an elliptical path.*"

At this point, there were difficulties. The understanding what means an ellipse and an elliptical path became a necessary task to solve. The teachers' expertise was essential to demonstrate and exemplify this geometric figure. All groups had assimilated it. Once we overcome this initial problem the assimilation of the Kepler's first Law was done. The assimilation of the Kepler's second Law was easier after the first Law had been done. The assimilation of the Kepler's Laws was observed in all groups by observing the interaction between its components and the interaction between the groups and the teachers.

The third question on the Kepler's third Law was the harder to students understand. Despite all groups difficulties to understand this law, they all understood the importance that Mathematics has in modern science practice combined with observational measures and laboratory support to legitimate a scientific theory.

"*Yes, because it became the predictions more correct, for example, the eclipse which had reduced the margin of error at the time of Kepler*;"

"*Yes, because when scientists are searching for something, they use mathematical methods to prove the experiment. This method has proven to be essential for the study of modern science*;"

"*Yes, because all the research related to space discoveries are made through Mathematics*;"

"*Yes, because at these times scientists use to apply mathematical calculations to solve any kind of problems*."

The fourth question also was unanimity in the groups' responses; we can see some answers transcribed below:

"*Yes, because the theories which we are led to believe today are based in the four principles proposed by Galileo*;"

"*Yes, because these Galileo 4 proposed statements say that for all research there is the need to carry out experiments to try to prove it*."

A.3. Third class – Galileo experiments and the inclined plane

In this session we had developed the work focusing on the experiences made by Galileo Galilei (1564 - 1642) and the experiments necessity to prove a theory. The students were separated into groups, the same as the first and second class and had received a handout distributed by the teacher to begin the reading. As the groups progressed in reading, the discussions were also intensified, requiring the presence of the teacher to guide, to organize, or to add some detail. Next, the students tried to find a consensus to respond, in writing, the answers of the questions posed at the end of the handout.

The first question was concerned with Galileo's pendulum use to prove that "two bodies of different mass fall together if abandoned at the same time and height." Against Aristotle's idea that had claimed that "heavier bodies fall faster because it has more urgency to reach their natural place." The Aristotelian view was accepted by some groups (groups I, II and IV of class 101, groups I and II of class 102 and groups I, II and III of class 103) as observed in responses to question 3 of the first class handout. By examining the questionnaire responses of this class, we found that some groups have changed their opinion, but not all. At first eight groups had agreed with this statement. Three groups remained in agreement, the groups II of the three classes. Their views are expressed as follows:

"No, because the greater the mass of a body is the faster it will reach the ground, the experience of the Pisa's Tower is a myth, we don't known if it was done;"

"No, it is obvious that a stone and a piece of paper dropped from the same time and height, the stone comes first than the sheet of paper to the floor."

We should emphasize that the handout do not mention at any time the experience of the Tower of Pisa, this information was included for any member of the group. All other groups agreed with Galileo in relation to the pendulum's experience, as we can see in the transcripts below:

"Galileo was able to prove that the two pendulums went up and came back together proving that the Ptolemaic theory was false;"

"Yes, because as an light object as a heavy object spend the same time to reach the ground, and both are caused by the same action (gravity);"

"Yes, because gravity is exerted in the same way in both stones the lighter and the heavier;"

"Yes, because the mass don't matter, the wire length and the wire vertical angle are the important parameters."

We can see that students already use gravity as an explanation for falling bodies and that the four transcripts are complementary, that is, if different mass does not interfere with pendulums movement, this means that the claims of Aristotle in relation to falling bodies were incorrect.

Concerning the second question all groups agreed with the conclusions drawn by Galileo from the three observations made with the telescope. Groups III of classes 102 and 103 defended the view that the first observation, where Galileo stated that "the Moon's surface is rough and irregular and not smooth and perfectly spherical as previously believed,"

"It did prove neither the Ptolemy's theory nor Copernicus's theory."

The telescope made it possible to observe "satellites rotating around Jupiter", *i.e.*, the observations with the telescope had contradicted Aristotle's statement "that all heavenly bodies revolved around the Earth, the center of the universe", in addition, the phases of Venus indicated that it should revolve around the sun, as Copernicus said.

"Yes, if the Jupiter satellites revolve around it, we find that not all the celestial bodies revolve around the Earth (contrary to Aristotle's idea that everything revolved around the Earth). Also if Venus has phases like the Moon, it confirms that it rotates around the Sun, because the Sun sends its rays in all directions."

We feel therefore that the observations made by Galileo were not sufficient to demonstrate that the heliostatic system developed by Copernicus offered better results than that of Ptolemy. However it was sufficient to show that Ptolemy's claims were not true.

On the third question, all groups stated that:

"Should measure the angle of plane inclination to horizontal, the masses of different balls, the distances and times which balls was spent to walk through defined distances."

Groups I, II and IV of class 101, groups I and II of class 102 and groups I, II and III of class 103 described the procedures that should be followed to see if the falling velocity was constant or not, as we see in the responses of this question:

"for an angle chosen and fixed, we should set up proportional distances, let the ball down several times from the same point and measure the time taken to travel each distance;"

The groups II of class of 101 and 102 and group III of class 103 added that:

"This procedure should be repeated for balls of different masses."

These groups had accepted the scientific method proposed by Galileo. It is necessary to define a problem (falling bodies), to formulate a theory / prediction to be checked (fall speed constant or variable mass interferes or not), completion an experiment with a variation of the parameters (inclined plane, pendulum, distances, times and masses) and, finally, comparing the data obtained from the experiment with the theory / prediction proposal.

Concerning the fourth question the assimilation of the concepts in also occurred because all groups agreed the mistake Galileo was:

"To consider circular paths."

And the groups I, II and III of classes 101 and 102 and groups I and III of the class 103 added that:

"Galileo probably continued to believe in the perfection of the circle."

Groups IV of classes 101 and 102 added that:

"For an object that is moving to perform a curve it is necessary to apply a force."

A.4. Answers after lab

After we had carried, lab experiments out the students answered individually a new set of questions related to last class contents. Some students dislike answering the questions alone because the previous activities were done in groups.

The first question: Explain the Aristotle's conceptions of movement are discussed in the following:
Considering the three classes, 91.5% (65 students) divided the movements into:

"Natural and violent, specifying for terrestrial bodies the need for an external agent acting on the body so that it enters and remains in motion."

Compared with the handouts responses, we found that this question was almost a unanimous agreement with Aristotle conceptions, except for group VI of class 101. On the motion of celestial bodies, only 56.3% (40 students) responded on the uniform circular motion of bodies, saying that:

"For the Greeks the circle was a perfect figure and the sky's movement should be perfect, i.e. in the sky all movements are circular."

Regarding the second question: Explain the geocentric system proposed by Ptolemy, and why he has survived so many centuries?

On the Ptolemy's geostatic system, 84.5% (60 students) explained the scheme developed by him:

"With the Earth stop in the center and the planets and the Sun turning in a circle with constant speed around Earth," and 63.4% (45 students) said:

"It was forbidden to question the authority of Aristotle, so it took so long for his ideas were challenged."

We found that modern concepts about the Solar System was accommodated on this point because the groups did not accept and did not understand the system proposed by Ptolemy because the Copernicus heliostatic system was studied in elementary school.

Regarding the third question; Copernicus had proposed the heliocentric system. It was in opposition to Aristotle's views. Look for an argument (or experience) that the Earth is at rest.

The argument most often cited by students, with 53.5% (38 students), can be read below:

"When we play a stone up, it comes back of our hands, proving that the Earth stands still."

Because if you were in motion the stone would fall to the side and not in our hands. This Aristotelian argument has been modified, as we shall see in the answers of question 8. In this question, a stone dropped from a tall mast of a ship moving rectilinear and uniform, falls at the foot of the mast and not behind. To carry out a change in this concept the teacher has put the following question:

"If you throw a coin up in a bus that moves with constant speed, where it will fall?"

This question has caused much discussion within the groups and allowed the imbalance necessary for a process of change to be initiated. The second argument most often cited in the third question, with 39.4% (28 students), was:

"If a heavy body search, so urgently, in its natural place (Earth) is more than reasonable to assume that this point is the center of the universe, i.e. the center of the earth."

This argument was also modified, as we shall see in the question 7. The Galileo's inclined plane experience was very important to change this view. The pendulum experiment was not conducted with the students but helped the teachers to reach a positive feeling about non-Aristotelian concepts. Five students (7%) did not answer this question.

Regarding the fourth question; Name two observations made by Galileo to prove the Copernicus theory.

The two most cited comments by the students in this question were:

"The satellites rotating around Jupiter,"

77.4% (55 students),

"The phases of Venus (like the Moon phases),"

63.4% (45 students) and 56.3% (40 students) cited:

"The Moon's surface rough and uneven and not smooth and perfect as the Aristotelians claimed."

All students answered this question, but 42.3% (30 students) mentioned only one of the arguments above. Any of the arguments cited above cast doubt on the perfection of the celestial movements advocated by Aristotelian.

Regarding the fifth question: What are the changes introduced by the 1st Kepler law? How important are these changes?

84.5% (60 students) said that the first law was revolutionary because:

"The paths of the planets are no longer circular but elliptical,"

i.e., the circle as a perfect figure worshiped by the Greeks ceased to be the trajectory of the planets. Six students (8.4%) did not answer this question and 5 students (7.0%) had confused with the second law, stating that:

"Heavenly bodies closer to the Sun acquired higher speeds and lower speeds farther."

Any of the above arguments breaks the Aristotelian paradigm of celestial motion, *i.e.*, the celestial motion ceased to be circular and uniform.

Regarding the sixth question: What are the changes introduced by the 2nd Kepler law? How important are these changes?

Regarding the second law of Kepler, 77.4% (55 students) said that was revolutionary because the planets:

"No longer have constant speeds, getting faster speeds when the planets are closer to the Sun and smaller when they are more remote."

Again six students (8.4%) did not respond and five students (7.0%) confused it with the first law.

With respect to the seventh question: Using an inclined plane Galileo did experiments to prove that the falling speed was not constant and not dependent on body mass. What should be measured to achieve these goals?

Only five students (7.0%) did not answer this question. However, 93.0% (66 students) stated that:

"it should measure their masses, times and distances,"

and 49.2% (35 students) suggested measuring

"The plane inclination angles,"

and described the procedures that should be followed to achieve the Galileo's goals, that is, to prove that the speed of a falling body is not constant and is independent of its mass.

With respect to the eighth question: Galileo, through a thought experiment, proposed that if a boat is moving straight and uniform and a stone is dropped from the top of the mast, where should it fall? For Galileo the rock fall at the foot of the mast (ii) while the Aristotelians maintained that it falls behind the foot of the mast (i). Who was right, Galileo or the Aristotelians?

This was the most difficult question for students to respond because it was not discussed in-group in the classroom. Each student had to think alone about the scenario. Moreover, this issue raises questions about the need for an external agent acting on a body so that it continues to move, espoused by Aristotle and accepted by almost all groups (except group VI class 101) in the first phase of work. Even so, 63.4% (45 students) stated that:

"the rock would fall at the foot of the mast making clear the air resistance presence,"

as defended by Galileo, while 28.2% (20 students) stated that:

"the stone would fall behind the foot of the mast,"

as well as the Aristotelian, just like when we played up a ball of paper inside a moving vehicle, it does not fall into our hands. Six students (8.4%) did not answer this question. A significant number of students, as most agree with Galileo, taking into account air resistance.

With respect to the ninth question: According to Aristotle "rest in the natural place is the final stage of all earthly bodies and to move a body, will always be necessary for a violent action. When the cause (force) is finished, the body must stop. Do you agree with this statement, why?

This was the most important question in order to verify a conceptual change related on the need for a force acting on a body so that it is in motion, *i.e*., when the force is finished the movement is finished, championed by Aristotle and confirmed by almost all groups, with the sole exception of group VI of the class 101 in the first class time. We can see that conceptual change was achieved as 84.5% (60 students) stated that:

"you only need a force (or external agent) to put a body in motion, if stopped, or to increase or decrease the speed of a body already in motion."

On the 84.5%, 49.2% (35 students) used the inclined plane experience to justify their answers, stating that:

"In the horizontal plane we need only a push to put the ball in motion and it assumes a constant speed without the need to keep pushing as long as the friction is very small. In the inclined plane the ball speed increases as it descends because weight force acts at all, or if there is force acting on a body its speed is increased, that is, acceleration is present."

V. DISCUSSION

In this section we are going to discuss our classroom experience results. We have done a categorization of Aristotle ideas. These categorizations helped us to interpret student's answers and support our conclusions.

1- There are two kinds of movement: natural brought by internal causes and violent brought by external causes.

2- There are two kinds of natural movements: radial that can be ascendant or descendant in the Earth and uniform around a circle in the Heavens.

3- Natural and violent movements are in opposition.

4- Natural movements are for bodies reach their natural place.

5- Bodies seek their natural place; water and earth seeks ground while fire and air seeks heavens.

6- To have a violent motion we need an external action. No external action, no violent motion.

7- The final state of material bodies is rest in their natural places.

8- Bodies do one kind of movement each time.

9- Heavier bodies should fall faster than lighter, because they have urgency to reach their natural places.

10- Earth is in the center of Universe. Bodies falling should seek the center of the Earth.

11- When we play a stone up, it comes back of our hands, proving that the Earth stands still.

12- Celestial bodies are perfect spheres.

These categories helped us to build some graphics.

The student's ideas about movements were tested using History of Science and inclined plane experiment showing in a first time that students think like Aristotle was thought. They advocated that material bodies have a natural place where to go, and natural movements bring material bodies to its natural places. The M.C.U. is a natural movement because it is the celestial body's movement. A celestial movement should be circular and perfect. Almost all students had defended that bodies movement is caused by an external action (force). If external action stops, movement stops too. Any movement directed out to natural places requires an external action and is called violent. Horizontal movements do not come to any natural places. They are violent movements too. The four elements Water, Fire, Air and Earth were used to justify these points of view. Figures one, two, three and four show the evolution of the students conceptual profiles before lab.

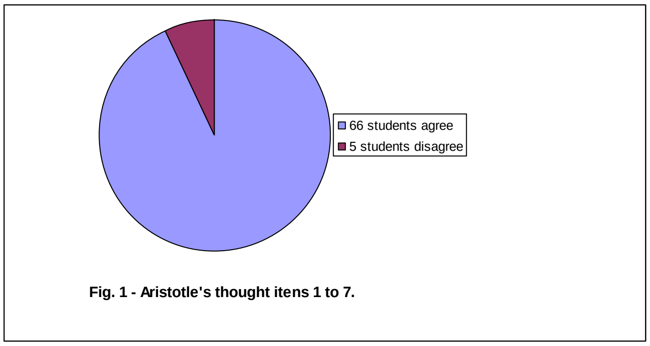

FIGURE 1. Number of students agreeing with Aristotle before lab considering items 1 to 7.

The group VI of class 101 had disagreed with Aristotelian point of view because the students in this group had already studied movement ideas before. The students had disagreed of the Aristotelian hypothesis "a body thrown up in air makes each time one kind of movement, and take an inclined straight path until its maximum height. After this point bodies free fall to its natural places." The argument they were used to disagree is "when a ball is kicked up the observed movement don't match."

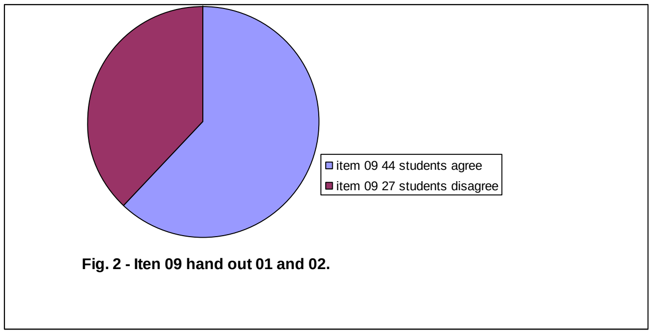

FIGURE 2. Before lab more students agree heavier bodies should fall faster than lighter.

The student's main disagreement was free fall: "heavier bodies fall faster because its needs to reach its natural place is bigger than lighter bodies," and "a body vertically thrown up fall in the same place it was thrown because Earth is at rest in the center of the Universe." The students were divided in order to answer about these two statements in the first two classes. In the third classes, we put these points again through the two pendulums thought experiment. After this class only three groups continued by saying Aristotle was correct. At this point previous education and extra-school life had gotten words and resources, which the teacher had not already used. The example is the Tower of Pisa experiment, which students believe to be a myth whose results were not trusted. The friction was introduced directly or not when students had suggested experiments to be done in order to clarify concepts about free fall as "drop together a sheet of paper and a notebook and look if they reach the grounds at the same time or not" as a student into group V of 101 class done. This suggestion was repeated by groups II of the 3 classes in the third handout activity where a stone and a sheet of paper were dropped together and the stone was supposed to fall first. The weight and gravity concepts were used fuzzy and naively by the students in their reasoning to deny Aristotelian point of view. Mass, density and weight were confounded showing students need to work hard these concepts. We should remark all groups agree with inertia is a real thing, however only 4 groups had used the inertia concept before the third handout. A criticism is done related to Galileo's stubbornness trying to maintain heavens circular movement because it is perfect and celestial bodies moves with constant speed. At least, one group advocates that to get a circular motion an external action is necessary. It seems for us that this concept was in the zone of proximal development for around 50% of the students on the evaluation after lab.

The other 50% seems to be reached the Newtonian concept of inertia [33, 34].

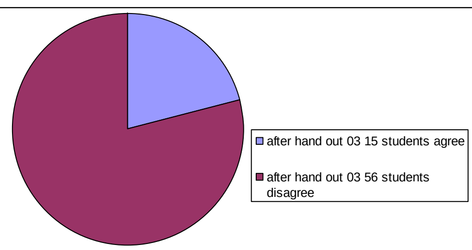

Fig. 3 - Iten 09 hand out 03.

FIGURE 3. After hand out 03 and before lab students change their thought. Heavier bodies aren´t faster than lighter.

The students were able to talk about each model or concept of movement after the activity had finished although not at all were in the zone of real development. A conceptual profile about movement was created on the students. We hope that this construct could help to change to zones of real development richer.

The heavens were discussed in all 3 classes. The Aristotelian view and its Ptolemy improvements were compared with Copernican view and its Kepler improvements. The students denied Aristotle and Ptolemy points of view because they had already known that Earth spins around itself and rotates around the Sun continuously. The Earth isn't in the center of the Universe and of course it is not at the center of the Solar System. The Sun is not in the center of the Universe and of course, it is not at the center of the Solar System even though the folks use to say that it is there. Sun is at rest in one focus of the elliptical planetary trajectory. Even though the Copernican model could be harder to understand that Ptolemy's model, students realize the Copernican model simpler and easier to use than Ptolemy's model. The Galilean observations with the eyepiece were accepted without conflict. Galileo's point of view after these observations were trustful, but it could not be used to deny Aristotle/Ptolemy beliefs or to legitimate Copernicus model of the world. Here another conceptual profile was created.

The Nature of Science and the scientist's work should be criticized after the four Galileo's rules for good Science had been discussed. Mathematical modeling and observational/experimental data test should be done to become trust Science results. Scientists use Mathematics to solve any kind of problems. Nowadays Science is a consequence of Galilean rules. After the second inclined plane experience had been done and data obtained with clocks and rules has been compared with which was obtained in real time measures using a computer, students realize the first procedure was unreliable. They doubt Galileo was able to get the information he claimed using water clocks or pulse counting to measure time. We showed to students Settle's 1961 paper where a description of an experiment following Galileo's steps and using Galileo's technology gets results that could be interpreted as Galileo did. Figures five and six provide support our conclusions after lab.

History of Science was a good tool to provoke discussions between the students about movements, solar system structures, Nature of Science and so on. By the time, History of Science had permitted to realize that students in this school lifetime have already brought social influences and previous knowledge that can't be ignored. The ideal epistemic individual in this age and school instruction there is not.

VI. CONCLUSIONS

In this work, a description is made of a classroom experience to teach movements with help of History of Science and the lab. We had presented the history of movement concepts from antiquity to the seventieth century revolution, aiming to show that the construction of scientific knowledge is a process, as we believe that Science Education should show to students how this process happens. A historical approach is necessary to show to the students that Science evolves and this has been a non-linear evolution.

Researchers in Science Education know that historical conceptions and common sense conceptions are the same in non-educated individuals [20]. Some conceptions show a great resistance to change, inclusive in well-educated individuals. Movement conceptions are in this situation. To teach and learn the laws of movements we need to consider their historical evolution and the coinciding points with common sense conceptions. An epistemological profile is built and the epistemological obstacles are determined. The first three classes show this process, students became knower of Aristotle, Ptolemy, Galileo and Kepler’s ideas. Their discussion in groups allows us to determine the coincidence points and the negotiation of meanings determine the obstacles. The lab introduces a disequilibrium factor. How they can get to the equilibrium again? It is necessary to build a new assimilation scheme to accommodate the new knowledge.

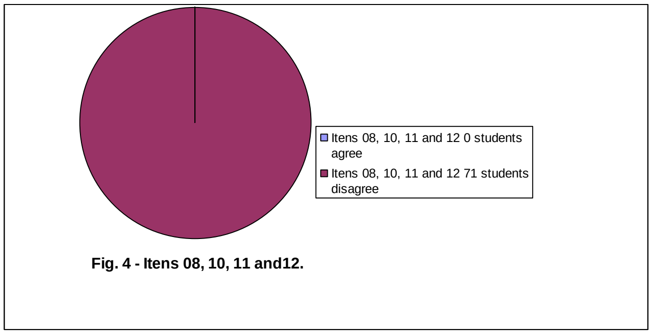

FIGURA 4. All students criticize Aristotle and Ptolemy on Solar System motions. Students had brought modern concepts about Earth movements before lab and hand out activities.

The laboratory represents the technical mediation between individual and object. Conceptual discussion based on lab information and historical facts with negotiation of meanings proceeds to build the new assimilation scheme and the final accommodation. Previous knowledge brought by the students is not replaced, but included in the epistemological / conceptual profile. A conceptual change will be accomplished after knowledge is majored. We think that the student's answers to the nine questions after lab, when compared with the questions worked out in class, confirm our theoretical understanding. In this work, we tried to bring the students to the ideas about movement, developed in ancient and early modern science, and to discuss the meaning of these ideas for the men that advocated it. Our results show that in the beginning a significant percentage of our students thought as antiquity's men. An experiment was planned and performed to answer whether the predictions made by Aristotle and Ptolemy with his theory of motion, or Galileo and Kepler with their world models agreed with lab results.

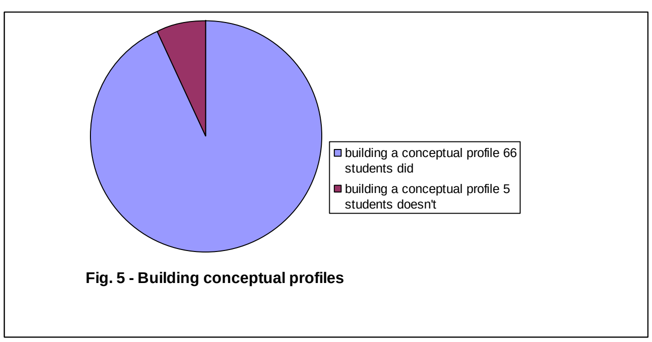

FIGURE 5. After lab a conceptual profile was created. Students were able to describe Aristotle, Ptolomy, Copernicus Galileo and Kepler´s thought, although someone had stayed Aristotelian.

The result shows that the History of Science is of great help to discuss ideas and scientific concepts and allows the teacher to know what the students' conceptions are and should be considered in the teacher's planning. Our results could be compared with Lopes Coelho's results [35, 36] and agree with Seroglou and Koumaras[37], Heilbron[38], Kalman[39] and Kalman and Aulls[40] who have advocated inclusion of History of Science inside Physics teaching. Moreover, it is clear that use of the laboratory should take place after the theoretical model is built, not before. The laboratory serves as a place to test how theoretical models work and to evaluate the accuracy of the measurements. The measurements consistency with the theory scope is obtained from the lab.

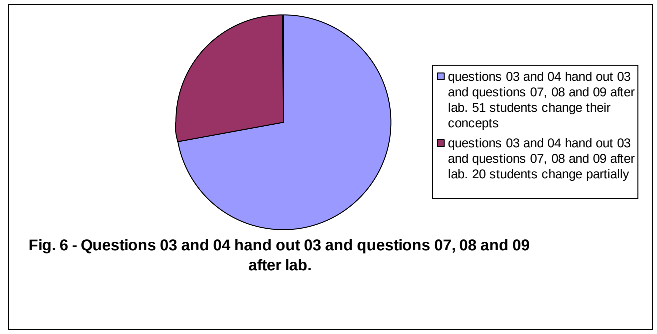

FIGURE 6. After questions 03 and 04 in hand out students had started a discussion about Methodology and Nature of Science. They agreed Mathematics is in grounds of modern Science and Galileo´s rules to make good science are used yet. In the last questions after lab they had used the inclined plane experiment to reason against Aristotle and support Galileo and Newton´s rules.

An analysis of the student's answers seems to show that a conceptual profile [25, 26] was build related to movement concepts. Students can identify clearly Aristotle, Ptolemy, Copernicus, Galileo and Kepler ideas and choose the Kepler/Copernicus model of Solar System in contrast with Aristotle/Ptolemy system. The principle of inertia needs more work for at least the 20 students that answered the eight question using Aristotelian concepts.

The 35 students that had used the inclined plane to justify the answers to question nine seems to be in a Newtonian zone of real development or in a Piagetian point of view they had accommodated the concepts of motion and are in a equilibrium state. It seems for us that we were well successful in use lab and History as educational tools to teach movement concepts. The other 36 students that didn't reach the Newtonian stage can be in a zone of proximal development or in a Piagetian point of view they need new assimilation schema to accommodate motion concepts. The disequilibrium caused by comparison between historic beliefs and experimental results, even though it isn't violent, couldn't provoke a new equilibrium for these students. However a conceptual profile was created to become easier to reach the new equilibrium state in the future. The teachers should follow these students until their education is completed. The use of History of Science had permitted a discussion about the Nature of Science. Students are committed with Galileo's rules to make good science. They believe that modern science is a consequence of these rules and scientists use Mathematics to solve all kind of problems. They believe lab experiments and observational data should be compared with theory to legitimate it.

Finally we hope that this paper could help any teacher to realize he can do good teaching and why not good science using simple tools.

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