The Invention of the Hot Air Balloon

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When we think of the hot air balloon, we think of adventure and power—but also of simplicity. After all, the hot air balloon—which does not have an engine—is virtually noiseless. The hot air balloon is also mysterious—how can a heavy basket attached to a gas-filled balloon rise into the air ‘all by itself’? Students will be will be motivated by the desire to understand ‘how it works’ as much as by the desire to discover how the inventors of the hot air balloon came up with the idea and managed to build their invention.

From mythology to play: how can man achieve flight?

From the fables of antiquity and the myth of Icarus to the machines imagined or designed by Bacon and da Vinci (the best-known of the early flying machines), man has always been fascinated by flight. Children also share the dream of flight, as demonstrated by their interest in playing with paper airplanes, party balloons and other such objects.

One way to begin the unit is by taking a survey of non-motorised flying objects with which students are familiar or with which they play. These might include paper rockets or airplanes, kites, balloons, para-gliders and gliders, for instance. This will familiarise the class with the topic and will allow the students to begin to identify certain characteristics.

The ‘how’ of flight is a question that will emerge early on in the activity. Students will quickly identify causes, such as the muscles of the hand that throws a paper airplane; the wind and tension on the string or rope for a kite or para-glider; the pull of another airplane for the glider, etc. However, children will have a more difficult time understanding the helium balloon, which is similar to the hot air balloon in that it appears to move through the air all by itself. It is this implicit association with the helium balloon that hinders children’s (and not only young children’s) understanding of the hot air balloon.

If, during the preliminary discussion, students mention airplanes or rockets, the teacher may put forward the presence of an engine (a combustion engine for the airplane; a propulsion engine for the rocket) in order to explain that, in these instances, movement is caused by a system that produces energy from combustion. This distinction may not be easy for children to make because, in the case of the hot air balloon, even though gas is burned under the opening of the balloon’s envelope, the balloon is not powered by a combustion engine (like that of a car). For a hot air balloon, the combustion of a gas serves only to heat the air contained in the balloon. When the gas is turned off, the hot air balloon does not suddenly fall out of the sky; it can continue to rise even after the gas is turned off. It will then come down gradually as the air inside the balloon cools off.

A ranking activity will help students to find their bearings and figure out which questions need to be asked. Children will identify the different factors to consider in the movement of non-motorised flying objects, such as the cause of movement, the shape of the object (a paper rocket does not glide like an airplane), or the type of material from which the object is made. They will also become aware of the enigma of movement when comparing the helium balloon to the hot air balloon. What makes them go up? Why don't they always stay up in the air? How do you steer them?

There are two ways in which the teacher can extend the activities included in this unit:

– Through history: Before the heat engine was invented, what means of flying did man imagine? This will provide an opportunity to examine how the first hot air balloon was made (see CD-ROM).

– Through science, with a number of different options that will be developed later on in this document: Why do helium balloons and hot air balloons rise up into the air all by themselves, while the balloons we blow up with our breath fall to the ground? Why do we heat the air inside a hot air balloon? Finally, how do balloons inflated with hot air or helium stay in the air without an engine?

Learning how to use observation

In order to understand how a balloon inflated with hot air rises into the air, children will need to overcome some existing mental schema that are often based on false beliefs. Students may believe that, in order to make any balloon rise into the air, all you need to do is inflate it. Likewise, the description of the hot air balloon will lead students to believe that the balloon flies away because it is propelled by the hot air inside it—this is a mechanical vision of the concept. This mechanical vision is inaccurate, however. Students are familiar only with traction mechanisms (using string, rods, etc.). In this case, they will have a hard time understanding 'what is pushing or pulling' the balloon. Students have not yet been introduced to Archimedes' principle, which is the key to understanding the process of ascension. This raises the need to create an opportunity for students to gain a qualitative understanding of floatation mechanisms in fluid.

Archimedes' principle

In order to introduce Archimedes' principle, the teacher may want to talk about the students' experiences at the beach or the swimming pool: Floating makes them feel lighter, like they are being lifted up, especially when they float on their backs. However, this concept is a complex one. It involves several factors at work simultaneously, which makes it a difficult concept to study at the elementary level. It is best to find a simple, qualitative approach to the concept, avoiding attempts to put forward any sort of formula.

To do this, the class may conduct a series of hands-on experiments in which they compare the influence of different factors taken two-by-two (the relationship between weight/volume/shape). The following experiments will provide basic problem-solving situations.

Experiment 1:

Materials:

– Five identical hard plastic cups (which will be referred to as 'cup 1')
– Clear plastic basins (10-litre) filled with water
– An electronic scale accurate to the gram
– Caster sugar, semolina, modelling clay, rice, fruit syrup.

In groups, students must gradually fill their cup—which has been placed in one of the water-filled basins—with sugar, semolina, etc., stopping before the cup begins to take on water. In other words, students must stop before the cup sinks (when the edge of the cup is at the surface of the water and the rest is under the surface or 'submerged'. Once this balance has been reached, students weigh the material in the cup.

The groups then compile their results. They generally observe that all of the groups obtain the same weight down to the gram, despite the fact that the groups filled their cups with different materials.

This will raise some questions. First of all, what would happen if the cup was made lighter? Students may then put forward their hypotheses and test them.

While doing this, each group measures the height of the cup that is above the surface of the water and correlates it with the amount of material they removed from the cup. Students can enter their results in a two-column table. Analysing the variation in height in relation to the decrease in the amount of material in the cup will allow students to draw the following conclusion: For a given volume (the cup), the lighter the mass, the higher the cup rises above the surface of the water (the class can then make a measurement table using the mass inside the cup/height above surface of water).

Experiment 2:

The materials are the same as for the first experiment, with the exception of the cups, which will be replaced by larger recipients (wider and higher), which we will call 'cup 2'.

In order to compare cup 1 and cup 2, the teacher can ask the class which one has the greater volume and what type of experiment would allow the class to check the hypothesis put forward. In general, the groups tend to fill cup 2 to the very top; when they pour the contents into cup 1, it of course overflows. The class could also use a measuring cup to measure the exact volumes of the cups.

This raises the following questions: What happens if you pour the amount of material that pushed cup 1 to its sinking point into cup 2?

Students will put forward their ideas ('It will sink', or, 'It will float better', etc.), carrying out the experiment (with the sugar, the semolina, etc., each group using the same material used in experiment 1) and making the following observations: Cup 2 floats to the surface of the water (it emerges) regardless of which material is used.

This will lead to the conclusion: For a given mass, the larger cup floats better.

These experiments will demonstrate to students the complexity of floatation while introducing them to Archimedes' principle. Importantly, this introduction to what the principle actually means in the real world is accomplished qualitatively by examining concrete aspects—without the use of mathematical formulae. Students will end up identifying and linking the two factors at work: volume and weight.

Up until this point, the class has worked with water and various materials: sugar, semolina, etc. The conclusions reached were valid regardless of the material used—now it is time to look at the same phenomena in the air.

The expansion of air

An experiment can be conducted to show that air expands when heated. You will need two identical glass bottles in order to conduct the experiment. Remove the caps or corks from both bottles and cover the mouth of each with a balloon. Place one of the bottles in a double-boiler. The teacher may opt to present the experiments to the whole class. However, the experiments are simple enough that groups of students can conduct them in front of their classmates.

The teacher should ask the students to compare the volume and mass of the two bottles. They are identical—both bottles are the same—and they thus contain the same amount of air. After several minutes, the class will see that the balloon placed over the mouth of the bottle in the double-boiler has begun to inflate. Why does this happen?

The students may then put forward their ideas, pointing out any differences they have noted between the two bottles. They may note that the air in the bottle placed in the double-boiler has been heated up. This will lead to the following conclusions:

– For a volume of air that is initially identical (the volume of air contained in the bottle), the balloon on the bottle inflates when the air inside is heated.

– If the balloon inflates, that means that the air in the bottle is moving upwards. In order for this to happen, the heated air must increase in volume (or ‘expand’).

– The volume of the system (bottle + balloon) increased even though no air was ‘added’. The mass of the system thus remained the same even though the volume increased (here, to clarify any confusion between mass and volume, the class can weigh the system when it is cold, and then when it is hot—but this must be done very quickly).

This will confirm the conclusion reached by the class during the previous activity. Given the same mass, the cup with the greater volume floated better.

Following some discussion, students will be able to imagine an ‘air bubble’ in place of the bottle. They will understand that, when heated, the air bubble will increase in volume. Therefore, just like with cup 2, which rose above the surface of the water due to its larger volume, the air bubble, larger in volume when heated, rises up into the air. But what about for the hot air balloon? The hotter the air, the lighter the mass contained in the volume and the higher the balloon rises—a hypothesis that can be verified by building a hot air balloon (see below).

When the air contained in the envelope of the hot air balloon is heated, it expands—in other words, it increases in volume. However, because the envelope does not expand, some of the air must escape through the opening. Therefore, the mass of the hot air inside the envelope will be smaller than when it was filled with cold air. Hence, a hot air balloon filled with hot air weighs less than a hot air balloon filled with cold air—this is what allows it to rise. However, when the hot air balloon rises, the air inside the envelope cools down and decreases in volume. Cool air from the outside makes its way into the envelope, the hot air balloon gets heavier and it descends.

Once students have mastered these concepts, the teacher can introduce the kinds of gas used (hot air for the hot air balloon and hydrogen for the balloon invented by the scholar Charles at around the same time). Students will understand (by referring to data on the gases used—1 litre of cold air weighs 1.3 g, while 1 litre of hot air weighs less than 1 g; 1 litre of hydrogen weighs a tenth of a gram—and calculations comparing the weights of equal volumes of different gases) that a balloon filled with hot air is heavier than the same balloon filled with hydrogen (the use of this gas was abandoned after the tragic explosion of the dirigible the Hindenburg in 1937).

The origins of the invention

The hot air balloon activity also provides an opportunity to show students that the invention of the hot air balloon was the result of the convergence of multiple processes: technological, scientific, economic and political. Looking at so-called ‘trail-blazing’ innovations offers a chance to reorient the traditional conception of individual genius toward a conception of collective thinking and development. Reading historical documents will allow students to review the different stages in the invention of the hot air balloon by examining the importance of a variety of different events that led up to the discovery.

It is interesting for students to know that, long before they began to work on the hot air balloon, the Montgolfier brothers had already taken an interest in and read several works on air navigation and the properties of gases. Here, it is useful to read the report submitted to the Academy of Sciences in Paris on the Montgolfier brothers' 'aerostatic machine' (see CD-ROM). The report shows the influence of prior research on their work.

The teacher can further play down the role of chance by telling students the story of Joseph's shirt drying by the fire. This event would not have been important if, at the same time, Joseph had not been thinking about how to fly while looking at an engraving of the Spanish siege of Gibraltar.

The results of the various experiments conducted shows the important role played by the Academy of Sciences in terms of certifying the discovery, and that of Louis XVI, who hoped that this promising discovery would enable him to carry out his plan for transporting men for military purposes—an idea shared by the members of the Academy, as demonstrated by the report mentioned above.

Finally, students will note that, in the 18th century, inventors were not necessarily scholars. Sometimes, an ingenious idea and perseverance took the place of scientific or technical knowledge. An examination of the long list of experiments conducted by the Montgolfier brothers, which resulted in a series of changes and improvements, will allow students to identify the qualities that enabled the brothers to reach their goal.

Building and testing a hot air balloon

The students have now studied the physics behind the hot air balloon. They now know how and why the hot air balloon rises without the help of an engine. The story of the Montgolfier brothers shows that they weren't able to make their machine 'fly' until they had mastered the scientific principles that explained how objects could 'float' in the sky. However, conceptual understanding and actual experience are two different things!

In this activity, students will reproduce a pre-existing model. This is because the activity presents a number of significant challenges—mainly technical—that can be quite daunting. What is more, the students will have to build their hot air balloon with everyday materials (the use of items similar to those used by the Montgolfier brothers adds a cultural dimension that children enjoy). The students will not be allowed to use any special tools or super glue. In order to build the balloon, they will have to cut carefully and make adjustments. Cooperation will be the key to completing the activity.

To ensure that the activity is successful, the teacher should divide the class into groups and explain the steps in building the balloon according to the usual process for this type of hands-on classroom activity. This gives students an opportunity to think about how to determine the tasks they will have to complete, the materials they will need, the different solutions available (such as the best kind of glue or paper to use), the steps to be taken in building the balloon and the delegation of work among group members.

Additional tips are available at:
http://www.inrp.fr/lamap/activites/air/idees/temoignage/montgolfiere.htm (Also see Cemea fact sheets available on line on the *La main à la pâte* Web site). [First link does not work. Perhaps provide link for Cemea fact sheets?]

The school in Gourgé followed this procedure:
Materials:

– Six sheets of coloured tissue paper
– Thin card
– A pair of scissors
– A pattern in the shape of half of a gore (students will use a total of six gores for the balloon envelope)

Instructions:

The hot air balloon today: a technique is reborn

Following the Montgolfier brothers' invention, all of Europe became infatuated with 'lighter-than-air' flying machines. The race for speed ensued and, with it, the aerostat Channel-crossing craze. Fierce competitiveness between Charles and Pilâtre de Rozier, a pioneering hot air balloon pilot, resulted in death. In order to increase his speed, Pilâtre de Rozier used a hydrogen balloon along with his hot air balloon in his attempt to cross the Channel. The balloon exploded, revealing the danger of balloons of all types. After the incident, hydrogen balloons were no longer used. Hot air balloons were virtually abandoned until the second half of the 20th century. This was due to the fact that it was not possible to carry enough straw (for fuel) to go as far as with a hydrogen balloon. At the beginning of the 20th century, Louis Godard invented the propane burner. However, the invention was not effective enough to make the hot air balloon truly useful. It was not until the 1960s, with the advent of new materials and, above all, the use of more powerful propane burners that hot air balloons came back into use.

Students may also research new uses for the hot air balloon. Today the hot air balloon is used for advertising or as a leisure activity for those who love to take to the air.

At this point in the unit, it would be wonderful if the students could see a contemporary hot air balloon in person if they have the opportunity. If not, they can still do some research into the structure of today's balloons. They will see how important new materials—non-flammable, light materials that stand up to high temperatures—have been in producing hot air balloon envelopes. They may also examine the characteristics of the burner and learn how it works.

The propane burner is very simple, in fact. The gas in the tanks is under pressure—therefore, in liquid form. It moves through an evaporation coil in which it expands and turns to gas, which can then be burned. The air in the envelope is then heated to up to 100° Celsius and the balloon becomes lighter than the same volume of surrounding air. The pilot's job is to turn the burner on at just the right moment. The burner does not stay on all the time. It is turned on and off, and the effects of the burner are felt around 10 seconds after heating. This means that the pilot must plan ahead and take into account the cooling of the balloon.