Students' ideas about Blaise Pascal experiment at the Puy de Dôme Mountain

Cécile de Hosson[1], **Bénédicte Caillarec**[2]
[1]Laboratoire André Revuz, department of physics, University of Paris Diderot-Paris7, France.
[2]Collège Jacques Prévert, Gaillard, France.

E-mail: cecile.dehosson@univ-paris-diderot.fr

(Received 20 April 2009; accepted 16 May 2009)

Abstract

In 1647, Blaise Pascal suggests to raise Torricelli's mercury barometer at the top of the Puy de Dome Mountain (France) in order to test the "weight of air" assumption which can be considered as the primitive form of the air pressure concept. This experiment, conducted in 1648, takes place in the backdrop of the controversy surrounding the existence of vacuum and is variously interpreted. Thus, the "weight of air" assumption as a cause of the variations observed during the ascent of the Puy de Dome is not unanimously approved among the scholars of the seventeenth century. We find a similar difficulty among students interviewed after instruction: they struggle in considering Torricelli's device as a measuring instrument associated with the changes of the air pressure**.**

Keywords: Pressure, history of science, students' reasoning.

Resumen

En 1647, Blaise Pascal sugiere levantar el barómetro de mercurio de Torricelli en lo alto de la Montaña Puy de Domo (Francia) para probar lo que se conocía como: "el peso del aire", la suposición de lo que puede ser considerada como la forma primitiva del concepto de presión atmosférica. Este experimento, conducido en 1648, ocurre en el telón de la controversia que rodea la existencia de vacío y es interpretado de forma diversa. Así, "el peso del aire" como una suposición de la causa de las variaciones observadas durante la subida a Puy de Domo unánimemente no es aprobado entre los colegiados del siglo decimoséptimo. Encontramos una dificultad similar entre estudiantes entrevistados después de la instrucción: ellos luchan en contra del dispositivo de Torricelli, considerandolo como un instrumento de medición asociado con los cambios de la presión atmosférica.

Palabras clave: Presión, historia de la ciencia, razonamiento de estudiantes.

PACS: 01.40.Fk, 01.50.My, 01.65.+g **ISSN 1870-9095**

I. INTRODUCTION

The advantages that could be gained from the history of science have been the target of a wide current of researches in science education over the last decades. First influenced by philosophers and psychologists, some researchers focused on a revival of Piaget's "cognitive ontogeny recapitulates scientific phylogeny" thesis [1] and early questioned the psychogenesis of individual learning and the development of scientific thought as following parallel paths [2]. In this context, similarities between students' ideas and ideas staged in the past have been evidenced [3, 4] and discussed [5]. After years of researches and findings, history of science providing the teachers with the difficulties that pupils should face while learning science is now admitted. In that perspective, we question the difficulties that underlie the explanation of the torricellian barometer (figure 1) and its use by Blaise Pascal at the Puy de Dôme Mountain.

II. HISTORICAL GUIDELINES

The rise of the air pressure concept fell within the scholar community of the seventeenth century in the backdrop of the controversy surrounding the existence of vacuum. This controversy was inherited from Greek science and revived by Galileo in 1638. In his Discourses *Two new sciences*, Galileo reported that a suction pump could not raise more than about 10 meters lengths of water. Because of the Aristotelian doctrine "Nature abhors vacuum" asserted that vacuum could not exist, it was believed that the water was raised by the horror of vacuum: the water was drawn in to fill up a space that otherwise would be empty. But beyond ten meters high an empty space was formed that water refused to fill. Until the seventeenth century, this was explained by an idea widely supported by the scholastics authorities: the loathing expressed by the nature for vacuum (for water) was limited to about ten meters. In 1644, Evangelista Torricelli suggested a new interpretation of this phenomenon: the limit of pumping up the water lied in the effects of the weight of air. Torricelli thought that the level the water stayed at (thirty-four feet – ten meters-) was reflective of the force of the weight of air pushing on it (specifically, pushing on the water in the basin and thus limiting how much water can fall from the tube into it).

The mercurial barometer device (figure 1) was performed in order to test the "weight of air" assumption that can be considered as the primitive for of the atmospheric pressure concept. It consisted of a glass tube, sealed at one end, filled with pure mercury and inverted in a basin of mercury. The mercury in the tube sunk slightly, creating above it a free space (the torricellian space). The barometer device relied on the idea that the mercury column standing at a height of about seventy-six cm above the level of mercury in the basin was balanced by the weight of the "sea of air" pressing on the surface of the mercury. With this experiment, Torricelli established a **causal link** between the action of the atmosphere and the suspension of the mercury in the tube.

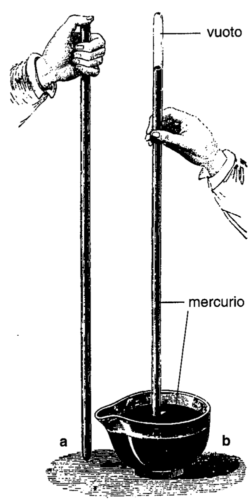


FIGURE 1. Torricelli's experiment. A glass tube (closed at one end) was fulfilled with mercury. Then, after closing the mouth of the glass tube, Torricelli tipped it upside down in a basin also containing mercury. Uncovering the mouth of the tube, the column of mercury only partially fell down, creating above it a free space (the torricellian space).

This interpretation was echoed by Blaise Pascal who assumed the weight of air assumption as a turning-point for an original experimental program based on a method of variations. The question was not to evidence the existence of vacuum anymore but to test the weight of air assumption making the external conditions vary. For Pascal, if the column of the mercury inside the tube was dependent on the weight of air, it should decrease during the ascent of a mountain. Indeed, the weight of air is weaker at the top of a mountain because there is much more air hanging over the bottom than over the top of a mountain. In 1647, Pascal wrote to his brother-in-law, Florin Perier, living near the mountain called the Puy de Dôme (France). Perier was instructed to take a barometer up to the Puy de Dôme and make measurements of the column of mercury along the way. He was then to compare it to measurements taken at the foot of the mountain to see if those measurements taken higher up were smaller. In September 1648, Perier carried out the Puy de Dôme experiment and found that Pascal's predictions were correct. The mercury column stood lower the higher one went. Pascal assumed that the change in the weight of the atmosphere was the cause of the change in the mercury column contained in the glass tube. But this interpretation did not end the controversy surrounding the existence of vacuum. The weight of air assumption was rejected by scholars such as Father Etienne Noël, Hobbes or Linus convinced that the air was too light-swing against the weight of a seventy-six cm mercury column.

The elaboration of the "fluid" idea (unifying both liquids and gases) as an environment endowed with material properties (like a non-zero mass) played a determining part in the conceptual processes conducted by both Torricelli and Pascal. In his letter to Ricci, Torricelli compared the atmosphere with a "sea of air" that would have properties similar to those of a sea of water [6]. The conceptual approach of Pascal relied on the same analogical process. In 1663, Pascal published two treaties: the *Treaty on the equilibrium of the liquors,* and the *Treaty on the weight of air*. In the first treaty, Pascal characterized the action of an immersing liquid (the water, in this case) on a solid immersed, by specifying two essential properties: "liquids weight following their high" and "water acts on immersed solids by pressing them on every side" [7]. In the second treaty, Pascal endowed the atmosphere with properties identical to those of the water: because the air has a non-zero mass, it is lighter and less dense in altitude rather than at the sea level and its action is also exerted in all directions. This construction formed the origin of the hypothesis of the "gravity of air" that was tested by Pascal then by Boyle in experiments where the variations in the amount of the outside air played a foreground part [8]. A few years later, a similar reasoning based on the analogy between air and water led Edme Mariotte to reaffirm the assumption of the atmospheric pressure. In his treaty concerning the *Nature of the air*, he suggested to immerse the barometric device into the water at different depths [9]. The changes in the mercury column consecutive to this immersion being of the same nature as those found by Pascal and Boyle in the air confirmed the effects of the action of air.

We will show that the controversy surrounding the historical development of the air pressure concept during the seventeenth century reveals resonances with students' difficulties concerning the role of the air pressure in Torricelli and Pascal experiments.

III. RESEARCH BACKGROUND

There are numerous researches concerning children's ideas about air pressure. An interesting synthesis of the main results of theses researches can be found in the Henriques report presented at the NARST conference in

2000 [10]. While keeping in mind the work on the youngest ideas on air and its action on objects [11, 12] we summarize here those that are specifically dedicated to students' reasoning about pressure. These results take part in the framework of our questioning.

The unifying concept of "fluid" doesn't always seem to be operational for students: if most of them rightly assert that the pressure increases with depth in liquids [13], some incorrectly think that the atmospheric pressure increases with the altitude [14]. However, some difficulties arise equally for liquids and gases: the pressure in a fluid is usually confused with the forces exerted by the liquid [13], it is often associated with the volume of the fluid surrounding a immersed solid and not only with the depth (or altitude) [15], and its action is widely seen in one direction (usually down) [12, 13, 16]. In addition, "vacuum" is sometimes seen as an entity endowed with some mechanical properties as aspiration [11, 17]. Furthermore, most of young people are struggling to admit its existence [18].

We wonder to what extent these ideas form obstacles to the understanding of Pascal experiment at the Puy de Dôme Mountain, and to what extent they are close to ideas staged in the past.

IV. OVERVIEW OF THE RESEARCH

The creation of the Puy de Dôme experiment by Blaise Pascal and the interpretation of Torricelli's barometer are based on the establishment of a causal link between the action of the outside air and the suspension of the mercury in the glass tube. This link requires knowing about the properties of air (including its weight). In this research we wonder to what extent students who learnt about hydrostatic perceive Torricelli's device as a barometer. To do so, we will answer the three following research questions:

- Do the questioned students accept the existence of a causal link between the air pressure and the suspension of the mercury contained in the glass tube?
- If they do so, do they associate the action of the outside air with the emptiness of the Torricellian space?
- If they don't, what kind of reasoning do they perform?

The research was conducted through the analysis of students' answers to written questions posed after instruction on hydrostatic laws. 128 students spread over three different French science universities were questioned during years 2006 and 2007 (*i.e.* 22 during year 2006 and 106 during year 2007). All of them are third-year University students involved in a future primary school teacher course. They all studied the concept of pressure in upper secondary school and hydrostatic laws during their first-year University.

To answer these questions, we developed a paper-and-pencil test from the Puy de Dôme experiment (appendix). The test is presented as a support for an inquiry. In the first question (Q1) the students are asked to explain Torricelli's experiment. This request is supplemented by a question about the nature of the torricellian space (Q2). Finally, the students are asked to interpret the outcome of the experiment at the top of the Puy de Dôme (Q3). The answers to the test are analyzed in an inductive way according to the principles of the Grounded Theory [19].

The expected answers can be sum up as follow: the mercury in the vertical tube is balanced by the outside air. The pressure exerted by both the outside air and the mercury column at the same level on the surface of the mercury in the basin is equal (answer to Q1). Since the atmospheric pressure decreases with altitude, the mercury column is lower in altitude (answer to Q3). Concerning question Q2, answers such as "vacuum", "nothing" or "gaseous mercury" will be considered as correct although we know that the Torricellian space is not really free of any matter: this region contains a small amount of vapor, which itself exerts a pressure on the liquid in the closed tube. But the vapor pressure of mercury is so low (0.0017 torr at 25 ^{o}C) that it can be neglected.

We first conducted an exploratory study with twenty students in order to emphasize major trends of reasoning. This preliminary study prevailed on us to highlight explanations involving sub-part of the Torricellian device. The definition of these sub-parts has enabled us to identify groups of answers where the interactions between several sub-parts take a determining role. Thus, we divided the Torricellian device in four sub-parts as described in the figure 2. It appeared that few students considered the device in a global way by including the action of the outside air in their reasoning.

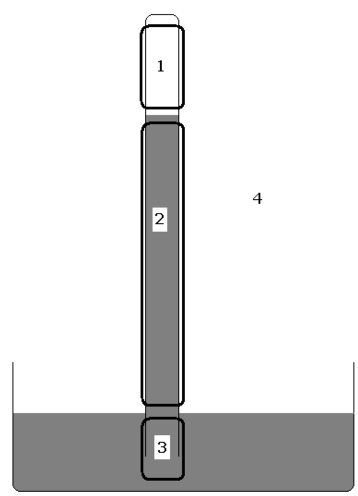


FIGURE 2. Sub-parts of the torricellian barometer used by some students in their explanations. Sub-part 1: Torricellian space (Torr), sub-part 2: mercury contained in the glass tube (Hg tube), sub-part 3: mercury contained in the basin (Hg basin), sub-part 4: The atmosphere (Air).

The former subdivision allows us to analyze the answers to questions Q1 and Q3 with respect to the following headings:

- Answers that explicitly establish a causal link between the action of the air on the surface of the mercury in the basin and the partial descent (or suspension) of the mercury in the tube. In those answers, the outside air is mentioned, the mercury tube as well. The vocabulary used by the students describes a situation of balance between both air and mercury. These answers are coded as follows: "Air / Hg (tube)”.
- Answers in which the mercury column appears as a central element in the reasoning of the students. Its suspension and its variation are explicitly linked to the action of another sub-part of the system (that may be either the Torricellian space or the mercury in the basin) or a variation of an experimental setting. These are local answers coded as “loc”. They exclude the outside air.
- Answers reduced to the single use of the word "pressure". Considering the test, these answers don’t inform the researcher on the reasoning process underlying. These answers (coded as “pressure”) remain hard to interpret: they are not analyzed.
- No answer or “I don’t know” answers quoted as “NA”.
- Answers that can’t be classified coded as «Others».

V. RESULTS ANALYSIS

In this part, we will first give an overview of the major outcomes of this investigation. Then, we will look at these results by adopting a more comprehensive viewpoint as we focus on the coherence of students’ answers to all three questions. These results will then be put into perspective with historical elements.

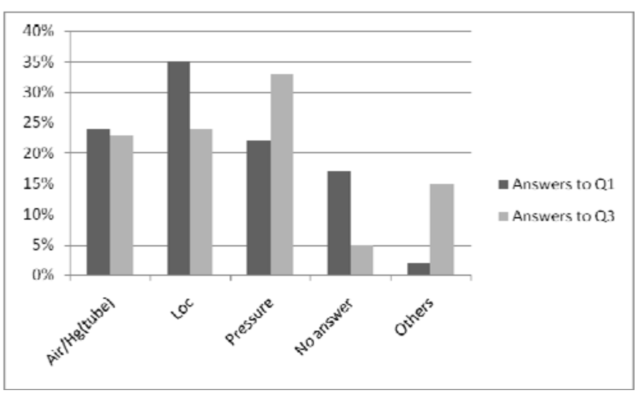


FIGURE 3. Distribution of the answer to Q1 and Q3.

In figure 3 we present the distribution of the answers given to questions Q1 and Q3. The role played by the atmospheric pressure in both suspension and changes of the mercury column doesn’t seem obvious for the questioned students. Indeed, only less than a quarter of them provide an answer to Q1 and Q3 combining explicitly the action of the outside air and the suspension (or the variation) of the mercury in the tube. A lot of students (22% out of the answers to Q1 and 33% out the answers to Q3) explain the suspension and the variation of the mercury column using the only word “pressure” and have no indication concerning the nature of this “pressure” and the way it acts. 17% do not answer Q1. This percentage decreases in Q3 (5% out of the questioned students do not answer to Q3). Fifteen (out of 128) students who did not answer to Q1 give a “pressure” answer to Q3. The description of the experiment and the result obtained by Pascal might have influenced their answer (this experiment is usually introduced during the lesson concerning the pressure concept). Moreover, in the “others” answers we find tautological sentences where the variation of the mercury column is only associated with the variation of the altitude.

A non-negligible part of answers to questions Q1 and Q3 (45 of the 128 responses to Q1, and 30 of the 128 responses to Q3) reflects local or partial reasoning. Some of them are based on the setting up of links between two sub-parts of the barometric device, even though it would require a rather global approach, or at least, an approach combining an element out of the barometric device (the outside air) and the device itself. In this regard, we were able to pinpoint three major types of explanations:

- Explanations located on the mercury column itself (Hg(tube), table I). In this case, the reasoning implemented by the students involves outdoor conditions (temperature, pressure) responsible for the decrease in the initial volume of mercury. The variation of the column during the ascent of the Puy de Dôme Mountain comes from a contraction due to the change in pressure or temperature, or to a change of state, but it is not the result of the fall of a part of it in the basin.
- Explanations setting up a link between the action of a substance contained in the Torricellian space and the variations of the mercury column (Torr/Hg(tube) in table I). In this case, the substance contained in the Torricellian space pushes the mercury down. This action is higher at the top of a mountain as the pressure increases with altitude according to students. These explanations are consistent once the hypothesis of the increasing pressure is raised, and they cannot be refuted by the outcome of the experiment.
- Explanations based on an action between the mercury in the basin and the one in the tube (Hg(tube)/Hg(basin) in table I). In the latter case, the interface between the two “mercuries” is a physical limit itself: the mercury in the basin plays the role of a media and sustains the mercury column. This explanation seems inadequate to explain what happens during the Puy de Dôme ascent: two-thirds of the students using it in Q1 renounce in Q3.

In table I we sum up the links made by students between the different sub-parts of the barometric device. The criteria for classifying these answers are also specified.

We now focus on the perseverance of the students’ type of reasoning for Q1 and Q3, and its link with the nature of the Torricellian space content in response to Q2. A significant number of students persevere in maintaining their reasoning across the test. Table II below reflects this perseverance: it shows the distribution of the students who suggest a certain type of answer in Q1 (Torr/Hg(tube) link, for example), and who maintain it in Q3. In this table we can see that 21 (out of the 128) answer by implementing a causal reasoning that combines the action of the outside air and the suspension of the mercury in the tube all along the three questions of the test. All these students give a correct answer to Q2, that is "vacuum", "nothing" or "gaseous mercury". But the converse is not true. Thus, all the students who answer "vacuum" or "nothing" to question Q2 (62 out of 128) don't necessarily explain the suspension of the mercury column by the action of the outside air. For 37 out of them, the reason for the suspension concerns either the action of the mercury in the basin or the action of a physical parameter as the pressure or the temperature.

TABLE I. Criteria detained for grading students local answers to questions Q1 and Q3 depending on the sub-system under consideration.

Sub-part(s) & description	Criteria of classification detained
Hg (tube): The mercury in the tube	The decrease of the mercury column is associated with a decrease of the volume of this mercury in the tube for an identical amount of mercury in the tube. In those answers, we mark the influence of parameters such as the "pressure", the "temperature", the "gravity".
Torr/Hg(tube): Action at the interface between the torricellian space and the mercury in the tube:	The Torricellian space acts on the mercury in the tube. This action is marked by the use of expression such as "something pushes/appeals/detains… the mercury in the tube".
Hg(tube)/Hg(basin): Action at the interface between the mercury in the tube and the mercury in the basin:	The mercury column is "detained" by the mercury in the basin. In those answers, the "mercuries" of the two vessels are distinguished and explicitly interact.

12 students (out of the 128) explain the variation of the mercury column by establishing a link between the Torricellian space and the mercury in the tube. According to these students, the Torricellian space contains a material substance (which can be "air" or "a gas") that pushes on the surface of the mercury column: this action increases with altitude since the pressure increases with altitude. Even if these reasoning appear minority they lead to a very consistent interpretation of the experience of the Puy de Dôme: the presence of a substance in the Torricellian space fits here with the result of the experiment.

The answers focusing on the mercury column or involving the unique word "pressure" remain quite permanent. At last, only 4 among 15 keep on relying on a link between the mercury in the basin and the one in the tube from Q1 to Q3. In these cases, the answers to Q2 are not significant.

TABLE II. Distribution of the students who suggest a certain type of answer to Q1 and maintain it to in Q3. "Non-significant" means that the answer to Q2 can be correct or false. No link can be established between these answers and answers to Q1 and Q3.

Type of answer given by the students	Answers to Q1	Answer to Q1 & Q3	Nature of the Torricellian space
Air/Hg(tube)link	**25**	**21**	**"vacuum" or "nothing" or "gaseous mercury"**
Hg(basin)/Hg(tube) link	15	4	Non-significant
Torr/Hg(tube) link	**13**	**12**	**"Air" or "gas" or "gaseous mercury"**
Answers focusing on the mercury in the tube itself	17	14	Non-significant
Answers involving the word «Pressure» and nothing else	28	28	Non-significant

VI. DISCUSSION

The reasoning used by the students in their answers to our test reveal difficulties associated with the concept of pressure. These difficulties remain imbued with well known misconceptions. Thus, the fact that over three-quarters of the surveyed students do not explicitly take into account the action of the outside air to explain the suspension of the mercury column and its decrease suggests that they are struggling to accept the existence of the atmospheric pressure. This result is comparable to those obtained by Séré 20 years ago with pupils of secondary schools. For most of them, the atmospheric pressure is only recognized when the air is compressed or when it is in motion [11]. Some studies on students' ideas about air pressure have revealed a tendency to believe that it increases with altitude [14]. We find a similar trend in 10% of students involved in our study. However, we did not find an answer giving the vaccum properties such as "aspiration" as this could be the case in researches with younger students [16]. The persistence of certain difficulties about the atmospheric pressure revealed by our survey leads us to turn again to the history of science, particularly to the structure of the explanations given by the opponents to Pascal and Torricelli.

Scientists who fight Torricelli and Pascal's ideas focus on the nature of the Torricellian space. Doing so, they consider Torricelli's device in an intrinsic and local way. Similarly is it for students who don't take into account the outside air. However, differences emerge on both sides. The presence of a substance in the Torricellian space allows these students to explain the partial fall of the mercury in the tube. In other words, what seems surprising for these students is that mercury does not remain entirely within the glass tube. Conversely, the same argument was used by some critics of Pascal in the mid-seventeenth century to explain the suspension of the mercury in the tube. As an example, the Jesuit Francis Linus was committed to the principle that nature abhors vacuum. So committed, he posited not only an occupant of the Torricellian space but also a role for that occupant to play in the Torricelli's experiment. The occupant is the *funiculus*, a thread formed as the mercury column dropped; its role in stretching between the surface of the mercury and the top of the tube is to hold the mercury column up [20]. An asymmetry appears here between the reasoning of the questioned students and those of some scholars of the seventeenth century. Nevertheless, the Torricelli's experiment is not convincing to unequivocally evidence the existence of vacuum, neither in the scholar community of the mid-seventeenth century, nor among our students, but the reasons are on both sides, different.

The Puy de Dôme experiment allows to question students' ideas in the field of hydrostatic, but because it is misunderstood, it doesn't play the part of a crucial experiment neither in the learning, nor in the historical process: for the students we interviewed, it gives no evidence of the existence of vacuum (about half the students asserts that the Torricellian space contains something). Furthermore, it doesn't prove the existence of the atmospheric pressure or the way it changes with the altitude. I

VII. CONCLUSIONS

The Puy de Dôme experiment (as an extension to Torricelli's barometer), conducted in France in 1648 has been elaborated in order to test the hypothesis of the "weight of air" which can be considered as the primitive form of the air pressure concept. According to Blaise Pascal, the weight of air causes the suspension of the mercurial column. This experiment takes place in the backdrop of the controversy surrounding the existence of vacuum and is variously interpreted. Thus, the hypothesis of the "weight of air" as a cause of the variations observed during the ascent of the Puy de Dome is not unanimously approved among the scholars of the seventeenth century. Some scientists, strongly committed to the idea that nature abhors vacuum, establish a causal link between the substance contained in Torricellian space and the mercury. Thus, their reasoning are exclusively focus on the device itself. The outside air is not taken into account whereas it is known as having a non-zero mass. The interpretations involved in the scholar community of the seventeenth century led us to question how our students would understand the Puy de Dôme experiment. Our research shows that few of them set up a causal link between the action of the outside air and the suspension of the mercury column. The origin of this difficulty is quite different depending on whether we look at scholars of the mid-seventeenth or students' reasoning. For the scholars who criticize Pascal's views, the suspension of mercury relies on the *horror vacui* doctrine: the mercury in the tube doesn't flow too much so that vacuum can't take place at the top of the tube. Our students don't really subscribe to the *horror vacui* doctrine, but they struggle to consider the air as a fluid. This leads some of them to interpret the Puy de Dôme experiment with the idea that the pressure increases with altitude, even though they seem to have no difficulty to assert that the pressure in a liquid increases with the depth. For these students, liquids and gases seem not equivalent from a hydrostatic point of view. The setting up of this equivalence appears to be an important educational stake that could be supported by a specific reading of the hydrostatic works staged in the mid-seventeenth century.

REFERENCES

[1] Piaget, J. and García ,R., *Psychogenesis and the history of science* (Cambridge, NY, 1989).

[2] Carey, S., *Conceptual change in childhood*, (MIT press, Cambridge, 1985).

[3] Saltiel E. & Malgrange J. L., *Spontaneous ways of reasoning in elementary kinematics*, European journal of physics **1**, 73-80 (1980).

[4] Sanmarti, N. & Izquierdo, M., *The substantialization of properties in pupils' thinking and in the history of science*, Science and education **4**, 349-369 (1995).

[5] Saltiel, E. & Viennot, L., What do we learn from similarities between historical ideas end the spontaneous reasoning of students? *The Many faces of teaching and learning mechanics*, (Linjse ed., GIREP, Utrecht. 1985).

[6] Torricelli, E., *Letter to Michelangelo Ricci concerning the barometer (1644)*, Collected Works, vol. 3 (1919). New York.

[7] Pascal, B., *The Physical Treatises*, (Columbia University Press, New York, 1937).

[8] Boyle, R., *New experiments physico-mechanical touching the spring of the air and its effects*, (London, 1660).

[9] Mariotte, E., *Nature of air*, A Source Book in Physics (McGraw-Hill, New York, 1953).

[10] Henriques, L., *Children's misconceptions about weather: A review of the literature*, Paper presented at the annual meeting of the National Association of research in science teaching (2000) available in http://www.csulb.edu/~lhenriqu/NARST2000.htm

[11] Séré, M. G., *The Gaseous State* in R. Driver, E. Guesne & A. Tiberghien (eds.) Children's ideas in science, (Open University Press, London, 1985), 105-123.

[12] Engel Clough, E. & Driver, R., *What do children understand about pressure in fluids?*, Research in science and technological education **3**, 133-144 (1985).

[13] Kariotoglou, P. & Psillos, D., *Pupils' pressure models and their implication for instruction*, Research in science and technological education **11**, 95-108 (1993).

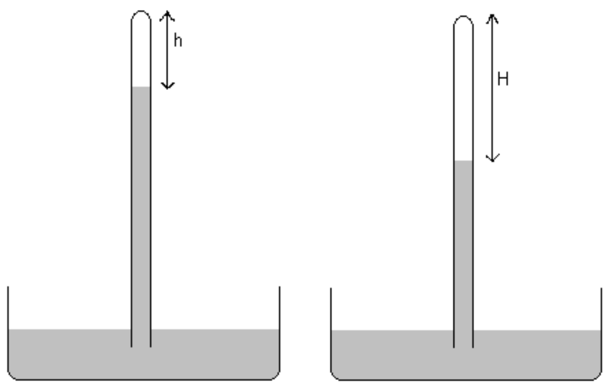
[14] Tytler, R. T., *Students' conceptions of air pressure: Exploring the nature of conceptual change*, International journal of science education **20**, 929-958 (1998).

[15] Viennot, L., *Teaching physics*, (Springer, USA, 2003).

[16] Smith, P. S. & Ford, B. A., Project Earth Science: Meteorology, Arlington, VA: National science teacher association (1996).
[17] De Berg, K. C., *Students' thinking in relation to pressure-volume changes of a fixed amount of air: The semiquantitative context*, International journal of science education **14**, 295-303 (1992).
[18] Nussbaum, J., *The particulate nature of matter in the gaseous phase*, in R. Driver, E. Guesne & A. Tiberghien (eds.) Children's ideas in science, (Open University Press, London, 1985), 124-144.
[19] Strauss, A. and Corbin, J., Grounded Theory methodology: An overview, In: *Handbook of Qualitative Research* (Denzin, N., K. and Lincoln, Y. S., Eds., Sage Publications, London, 1994). 1-18.
[20] Potter, E., *Gender and Boyle's Law of Gases*, (Indiana University Press, Bloomington, 2001), p. 298.

APPENDIX

Blaise Pascal, a physicist, mathematician and philosopher of the seventeenth century is much interested in the phenomena associated with fluids he calls "liquors". In 1648, he asks his brother-in-law Florin Périer, who lives in Auvergne, to carry out the following experiment at two different locations: a glass tube (closed at one end) is fulfilled with mercury. Then, after closing the mouth of the glass tube he tipped it upside down in a basin also containing mercury. Uncovering the mouth of the tube, the column of mercury only partially descends. The experiment is done first in the city of Clermont-Ferrand (around 400 meters high, experience 1 below) and second at the top of the Puy de Dôme Mountain (over 1400 meters high, experience 2 below). The mercury falls down more at the top of the mountain than in Clermont-Ferrand.



Experiment 1 Experiment 2

- Q1: Can you explain the result of the first experiment?
- Q2: What do you think there is in the space at the top of the tube above the mercury?
- Q3: How can you explain the difference between h and H?