Chapter 3

Alexander von Humboldt's scientific work

"Ideen können nur nützen, wenn sie in vielen Köpfe lebendig werden"

Alexander von Humboldt, in a letter to a friend in 1799

Introduction

If one were to choose among the greatest German scientific explorers and travelers of the 19th century, Alexander von Humboldt would certainly rank at the top. From 1799 to 1804 the charismatic adventurer conducted the first extensive scientific exploration of Latin America, in a arduous 6,000-mile epic journey and with his paradigm-changing discoveries, he changed the way we see the world.

In the 18th century, the need for a more precise knowledge and data collection was growing. Moreover, at the time where Lavoisier was making the base of the modern chemistry, where Delambre, Méchain and later Arago were measuring the terrestrial meridian, in order to have an objective base for the metric system, Humboldt and Bonpland introduced the systematically measuring in the scientific expedition (Thoulouze, 2003).

Moreover, no scientist in our time is still stimulating such interest and curiosity about his life and discoveries. Actually, the Musée des arts et métiers organize an exposition *"La Boussole et l'Orchidée. Humboldt et Bonpland, 1799-1804, une aventure savante aux Amériques"*, between 2 December 2003 till 31 May 2004 to commemorate the bicentary comeback of Humboldt and Bonpland from the New World in 1804. Also, there has been in Bonn and Berlin, Germany, an exposition about Alexander von Humboldt, *"Alexander von Humboldt Netzwerke des Wissens*" between 15 September 1999 and 9 January 2000, on the occasion of his 200 anniversary of his Latin American scientific expedition.

The best description of Humboldt was made by the American diplomat and writer-traveler Bayard-Taylor; on 25 November 1856, Humboldt aged then with 88 years, the American reported his last words when he took leave from the old man:

> *"Vous avez beaucoup voyagé et vous avez vu beaucoup de ruines; aujourd'hui, vous venez d'en voir une de plus!". "Pas une ruine, mais une pyramide!"* replied the American "*et je serrais la main qui avait touché celle de Frédéric le Grand, de Forster, compagnon de voyage de Cook, de Klopstock, et de Schiller, Pitt, Napoléon, Joséphine, tous les maréchaux de l'empire, Jefferson, Hamilton, Wieland, Herder, Goethe, Cuvier, Laplace, Gay-Lussac, Beethoven, Walter Scott, en un mot la main de tous les grands hommes que l'Europe a produits dans trois quarts de siècle. Ce n'était pas une ruine, assurément non, mais un temple humain, parfait comme le Parthénon" (Duviols & Minguet, 1994).*

Humboldt and his friend, the French Botanist Aimé Bonpland, explored the coast of Venezuela, the Amazon and the Orinocco Rivers, and much of Peru, Ecuador, Cuba, Colombia and Mexico between the years 1799 till 1804. Humboldt did extensive mapping of these countries of northern South America, known as the equinoctial regions. During their expedition, Humboldt and Bonpland collected plant, animal, and mineral specimens. They studied electricity in animals (*Electrophorous electricus,* or the electric eel). Humboldt discovered what is now called the Humboldt Current (also known as the Peru Current) off the west coast of South America, while he was investigating why the interior of Peru was so dry.

Humboldt climbed mountains, with his ascent of Chimborazo (6,265 m) remained a world mountain-climbing record for nearly 30 years. He became the first person to ascribe sickness to lack of oxygen in the rarefied air of great heights.

Humboldt was the first European to witness native South Americans preparing curare arrow poison from a vine; he was also the first person to recognize the need to preserve the cinchona plant (its bark contains quinine, which is used to cure malaria and it was terribly over-harvested at the time). Humboldt was the first person to make accurate drawings of Inca ruins in South America (he visited the ruins at Canar, Peru). Humboldt and Bonpland discovered and mapped the Casiquiare Canal, the only natural canal in the world that connects two major rivers (the Orinocco River and the Negro River, a tributary of the Amazon. Humboldt was also the first person to discover of guano (the dried droppings from fish-eating birds; it is an excellent fertilizer). He was also the first to send guano to Europe. He made the first scientific exploration of the Guacharo (or oil-birds) cave. Of great importance are the meteorological data, with an emphasis on mean daily and nightly temperatures and Humboldt's representation on weather maps of isotherms (lines connecting points with the same mean temperature) and isobars (lines connecting points with the same barometric pressure for a given time or period). Even more important were his pioneering studies of the relationship between a region's geography and its flora and fauna. Humboldt was among the first to interest astronomers in shooting stars and his method for determining the light intensity of southern stars was an original contribution to astronomy (Astronomische Nachrichten, 1839, pp. 225-230, cited in Biermann, 1972). He was the first to note the significant decrease of magnetic intensity with the appearance of the aurora borealis. He gave a qualitative explanation for the amplification of sound at night.

Humboldt was named "savant-citoyen du monde" or universal citizen. He could talk ten languages (Biermann & Schwarz, 1997); Charles Wilson Peale, Humboldt portraitist, accompanied him in their way to meet Jefferson in 1804 from Philadelphia to Washington. He wrote in his diary: "the Baron spoke English very well, in the German dialect. Here I shall take notice that he possessed surprising fluency of Speech and it was amusing to hear him speak English, French, and German Languages, mixing them together in rapid Speech".

The American Treasury Minister, Albert Gallatin, said about him: "He speaks… twice as fast as anybody as I know, German, French, Spanish, and English, all together".

Humboldt showed humanistic attitudes, including a plea against slavery. His trip ended in a glamorous way; he and Bonpland were the guests of President Thomas Jefferson in Washington for three weeks in 1804.

Humboldt was the founder of many science disciplines; anthropology, ethnology, comparative climatology, meteorology, landscape archaeology (his studies of Andean and Mexican antiquities), volcanology, biogeography or plant geography, orography and oceanography. His enthusiasm for the popularization of science prompted him to give a course on physical geography to the professors and students of all faculties of the University of Berlin, part of which he repeated in a public lecture to an audience of more than 1000, from the "König bis zum Maurermeister". He also organized in Berlin in 1828 one of the first international scientific conferences.

Humboldt left a huge publication; the German Humboldtian biographer J. Löwenberg had itemized 636 works of Alexander von Humboldt between 1789 till 1870 (original editions, books or articles written in collaboration with other authors, re-edition or translations) (Minguet, 1969). In fact, Humboldt spent 25 years in Paris working on his *Voyage in the equinoctial regions* (30 volumes; 20 in folios and 10 in quartos). Besides, he published in later years of his life *Kosmos* in 5 volumes. Finally, during all his life, he wrote around 50.000 letters (1300 letters per year) (Minguet, 1969).

Although it is so difficult to grasp his actual achievements, but there is no Humboldtian law.

7 Alexander von Humboldt: his Curriculum Vitae.

The following chronological biography of Humboldt life and work is both a translated passage taken from the German literature „Alexander von Humboldt, Netzwerke des Wissens“ (1999) and from the “Dictionary of scientific Biography (Scribners, 1972).

1769 14. September: Born in Berlin in a noble family, living at Tegel Mansion.
1777-1787 Private lessons in Tegel, his tutors were among others Kunth and Campe.
1779 6 Januar: his father, the Major Alexander Georg von Humboldt died.
1787-1788 Study of the Cameralism or “Cameralwissenschaft” at the University of Frankfurt/Oder; return to Berlin, private study in Botanic under the guidance of Karl Ludwig Willdenow.
1789 25 April: matriculation at the university of Göttingen.
24 September till November: a study trip with J. van Genus from Göttingen via Speyer to Mainz (to meet Georg Forster), Cologne, Pempelfort, Münster, Kassel and going back to Göttingen.
1790 *Mineralogische Beobachtungen über einige Basalte am Rhein.*
Traveling through Europe with Georg Forster.
25 March till the end of July: travel with Georg Forster from Mainz via Cologne, Brussel, Amsterdam, to England. His return journey was via Paris.
1790-1791 August till April: study at the Academy of Commerce in Hamburg.
1791 End of April: return to Berlin.
14 June: began his study at the School of Mines in Freiberg, Saxony. Friendship with Karl Freiesleben, who was a Saxonian mining official.
Middle August: traveling with Freiesleben through the Bohemian Mittelgebirge.
1792 27 February: mining assessor in the mining department in Ansbach-Bayreuth in the Prussian part of Upper Franconia.
22 September: beginning of an inspection tours of salt mines from Bayreuth, via Munich and Salzburg to Vienna and then to Breslau in Poland and back to Berlin.
1793 *Florare Fribergensis specimen.*
20 June: member of the Leopoldine Carolinian Academy of Naturalists. Middle June he received the elector of Saxony’s gold medal for art and science.
1794 14-19 December: first visit of Goethe in Jena.
12 July: he went again in the Netherlands, partly under diplomatic auspices.
1795 1 May: he became a mining leader.
July till November: he made an extensive trip with scientific purpose through northern Italy and the Swiss and the French Alps.
1796 July: in mission travel in behalf of the Prussian king to negotiate a treaty with the commander of the French troops entering Württemberg, in order to effect the formal neutralization of the Franconia principalities.
19 November: death of his mother Elisabeth (of a French Huguenot family), bringing him a large fortune and financial independence. Humboldt ended his civil service on his wish. He started the preparations of his voyage.
1797 *Versuche über die gereizte Muskel- und Nervenfaser.*

March till May: Travel to Jena and Weimar. Meeting with Goethe, Schiller and Schelling.
Astronomical bearings and geographical positions studies by von Zach.
30 May: travel from Jena via Dresden and Prague to Vienna, from August till October, where Humboldt prepared himself intensively for his trip in the West Indies.

1797-1798 End October till April: Humboldt is in Salzburg; experiments with Leopold von Buch. Many excursions.

1798 24 April: departure from Salzburg to Paris. First meeting with Aimé Bonpland in Paris. Both traveled to Marseilles, where he busied himself with geodetic measurements and botanic field studies, hoping to sail to North Africa and to join Napoleons campaign to Egypt (planned voyage failed because of political circumstances).
15 December: departure of Humboldt and Bonpland to Spain.

1799 *Versuche über die chemische Zerlegung des Luftkreises* and *Über die unterirdischen Gasarten.*
En route to Madrid by way of Valencia and Barcelona, he established data for a relief map that for the first time clearly outlined a sizeable region.
In March they received permission to make a research through the Spanish colonies.
5 June: He and Bonpland sailed from La Coruna with "Le Pizzaro".
19-25 June: a stop at Tenerife in the Canary Islands.
16 July: they landed in Cumana in what is now Venezuela after 41 days of sailing.
18 November: sailing from Cumana to La Guaira, then to Caracas.

1799-1804 his Voyage to South America and the USA together with Aimé Bonpland is divided in three phases:
- Voyage from the Orinocco to the Amazon.
- Stay in Cuba, voyage to Columbia, Ecuador and Peru.
- Voyage to Mexico and the USA.

1804 9 July till 3 August: sailing from Philadelphia to Bordeaux in France, the end of his travel in the New World.

1805 19 February: nomination as a member of the Berlin Academy of Science.
11 March till end October: travel to Italy, visiting his brother William (who was the Prussian Gesandter) in Rome. He went to Naples. Ascension of Vesuv with Gay-Lussac and Leopold von Buch.
16 November: after 9 years of absence, Humboldt is again in Berlin. He stayed there till 1807.
Starting his American work *Voyage aux Régions Equinoxiales du Nouveau Continent.*

1807 *Ideen zu einer Geographie der Pflanzen nebst einem Naturgemälde der Tropenländer.*
13 November: Humboldt left Berlin. He was sent on a diplomatic mission to Paris, where he remained until 1827, making trips to London, Vienna, Bratislava, and Italy.
Only in Paris could Humboldt have his research findings properly evaluated by first-rank scientists, and only there could he avail himself of the best artists and technical resources.

1808 *Ansichten der Natur.*

1809-1814 *Versuch über den politischen Zustand des Königsreichs Neu-Spanien* written in French.

1814 31 March: the Allied occupied Paris. Humboldt assisted the king, and guided him through the museums and the theaters. He intervened by the Prussian troops on behalf of French scientists (e.g., the infantry unit took place in the quarters of the Museum d'Histoire Naturelle. Cuvier, panicked, sent a message to Humboldt, who intervened immediately in his favor by the General von Goltz).

1817 November: travel to London.
1822 September: travel to Verona with the Prussian king. Travel to Naples and many ascension of Vesuv.
1823 *Geognotischer Versuch über die Lagerung der Gebirgsarten in beiden Erdhälften.* January and February: short stay in Berlin
1825 July: travel to Brittany.
1826 October and November in Berlin.
1827 14 April: Humboldt left Paris and visited London. He took his definite domicile in Berlin.
He became honorary president of the "Société de Géographie" in Paris. The French never forgot Humboldt's earnest intercession, during the occupation of France by the allied troops, on behalf of scientific institutions, nor his fight to save private property, including that of Laplace.
1827-1828 3 November till 27 April: lectures called "Kosmosvorträge" at the university and at the Opera in Berlin.
1828 September: he led the VII Conference of the German Naturalists and Doctors Society in Berlin.
1829 12 April till 28 December: he set out on his Russian Siberian trip as a guest of the Tsar, accompanied by the mineralogist Gustav Rose and the naturalist Christian Gottfried Ehrenberg. They traveled in carriages as far as the Altai Mountains and the Chinese frontier.
1830 28 September till middle January 1831: Humboldt fulfilled in Paris diplomatic assignments. He was traveling under the mission of the "Berichterstatter or Geschickter" of the Prussian king.
1831 Humboldt used his stay in Paris to write and publish his scientist and literary works. He also obtained the advice of his learned friends, especially Arago, in composing the Asian travel journals and in composing a long-worked-on history of medieval geography. He published the results of his Russian trip, *les Fragments de Géologie et de Climatologie Asiatiques,* which were also published in German the same year.
1833 September: participation at the Naturalists Reunion in Breslau, Poland.
1834 August: travel to Königsberg and Danzig. He started writing *Kosmos*, which he devoted most of his time till his last years.
1835 8 April: his brother William died.
August till December: in diplomatic mission in Paris.
1836 September: participation at the Naturalists Reunion in Jena.
1837 September: participation at the 100 Jubilee of the university of Göttingen.
1838 August till end December: in diplomatic mission in Paris.
1840 8 December: Humboldt is member of the Prussian "Staatsrat".
1841 May till November: in diplomatic mission in Paris.
1842 Middle January till middle February: in visit with the Prussian king in London.
31 May: Humboldt is an advisor on science and art of Friedrich Wilhelm IV and the first Chancellor of the peace division order "pour le mérite".
1842 September 1842 till middle February 1843: Humboldt is in diplomatic mission in Paris.
1843 Humboldt published his Russian travel work *Asie Centrale* in Paris.
1845 January till May: in diplomatic mission in Paris. He published the first volume of *Kosmos* (Vol. 2: 1847; Vol. 3: 1850; Vol. 4:1858; Vol. 5 posthumous 1862).
1847 October 1847 till January 1847: for the last time in diplomatic mission in Paris.
1849 *Ansichten der Natur,* an aesthetic presentation of research in natural science and geography and of "pictures of nature".

1853 *Kleineren Schriften.*
1857 Humboldt suffered of a light stroke.
1859 6 May: Humboldt died in his apartment in Berlin. He was inhumed on 11 May in the family graveyard in Tegel.

The first thoughts that come to one's mind after reading the above detailed and long chronological biography of Humboldt may be the followings:

- Because he was a member of a noble family, who had a close relation with the Prussian crown, he could be in contact with the most prestigious society members as well as with eminent scientists, scholars, artists, writers known in Europe and the famous politicians of his time.
- His family's wealth allowed him to afforded both independent thinking as well as freedom in realizing his goals and ideas.
- Due to his distinguished status as a member of many prestigious science academies in Europe, he was all the time up-to-date with every scientific and philosophical issue.
- Humboldt made numerous travels where he met many scientists, as well as learnt how to use the physical instruments and the measurement methods. All this showed Humboldt minute preparation and his determination to make the dream of his life comes true: doing a great scientific expedition.
- Humboldt was never in the same place more than two months, except when he was in Paris!
- He left monumental publications, so extended that it is in itself a considerable problem to read him, to understand him and later to use his ideas and to introduce him, the classroom and for 10-12 year-olds as a figure in science history!

8 Alexander von Humboldt's scientific beliefs and philosophical position.

The following text is composed from biographic information about Humboldt, especially from the article of Biermann in the Dictionary of scientific Biography, 1972, pp. 549-555, the New Encyclopædia Britannica (1991), the book of Charles Minguet (1969), the book of Duviols & Minguet (1994) and the catalogue of the exposition "La Boussole et l'Orchidée" du Musée des arts et métiers (2003).

Because Humboldt was a man of society *par excellence*, he was living in the center of the European cosmopolite capitals and at the same time he was very close to the Prussian king, his personality presented many facets: Humboldt the scholar, the diplomat, the explorer, the polyglot, the humanitarian and the one who contributed to the popularization of science. I will present his beliefs and his thinking according to these aspects.

8. 1 Humboldt as a scholar and as "Homme de Science".

The followings are citations (taken from Duviols & Minguet, 1994) from Humboldt's letters as well as what personalities who met with Humboldt, said about him.

In *"Mes confessions"*, Humboldt wrote:" *Jusqu'à l'âge de seize ans j'avais peu envie de m'occuper des sciences, j'avais l'esprit inquiet et je voulus être soldat… Presque toutes les sciences dont je m'occupe à présent, je l'ai apprises par moi-même et très tard."*. This passage showed how Humboldt was a lifelong learner, enjoying of a great perseverance and determination, two important qualities of a scientist.

At the age of 20, he already made his plans about his future intellectual itinerary. In a letter addressed to his friend Wegener, he wrote: *"Je suis prêt à faire les premiers pas à travers le monde, sans guide et en homme libre… Aucune passion ne m'entraînera. Des sujets sérieux et surtout l'étude de la Nature seront une retenue contre la sensualité."*

The Treasury Minister of the United States, Albert Gallatin, wrote about Humboldt on 6 June 1804: *"J'ai reçu un charmant intellectuel, le baron de Humboldt, le voyageur prussien de retour du Pérou et du Mexique… Le récit de son voyage, qu'il a l'intention de publier à son retour en Europe, dépasseront, à mon avis, toutes les productions antérieures de ce genre... J'étais vraiment enchanté et j'ai ingurgité en moins de deux heures plus d'informations que je n'en ai recueilli ces deux dernières années, dans ce que j'ai lu ou entendu. Il fait à peine plus de trente ans et il t'évite la peine de parler car il capte avec la plus grande précision les idées que tu veux développer avant que tu n'aies prononcé trios mots. Outre ses connaissances qui relevant de son voyage, l'étendue de ses lectures et son savoir scientifique sont époustouflantes".*

Goethe's judgment about Humboldt: *"Was ist das für ein Mann! Ich kenne ihn so lange und bin doch von neuem über ihn in Erstaunen. Man kann sagen, er hat an Kenntinssen und lebendigem Wissen nicht seines gleichen. Und eine Vielseitigkeit, wie sie mir gleichfalls noch nicht vorgekommen ist! Wohin man rührt, er ist überall zu Hause und überschüttet uns mit geistigen Schätzen. Er gleicht einen Brunnen mit vielen Röhren, wo man überall nur Gefäße unterzuhalten braucht und wo es immer erquicklich und unerschöpflich entgegenströmt"* (Brand, 2001).

Or what Humboldt said: *"On dit souvent en société, que je m'occupe de trop de choses à la fois, la botanique, d'astronomie, d'anatomie comparée. Mais peut-on interdire à l'homme d'avoir le désir, de savoir, d'embrasser tout ce qui l'environne? Pour un voyageur, la variété des connaissances est indispensable".* Such citations show, how much Humboldt was all the time full of enthusiasm for science.

Humboldt's studies familiarized him with technology, and he also acquired a background in economics, geology, and mining science. He studied botany with particular zeal and his trip of 1790 in Europe with Georg Forster, who had been with Cook on the second world voyage, has deeply influenced him.

Humboldt like his contemporaries, sought proof of the presupposed "life force" (*vis vitalis*). At Jena, he pursued this through galvanic experiments, among them painful personal tests, hoping thereby to throw light on the "chemical process of life". He also concluded extensive experiments and chemical effects on animals and plants, and also acquainted himself with anatomy. The results of his investigations were published in 1797; of special note was his original attempt to draw analogies between animal and plant life processes.

His interest in nature and science brought him closer with Goethe. Here he renewed and deepened his earlier contacts with him and Schiller. With his wide interests, he had an immediate rapport with Goethe, but Schiller saw him as a "man of much too limited intellect". This feeling, notwithstanding, Schiller published in his journal *Die Horen*, Humboldt's article "The Genius of Rhodes" (1795), an allegorical tale in "semi-mythical clothing" in which, agreeing with Schiller, Humboldt endorsed the theory of the life force; Humboldt later abandoned this position.

In Jena, Humboldt also learned techniques for making geodetic and geophysical measurements, and especially for taking astronomical bearings. He later regarded such bearings to be the basis for all geography, and criticized travel by routes that were needlessly uncertain for want of correct measurements.

Humboldt managed to handle both his official duties and his natural studies; he was intensively preparing himself for his scientific expedition (from 1792 till 1799); his use of the comparative method and his way of working were characteristic. Far from being a romantic, Humboldt was a thorough empiricist in studying general relationships in nature. Humboldt believed that: *"Pour concevoir la liaison de tous les phénomènes, liaison que nous nommons Nature, il faut d'abord connaître les parties, et puis les réunir organiquement sous un même point de vue"* (Duviols & Minguet, 1994, p 81).

In fact, the first record of Humboldt's interest in describing natural interrelationships is found in a letter dating of 24 January 1796 to the natural scientist Pictet: *"Je conçus l'idée d'une physique du monde"*.

For him facts, measurement, and number were the cornerstone of science, and not speculation and hypothesis. He believed in universal harmony and equilibrium in nature, and of oppositional forces in any development.

Humboldt's trip in 1795 to northern Italy and the Swiss and French Alps, in the course of which he met Alpine experts, learned about altitude effects on climate and plants, and came to recognize the evidence of the relief and the need for astronomical and geomagnetic observatories – exercised a lasting influence on him.

Geomagnetism also caught Humboldt's interest. In 1796, he discovered the magnetism of the Haidberg near Gefrees, northeast of Bayreuth – and his geomagnetic work occupied him for five decades.

In 1797, in Vienna, Humboldt heard accounts by Viennese scholars of their travels, studied West Indies plants kept at Schönbrunn. In Salzburg, he went on excursions with the geologist Leopold von Buch, with whom he also practiced in taking geographic bearings and made eudiometric measurements.

In 1798, Humboldt was in Paris, where he hoped to arrange his projected trans-oceanic travel. He read a paper *"Expériences sur le gaz nitreux et ses combinations avec le gaz oxygène"* before the Paris Academy.

Humboldt's reputation was steadily increasing; he received the Saxony golden medal for art and science and he became a member of the Leopoldine Carolinian Academy. He was present at the conclusive arc-degree measurement between Dunkirk and Barcelona. He contributed to the first relatively conclusive determination of magnetic inclination in Paris, set up galvanic experiments, and investigated the chemical composition of air in Gay-Lussac's laboratory.

In Paris, Humboldt had been assigned the diplomatic task to strengthen the ties between Prussia and France. Humboldt's travel journal was published in 34 volumes over 25 years; the volumes, including some 1200 copper-plates, cost about 780000 francs. It was written in French, except for the volume of Botany, which was written in Latin. This voluminous edition had much inconveniency: it is difficult to manage. And Humboldt, himself took attention of this. The big size of the books does not allow to sending them by post and their prices were exorbitant! Humboldt was unhappy: he, who dreamt to widespread his work to a large public, according to his dearest wish: being useful to a large number of people. He wrote in 1830 to Heinrich Berghaus: *"Hélas, hélas! mes livres n'ont pas produit l'effet salutaire que j'avais espéré, lorsque je commençai à les préparer et à les éditer; ils sont trop chers!".* This is why, besides his huge work, Humboldt edited more modest publications, easier to access, more manageable and less expensive (Minguet, 1969, pp. 11-12).

On one hand, his trip and monumental publications bankrupted him and this had prompted his return to Berlin: his dependence on the Prussian salary and the hope of utilizing the ties between the court at Berlin and the ruling house of Russia in order to make a long-planned Siberian journey. On the other hand, he also returned to his home with the explicit purpose of raising the level of mathematics and natural sciences to the point that Berlin intellectual life would compare to that of Paris.

Humboldt wrote in 1849 *Ansichten der Natur*[*] (1849), an aesthetic presentation of research in natural science and geography and of "pictures of nature".

In 1834, Humboldt wrote to his friend Varnhagen von Ense, that he started with writing the "work of his life": *"Mon titre est maintenant Cosmos. Esquisse d'une description physique du Monde…Je sais que Cosmos a quelque chose de prétentieux qui n'est pas sans une certaine afféterie; mais ce titre dit en un mot frappant ciel et terre"* (Duviols & Minguet, 1994).

When the first and second volumes of his work *Kosmos* appeared in 1845, they marked a genuine triumph. He wrote in a letter to Bessel, dated 14 July 1833: *"It is the work of my life; it should reflect what I have projected as my conception and vision of explored and unexplored relationships of phenomena, out of both my own experience and painstaking inquiry into readings in many languages"* (Biermann, 1972, pp. 549-555).

Indeed, the *Kosmos* is a popular book in the best sense of that term. The entire material world from the galaxies to the geography of the variable mosses, the history of physical cosmography, the needed stimulation of nature studies – he sought to present all this in vivid, "pleasing" language. His volumes III and IV contained his special research findings and added material; they were not equally successful, however.

In the area, which he especially cherished, geomagnetic measurement, Humboldt suggested in a letter (23 April 1836) to the president of the Royal Society of London, the worldwide establishment of geomagnetic observatories. Gauss, with whom he corresponded, had just conceived the theory of the *intensitas vis magneticae* (1833), and it was not easy for Humboldt to see a field long his own domain become the province of a more creative mind, now. Humboldt nevertheless acknowledged his own limitations. In 1789 he had almost discovered the Gaussian addition logarithms, but he later had to confess that he could "claim for himself no serious position in the higher realms of mathematics" (letter to C. G. G. Jacobi, 27 December 1846). He saw clearly the reciprocity of mathematics with both the natural sciences and industrial application:

> "Man cannot have an effect on nature, cannot adopt any of her forces if he does not know the natural laws in terms of measurement and numerical relations. Here also lies the strength of the national intelligence, which increases and decreases according to such knowledge. Knowledge and comprehension are the joy and justification of humanity; they are parts of the national wealth, often a replacement for those

[*] In this book, Humboldt mixed Latin poems, philosophy and science, and I did have difficulties to read him till the end, since I lost the tracks of his thoughts.

materials that nature has all too sparsely dispensed. Those very peoples who are behind in general industrial activity, in application of mechanics and technical chemistry, in careful selection and processing of natural materials, such that regard for such enterprise does not permeate all classes, will inevitably decline in prosperity; all the more so where neighboring states, in which science and the more industrial arts have an active interrelationship, progress with youthful vigor" (Kosmos I, 1845, p. 36).

8. 2 Humboldt as humanist.

The French Revolution had enhanced Humboldt humanitarian and democratic feelings; when he arrived in Paris in 1790, shortly before the anniversary of the storming of the Bastille, he wrote on 3 January 1791 to F. H. Jacobi: *"The sight of the Parisians, with their National Assembly and yet incomplete Temple of Liberty, to which I myself carted sand, stirred me like a vision before the soul".*

Indeed, Humboldt was influenced by "Humanitätsideal und Weimarer Klassik" (Brockhaus Enzyklopädie, 1989).

When Humboldt entered the Prussian mining service in March 1792, he invented safety lamps and a rescue apparatus for miners threatened with asphyxiation, himself testing these devices in dangerous experiments. Upon his initiative and funds he founded a "free mining school" to train miners, thus demonstrating early his lifelong social concern.

Besides his extensive literary and court activities, Humboldt remained devoted to humanitarian causes. He was responsible for antislavery legislation in Prussia and in his voyage to the new continent; Humboldt showed as much interest in early Indian monuments as in the current population figures, social conditions, and economic developments. He found slavery to be the greatest evil of humankind, and this remained a matter of paramount concern to him. He used his influence by the Prussian king for adopting a law that declares automatically free any slave, who walked upon the Prussia land, no matter his race or color.

Moreover, Humboldt spoke out against anti-Semitism and racism. Then, in 1842, he deployed huge efforts opposing to a "abominable loi", which permits institutionally a special status for Jews in Prussia. He justified his opposition: *"By asserting the unity of the human race, we also oppose every distasteful races assumption of higher and lower races of man. There are more adaptive, more highly educated, and more spiritually enriched peoples, but there are non nobler than others. All are equally ordained to be free"* (Kosmos I, 1845, p. 385).

Humboldt justified his visit to the United States for moral reasons, where *" cet unique coin de la terre où l'homme jouit de la liberté".*

Humboldt gave a major impetus to the study of the Americas. He studied the discovery and history of America and its economics and politics, particularly in Cuba and in Mexico. No wonder his trip has justly been called "the scientific discovery of America", and Bolivar once said in tribute: *"Humboldt has done more good for America than all her conquerors".*

Through Johann Gottfried Flügel, the United States general consul in Leipzig, Humboldt followed the progress of the natural sciences in North America and remained greatly interested in the development of this country. He nonetheless regretted later that there *"freedom is only a mechanism in the principle of profitability"* and that indifference to slavery was prevalent. He observed, *"The United States is a Cartesian spiral, sweeping away everything and yet boringly level"* (letter to Varnhagen von Ense, 31 July1854). He also complained that French rule was becoming more immoral through *"administrators who have been defrauding, extorting, and using violence in Algeria"* (letter to Caroline von Wolzogen, 6 May 1837).

Humboldt gave advice to many gifted youths along with encouragements, recommendations for awards, and often a financial help such young scholars, he even regarded them as "his children" (letter of Emil du Bois-Reymond to Karl Ludwig, 26 June 1849). Among the many young people in whom he took an early interest, was for instance the chemist Liebig.

The best proof of his wide interests and affectionate nature lies in his voluminous correspondence: about 8000 letters remain.

8. 3 Humboldt as a writer, teacher and his History of Science.

The first weeks he spent in Cumana, on the Venezuelan coast, Humboldt noted: *«Si tout ce qui nous environnait était propre à nous inspirer un vif intérêt, nos instruments de physique et de physique et d'astronomie excitaient à leur tour la curiosité des habitants. Nous fûmes distraits par de fréquentes visites : et pour ne pas mécontenter des personnes qui paraissaient si heureuses de voir les taches de la lune dans une lunette de Dollond, l'absorption de deux gaz dans un tube eudiométrique, ou les effets du galvanisme sur les mouvement d'une grenouille, il fallut bien se résoudre à répondre à des questions souvent obscures, et à répéter, pendant des heures entières, les mêmes expériences »* (A. von Humboldt, Relation historique du voyage aux régions équinoxiales du Nouveau Continent, 1814-1825).

A proof that Humboldt was a tutor for his Indian workers is presented in the drawing of Friedrich Georg Weitsch, *Humboldt et Bonpland dans la vallée de Tapia au pied du Chimborazo en Equateur, 1806*, which was realized on the indications of Humboldt (Figure 2).

Figure 2: Humboldt and Bonpland with the young Carlos Montufar, observed the distribution of vegetation in combination with physical factors. A detail on the right of Weitsch drawing; the copper barometer, serves to measure the altitude at every step of their Chimborazo progression.

While working in Paris on his monumental work, Humboldt used the libraries and also he obtained the advice of his scientist friends, among them was Arago. His long-worked-on history of medieval geography, which demonstrates his historical interests; indeed throughout his works is the manifest conviction that scientific progress is not accidental but the result of experience and “earlier development of thought”.

Morever, K*osmos* cites over 9000 sources and is thus an important reference for the history of science.

The preface of the first edition of his book *Ansichten der Nature*, Humboldt is concerned with describing to his readers the nature and at the same time, communicate scientific knowledge, which is physical geography. He aimed, on one hand, at sharing the emotion from seeing grandiose landscapes with the “âmes mélancoliques” and on the other hand, “application de l’esthétique aux objets de l’histoire naturelle”. Moreover, he wrote to Arago, in August 1827: *“La jeunesse allemande s’est jetée dans les écarts de la philosophie de la nature, parce qu’on ne lui a pas montré que, sans s’éloigner des vérités physiques, on peut encore parler à l’imagination”*. This formula resumes Humboldt’s motivation that animates him in his descriptions of the nature: to address to imagination without getting off of the scientific knowledge. (Drouin, 2003, pp. 62-63). Or, *“Le paysage … s’inscrit à la fois comme un objet de recherché scientifique et de contemplation esthétique… le nouveau dialogue avec la nature est remarquablement tonique; il s’engage comme un contact physique et non comme un lien mystique”* (Jacques, 2003, p. 114).

His 16 public lectures to a large audience in Berlin, the so-called the “Kosmosvorträge” were very popular; Humboldt talked about the *“die damals bekannten Objekte des Universums, die Milchstraße und Sternennebel, über die Evolution des Lebens, die geographische Verbreitung der Lebewesen, die Zahl der Tierarten, aber auch über Gestalt und Aufbau der Erde, über die Natureinheit des Menschengeschlechts, die Verurteilung der Sklaverei, die Abstammung der Menschen, Menschenrassen und deren Charakteristik, Theorie des Wissens, die Erkenntnis der Einheit der Natur in der Natur, über frühe Entdeckungsreisen und die Geschichte der technischen Erfindungen und über die Darstellung der Natur in der Kunst”* (Kosmosvorträge, 1827/28); for example, in the 13th lecture, Humboldt tackled the history of the development of science in the ancient civilizations, in Egypt, in the Arab World… till Columbus, Toricelli, Volta, etc…When one reads these lectures, one has the feeling as if reading a sensational story! So, how about hearing him with his lecturing zeal? Humboldt showed especially interest in the history of astronomy. Noting that these lectures were the plan of his monumental work *Kosmos*.

Here is a testimony from “Lettres Américaines” of a young French scientist Boussingault, who was invited by Bolivar to create science establishments in South America, about Humboldt’s love for helping young scientists and communicating his knowledge to others:

“Humboldt s’intéressait vivement à notre expédition. Nous devions non seulement parcourir les contrées qu’il avait visitées, il y avait vingt ans, mais surtout y résider. Bien des observations faites par lui devaient être complétées, étendues.

En géologie, en géographie, les progrès accomplis depuis son mémorable voyage exigeaient une révision attentive de terrains qu’il avait étudiés en passant trop rapidement. Des positions géographiques n’avaient pas été déterminées avec une précision suffisante. On peut affirmer que c’est à lui que nous dûmes d’exécuter des travaux qui n’ont pas été jugés défavorablement en Europe.

Humboldt voulait d'abord me connaître, me toiser. Il parlait beaucoup et bien. Je l'écoutais comme un élève écoute un maître, aussi se plut-il à me reconnaître comme possédant " le grand art d'écouter". Il me témoigna bientôt cette vive amitié qu'il m'a conservée jusqu'à sa mort. Il me fit présent de plusieurs instruments dont il s'était servi en Amérique: un surtout de poche, un horizon artificiel, une boussole à prisme, un planisphère céleste de Flamsted, précieuses reliques dont je tirai le plus grand parti et que je laissai à mon camarade l'infortuné colonel Hall.

Humboldt fit plus; il voulait m'enseigner l'usage de ces instruments, nous prîmes jour pour nous revoir à cet effet. Il demeurait sur le quai Napoléon, au quatrième, dans un appartement ayant vue sur la Seine, à peu près vis-à-vis la Monnaie.

Humboldt avait alors cinquante-cinq ans, taille moyenne bien prise, cheveux blancs, regard indéfinissable, physionomie mobile, spirituelle, marquée de quelques grains de petite vérole, maladie qu'il avait contractée à Carthagène des Indes. Son bras droit était paralysé des suites d'un rhumatisme gagné en couchant sur les feuilles mouillées dans les forêts des bords de l'Orénoque. Quand il voulait écrire, lorsqu'il voulait vous offrir la main droite, il relevait avec sa main gauche l'avant-bras infirme à la hauteur nécessaire. Son costume était resté le même depuis l'époque du Directoire: habit bleu, boutons jaunes,, gilet jaune, culotte en étoffe rayée, bottes à revers, les seules qui se trouvaient à Paris en 1821, cravate blanche, chapeau bossué, éreinté.

Je m'attendais à trouver le chambellan du roi de Prusse dans un splendide appartement; mon étonnement fut grand quand j'entrai chez le célèbre voyageur: une petite chambre à coucher, un lit sans rideaux, dans la pièce où il travaillait, quatre chaises en paille, une grande table en sapin, sur laquelle il écrivait; elle était recouverte de calculs numériques et de logarithmes. Lorsque la table était remplie de chiffres, il faisait venir un menuisier pour la rabote. Presque pas de livres: les ***Tables*** *de Callet, la* ***Connaissance des Temps****. Il dînait aux* ***Frères Provençaux****; dans la matinée, il passait toujours une heure ou deux au Café de Foy, où il s'endormait, après avoir déjeuné.*

Nos exercices du sextant commencèrent aussitôt après mon arrivée, nous mesurions l'angle compris entre la flèche des Invalides et le paratonnerre de l'église Saint-Sulpice. Nous prenions aussi une hauteur du soleil. Il n'omit rien dans mon instruction pratique, moyens de vérification, de constater l'erreur de collimation, tous les calculs étaient faits en écrivant sur le bois de la fameuse table. Je fus bientôt familiarisé avec l'usage du sextant et de l'horizon artificiel.

Tel était Humboldt avant mon départ… tel je le retrouvai à mon retour d'Amérique. Alors il était occupé à faire son interminable ouvrage. Son projet était de se fixer à Mexico, avec une société de jeunes travailleurs dont je devais faire partie.

Ce projet ne s'est pas réalisé à cause des révolutions, mais sans révolution, j'ai la conviction que son auteur n'aurait pas pu vivre toujours au Mexique. Il y serait mort d'ennui, malgré son amour pour la science". (J.-B. Boussingault, cited in Duviols & Minguet, 1994, pp. 116-117).

Humboldt's main objective was to demonstrate **the unity of nature** within the multiplicity of sense experience. Thus, his basic scientific attitudes were close to those of Goethe and Schelling. For him, facts, measurements and number were the cornerstone of science. So data collection in nature was a substantial part of his science. He believed in **universal harmony and equilibrium in nature** (Biermann, Kurt-R., in Dictionary of scientific biography, p. 549). Furthermore, being a lifelong bachelor and thus being able to dedicate every minute of his life to very many fields in Science, he developed an **encyclopaedic thinking.** According to Verstraete (2003), Humboldt was probably the last encyclopaedist of natural sciences, the last human mind able to encompass with one look "le

Ciel et La Terre, avec toute leur armée", pursuing all his lifelong one objective: how does function the world? And this would be answered by the experimental method; the credo of Humboldt: only the experimental method, founded on methodical observation "les faits, rien que les faits" and rigorous observation of facts, can display the functioning of the nature.

Indeed, Humboldt, still sharing the romantic epistemology about the holistic concept of nature, gave science empiricist, analytical and quantified aspects. His purpose was to offer the means to assemble the material of a global knowledge and to put nature in the economy of exactitude and precision, which were till that time reserved to mathematics. This what he did during his five-year Latin American expedition; in order to understand natural phenomena, he collected data with precise instruments necessary to the edification of a global and unified science. For this reason, the use of instruments and the quantification of the phenomenon was the secure means (Acot & Bourget, 2003, p. 86); for his voyage, Humboldt took with him around 50 measuring instruments (Voyage aux Régions Equinoxiales du Nouveau Continent, 1815) (the instruments are listed in Appendix B). No wonder that Peter Honigmann in his book "Gerlands Beiträge zur Geophysik" described him as the "Entdecker mit dem Meßinstrument" (cited in Brand, 2001).

During the last 25 years of his life, Humboldt was chiefly occupied with writing Kosmos, one of the most ambitious scientific works ever published. Written in a pleasant, literary style, Kosmos gives a generally comprehensible account of the universe as then known, at the same time communicating the scientist's excitement and aesthetic enjoyment at his discoveries. Humboldt had taken immense pains to discipline his inclination to discursiveness, which often gave his writing a certain lack of logical coherence. Kosmos, was within a few years translated into nearly all European languages.

Concluding remarks:

Due to an exceptional physical resistance of "fin d'acier" (according to Barbey d'Aurvelliy), Humboldt had a long life and he outlived all his family and friends (Arago, von Buch, Cuvier, Gay-Lussac, Bonpland, Goethe).

Humboldt had a clear visionary skill for events; he proposed a leveling of the isthmus between Panama and the mouth of Charges (for more than fifty years, Humboldt called for the construction of a canal linking the Atlantic and Pacific) and the furthering of science in the new World.

Furthermore, Humboldt believed in the scientific progress and in the humankind: persuaded that the scientific discoveries are the future richness of a country and hence of all the humanity.

Simon Bolivar said about Humboldt*: "Il a fait plus pour L'Amérique espagnole que tous les conquistadors réunis… tant que l'Amérique vivra, le baron de Humboldt restera présent dans le cœur de ceux qui apprécient à sa juste valeur le grand homme dont les yeux ont percé le voile d'ignorance qui l'enveloppait et dont la plume a su la dépeindre dans toute sa beauté. Mais ce n'est pas là les seuls titres que vous décernent les suffrages des Américains. Les particularités de votre caractère moral, vos éminentes qualités de générosité vivent parmi nous et nous sont à jamais agréables".*

Despite his accomplishments, Humboldt does not rank with the great discoverers or inventors, as he himself realized. No matter where he traveled, others had been there before him and had reported on their trips. But Humboldt saw broadly and comprehensively, and, where others perceived only isolated facts, he combined observations and saw unity in diversity. He was gifted with a quick intelligence and with boundless receptivity and powers of memory.

Despite his deficiencies, Humboldt towers as a servant of worldwide science and a humanist. His stimulating influence on his contemporaries and on science itself, his humanistic and democratic principles, and the unshakable faith in the constant progress of mankind have remained exemplary.

9 Humboldt' scientific observations, his correspondence and scientific expeditions.

In the following paragraphs, I will restrict my bibliographical research to Humboldt voyage to the new continent, because he dedicated 5 years on fieldwork where he covered every aspect in scientific research in his time related to Mathematics, Astronomy, terrestrial magnetism, Meteorology, Geology, Geography, Ethology, Economy, Historiography, Plant Geography, Botanics, Zoology und comparative Anatomy or Physiology. Finally, I will mention only events relative to my points of interests.

In a letter to his brother, dated 17 October 1800 from Cumana, his first stop, Humboldt wrote: "*nous sommes enfin ici, dans le pays le plus divin et le plus merveilleux. Des plantes extraordinaires, des anguilles électriques, des tigres, des tatous, des singes, des perroquets et de nombreux, très nombreux Indiens purs, à demi sauvages, une race d'hommes très belle et très intéressante… Nous nous promenons jusqu'à présent comme des fous. Bonpland assure qu'il perdra la tête si les merveilles ne cessent pas bientôt…Je sens que je serai heureux ici et que nous ces impressions me réjouiront souvent encore dans la suite*" (Duviols & Minguet, 1994, p. 30).

With this emotion of wonder and enthusiasm, Humboldt started his observations in the new World. These feelings will accompany him throughout his trip.

9. 1 Humboldt' *in situ* observations.

When Humboldt traveled with Aimé Bonpland to the new continent, he was 30 years old. He prepared for his great trip lasting for six years. Never before was a research explorer away for such a long time at his own expense. Humboldt, indeed, had a carte blanche granted to him by the Spanish king Charles IV. The king " was eager to make use of Humboldt's mining expertise, and he asked him to report back in particular on mineralogical findings" (Pratt, p. 116).

Before leaving the European continent, Humboldt wrote to his friend, Willdenow: *"I will collect plants and fossils, be able to make astronomical observations with splendid instruments, and I will chemically dissect the air. But all of this is not the main purpose of my trip. My attention will be constantly directed towards the harmony that exists in the combination of all forces and the influence of non-living creations on the living plant and animal worlds! In other words, I must find out about the unity of nature"* (Die Jugendbriefe Alexander von Humboldts 1787- 1799).

On their way to the new world, Humboldt and Bonpland made a stop between 19 and 25 June 1799 in Tenerife, the Canary Islands. There, they used their time in verifying their instruments and their methods of measurements. Humboldt aims for the volcanic Peak Tyde was *“l’examiner sous le rapport de la géologie, de la physique et de la géographie des plantes”*.

On 21 June 1799, Humboldt went on an excursion to the top of the volcano, for 2 days, accompanied with guides, carrying thermometers, a chronometer and a cyanometer; Humboldt measured the temperature of the crater, he verified the application of the barometric formula of Laplace*, corrected with the Ramond coefficient, which supposes a regular thermal variation with altitude (decrease of 93 toises-181 m- for 1º). The chemical analysis of the air coming up from the crater and its tenure in oxygen compared to that of the ocean level and finally the intensity of the blue sky.

During their 42 days of sailing, Humboldt was doing observations all the daylight, because the captain had imposed a total blackout because of the English marine. For this, Humboldt was busying himself *“à mesurer la température [de surface] de l’océan et à en trouver le poids spécifique grace aux excellentes balances de Dollond”*.

On 16 July, they arrived at Cumana, on the Venezuelan Coast. *“Les premières semaines de notre séjour à Cumana furent employées à vérifier nos instruments, à herboriser dans les campanes et à reconnaître les traces qu’avait laissées le tremblement de terre du 14 décembre 1797. … Si tout ce que nous environnait était propre à nous inspirer un vif intérêt, nos instruments de physique et d’astronomie excitaient à leur tour la curiosité des habitants”*.

On 7 February 1800, Humboldt and Bonpland left Caracas for the Orinocco river. They admired the botany of the river system, of which both were highly interested in, but also the lives and customs of the Indians, of which Humboldt's "biogeographic" interests played. With one tribe at the village of Barbula, they discovered the "cow tree," a distant relative of the rubber tree, so called because it provided a liquid from its bark similar to a cow's milk. One of Humboldt's servants reported that he drank from it everyday, "and Humboldt, not to be outdone … filled a calabash with the white thick liquid, raised the gourd to his eyes in a mock toast, … then took a deep draught." Bonpland just stared in disbelief (Hagen, p. 108). However, one other servant, "less fortunate, vomited up rubber balls for several hours" (Furneaux, p. 102).

The two conversed with Indians about "curare", a local medicine and poison. "They were aware of the theory that curare could only kill if taken intravenously", a fact utilized by the Indians with poison-tipped darts and arrows, and to test that theory, both drank small bits of it. Humboldt wrote in his narrative:"Its taste is of an agreeable bitter. The Indians consider the curare, taken internally, as an excellent stomachic" (Furneaux, p. 102).

Humboldt conducted research on the piranha, or caribe, and found it to be much less vicious than previous reports, as well as more recent exaggerations, have indicated. He wrote, "It attacks bathers and swimmers, from whom it often carries away considerable portions of flesh. When a person is only slightly wounded, it is difficult for him to get out of the water without receiving a severer wound. The Indians dread extremely these caribes, and several of them showed us the scars of deep wounds in the calf of the leg, and in the thigh, made by these little animals" (Furneaux, p. 102).

* By using the Laplace formula or the Ramond coefficient: **H = (18400+67.53T) logPo/P,** where H is the height in m, T= T-To (difference in temperature of air of the place we stand and temperature at sea level), Po and P are respectively the air pressure at sea level and that of the place. Both pressure are measured in mm of Hg.

However, possibly the most interesting experiments the pair conducted were on that of the electric eel. The world of electricity was still very new and very exciting in the year 1800, only recently having seen the work of Volta and Galvani prove some important concepts. In the region of Calabozo, the locals reported that the small streams overflowed with these eels, and since most people were extremely afraid of them, the gathering of the eels for experimentation proved to be a somewhat difficult process. The solution, at a price of about one dollar payment per man, was to run about thirty horses into the river, stirring up the bottom where the eels lay. Disturbing them, the eels began to discharge, and both because water is a good conductor, and that the eels would literally swim up to the horses' undersides, the horses ran wildly about in the water, trying to avoid the pain. With the Indians forcing them to stay in the water with harpoons, some horses were knocked unconscious, others lost complete control of their legs. In all, two of the thirty drowned before the rest were able to escape, but importantly, the eels had either been trampled upon, or simply got exhausted to the point where the Indians could easily harpoon them from the shore (Hagen, pp. 109-111).

Humboldt was then able to conduct his experiments, noting that most eels ranged from three to five feet long, were cylindrical in cross-section, devoid of scales, and had one long fin on their backs from head to tail. But, while observing these on the shore, he inadvertently stepped on one of them. He wrote, *"I do not remember ever having received a more dreadful shock from the discharge of a large Leyden jar, than which I experienced. … I was affected the rest of the day with a violent pain in the knees, and in almost every joint"*.

Humboldt also wrote of continued experiments: *"[I] often tried, both insulated and uninsulated, to touch the fish, without feeling the least shock. When M. Bonpland held it by the head, or by the middle of the body, while I held it by the tail, and, standing on the moist ground, did not take each other's hand, one of us received shocks while the other did not. … If two persons touch the belly of the fish with their fingers, at an inch distance, and press simultaneously, sometimes one, sometimes the other will receive the shock"* (Furneaux, p. 103).

In a letter to his brother, Wilhelm, Humboldt wrote: *"Je suis créé pour les Tropiques, jamais je n'ai été si constamment bien portant que depuis deux ans. Je travaille beaucoup, je dors peu; souvent quand je fais des observations astronomiques, je suis exposé au soleil pendant cinq à six heures, sans chapeau. J'ai séjourné dans les villes où la fièvre jaune faisait rage et jamais je n'ai eu même un mal de tête"* (Duviols & Minguet, 1994).

On 23 June 1802, Humboldt ascended the highest mountain of the world at that time, the Chimborazo, which derives from quechua *chimpu-raza or moutain of snow* (it was not yet known the height of Himalaya) without the adequat equipment and with no oxygen: *"en petites bottes, en simple habit, sans gants"*. In fact, Humboldt aim was not to conquer the top of Chimborazo, but to observe the relationship between the nature, living organisms, animals and plants, which is the core of his scientific project. Thus, during their long ascension, Humboldt, Bonpland and the young Montufar were devoted to observe the distribution of vegetation, studying its levels in function of the physical factors. Humboldt made a drawing of the mount summarizing this achievement:*"Lorsque du niveau de la mer on s'élève aux sommets des hautes montagnes, l'on voit changer graduellement l'aspect du sol et la série des phénomès physiques que présente l'atmosphère. Des végétaux d'une espèce très différente succèdent à ceux des plaines: les plantes ligneuses se perdent peu à peu et font place aux plantes herbacées et alpines; plus haut, on ne trouve plus que des graminées et des cryptogames. Quelques lichens couvrent les rochers, même dans la région des neiges perpétuelles"* (Alexandre von Humboldt, Tableau physique des régions équinoxiales, p. 37).

9. 2 The most important outcomes of Humboldt's voyage.

- Humboldt was not actually trying to discover much of anything new on this trip, "but to rediscover what was known only by a few, to subject his findings to a more thorough scientific analysis that they had received before, and to sift the mass of facts, theories, and nonsense though his sieve of remorseless logic" (Furneaux, p.101).
- Moreover, as it stated in *Welt erforschen – Welt konstruieren* (Heering, 1998 p. 106): „Die Durchführung von systematischen Messungen auf diesen Reisen wurde vor allem von Alexander von Humboldt gefördert. Humboldt versuchte auf mehreren Expeditionen und mit internationalem Engagement das Messen von Naturphänomenen auf die ganze Welt auszuweiten. Sein Interesse war es, die Anforderungen an die Genauigkeit der Messungen zu erhöhen, und das Sammeln von Beobachtungen und Daten auf weitere wissenschaftliche Bereiche auszudehnen. Eine ganz wesentliche Voraussetzung war die Entwicklung geeigneter Instrumente. Diese mussten kompakt und stabil sein und trotz alle Strapazen der Reise zuverlässig und genau funktionieren. Auch sollten sie möglichst leicht zu bedienen sein, damit sie von wissenschaftlichen Laien, z. B. Armeeoffizieren, benutzt werden konnten".
- Ernst Peter Fischer (2002, p. 46) wrote in his book *Die andere Bildung. Was man von den Naturwissenschaften wissen sollte* the following:„Das schöne an solchen Darstellungen [der Dichter], die auch dem Naturwissenschaftler gefallen, steckt darin, dass sie das enthalten, was Alexander von Humboldt in seinen Vorlesungen über den Kosmos einmal den «Hauch des Lebens» genannt hat. Wenn es gelingen könnte, den naturwissenschaftlichen Entwürfen diesen Hauch zu geben, dann würde auch für Außenstehende einsichtiger, dass hier geistige Genüsse zu gewinnen sind, die einem gebildeten oder bildungswilligen Menschen offen stehen".
- Humboldt's most influential teacher in his youth was the Freiberg geologist Abraham Gottleb Werner, leader of the Neptunist' school opposing the Plutonists. Indeed, Humboldt, still a scholar attacked the theories of volcanism but without embracing those of Neptunism. Humboldt's research corrected also some theories of his time; he was able to improve ideas on the role played by eruptive forces and metamorphosis in the history and ongoing development of the Earth's crust by the conclusions he drew from his observation of the Andean volcanoes. These conclusions disproved once and for all the hypothesis of the so-called Neptunists, who held that the surface of the Earth had been exclusively formed by sedimentation from a liquid state.
- Humboldt investigated again during his stay in Berlin a phenomenon that had aroused his interest in South America: the sudden fluctuations of the Earth's geomagnetic field – the so-called magnetic storms. It had been clear to him for a number of years that, in order to discover whether these magnetic storms were of terrestrial or extraterrestrial origin, it would be necessary to set up a worldwide net of magnetic observatories. In 1836 Humboldt still interested in the problem, approached the Royal Society in London with the request that it establish an additional series of stations in the British possessions overseas. As a result, the British government provided the means for permanent observatories in Canada, South Africa, Australia, and New Zealand and equipped an Antarctic expedition. With the help of the mass of data produced by this international scientific collaboration, the English geophysicist Edward Sabine later succeeded in correlating the appearance of magnetic storms in the earth's atmosphere with the periodically changing activity of sunspots, thus proving the extraterrestrial origin of the storms.
- The American journey of Humboldt and Bonpland remained a model of the scientific voyage:

- as an interdisciplinary enterprise: Humboldt and Bonpland were complements to each other: Humboldt the physician and naturalist, Bonpland the doctor and botanist – two ideal companions.
- by the abundance of data, measurements, observations and descriptions.
- by the affirmation that field work is essential in scientific research.
- by the emergence of new disciplines: plant geography, study of terrestrial magnetism, physical oceanography, climatology.
- by the painting of spectacles of the nature.
- by the attention turned on Spanish America on the eve of its independence: analysis of the Creole societies, denunciation of slavery, and rehabilitation of Indians.

It was a scientific adventure that marked these two men during all their lives and which finds its extension in today's research (Drouin & Lalande, 2003, p.11).

- Humboldt's *Political Essay on the Kingdom of New Spain* contained a wealth of material on the geography and geology of Mexico, including descriptions of its political, social, and economic conditions, and also extensive population statistics. For instance, Humboldt made precise statistics about the annual productions of Mexico in agriculture, Gold and Silver and compared them to those of Russia.
- Humboldt was the first who recorded about the life of the native Indians and slavery in Latin America and his books are still used as references for that era.
- In Humboldt's time navigators had the misconception that Earth magnetism was constant everywhere, and that changes of the needle compass during navigation were a defect in the apparatus. With his observations and daily measurements of the terrestrial magnetic field, Humboldt could prove that the Earth magnetism varied with longitude and that it undergoes changes yearly.
- Humboldt described and classified lots of plants and animals during his trip, still unkown to Europeans. When it was difficult to do detailed experiments, he sent samples (like filled bottles with air from Chimborazo) to Europe. Humboldt's herbarium contained 5800 species, among them 3600 were never described before (Drouin & Lalande, 2003, p.10). This means that he and Bonpland have enriched the international botanical inventory of species of that epoche of 5 to 6 %! (Duviols & Minguet, 1994, p. 65).
- During his trip Humboldt could verify the precision, the reliability, the inconvenience and the disadvantages of the instruments of that time (e.g. eudiometer of Volta, or the hygrometer were useless because of acute humidity of the air).

9. 3 Reproducing Humboldt's instrument: the Anthracometer.

"Voici la liste [des instruments] dont j'avais fait l'acquisition dans deux ans qui ont précédé mon départ; je crois qu'il est utile de la consigner ici, parce qu'elle peut servir à diriger le choix des personnes qui entreprennent des voyages lointains „ This is how Humboldt started the introduction of his *Recueil d'observations astronomiques, d'opérations trigonométriques et de mesures barométriques* (Appendix B). Humboldt drew up an exhaustive list of the carried instruments. These instruments were chosen according to two criteria: they must be made of resistant material and be of small size in order to carry them easily. For this, he asked the most famous manufacturers of the physical instruments in London, Paris and Geneva to prepare them.

In the bottom of his list, came the absorption tubes or *"des tubes d'absorption propres à indiquer de petites quantités d'acide carbonique ou d'oxygène, au moyen de l'eau de chaux* *on d'une dissolution de sulfure de potasse"* (Alexandre von Humboldt, Voyage aux régions équinoxiales du nouveau continent, Tome premier, livre 1, pp. 113-114).

These absorption tubes are supposed to be anthracometers, which were invented by Humboldt and described in details in his book *Versuche über die chemische Zerlegung des Luftkreises und über einige andere Gegenstände der Naturlehre* (1799, pp. 81-99). Humboldt explained its name: *„Der Name Anthracometer, welchen man diesem Instrumenten zu geben anfängt, ist nicht ganz sprachtig gebildet. Die lebendige Nervenfaser ist ein wahres Anthrakoskop, der Kohlensäuremesser aber ein Anthroxyometer. Er misst die Menge der Säure und nicht die Menge des Kohlenstoffs. Doch kommt es bei solchen Bennungen nicht auf die pünktlichste Genauigkeit an, und, da man gar eigentlich Oxyanthrakometer sagen sollte, so würde ich selbst den wohlklingenden Namen Anthrakometer vorziehen"*.

Remarkably, Humboldt's instrument is used to measure carbon dioxide and oxygen in air. So, it plays partly the same role as the eudiometer: it is used to measure the purity of air, that is, its oxygen content, information that was particularly significant for studies in respiration. For instance, in *Ninetheenth-Century Scientific Instruments*, there is detailed information about eudiometers. One of them, the eudiometer devised by Thomas Charles Hope (1766-1844) and published by William Nicholson in his *Journal of natural Philosophy, Chemistry and the Arts*, used a solution to absorb the oxygen and was intended for analyzing atmospheric air at lecture-demonstrations. It used alkali sulphide solution to absorb the oxygen. This was contained in a bottle, into the neck of which the tube with the air sample was inserted. When the bottle was placed under water and its side stopper removed, the level of the water rising into the graduated tube showed how much oxygen had been absorbed (Turner, 1983, p. 224). In fact, this type of eudiometer has the same principle of Humboldt Anthracometer.

The followings paragraph is the **verbatim** text taken from *Versuche über die chemische Zerlegung des Luftkreises und über einige andere Gegenstände der Naturlehre* (1799, pp. 90-99) and where Humboldt described in details the dimensions as well as the functioning of the Anthracometer (Figure 3). I succeeded to reproduce this instrument that importance resides in its historical value (Figure 4). I did not work further on it in order to use it. This was not my aim and it costed me lots of time, so I used it at school as an aid-material while I was narrating to students about Humboldt's life (Appendix C):

„Das instrument besteht aus einer 3.5 bis 4 Linien weiten, etwa 12 zoll langen sehr starken Glasröhre, die sich unten in eine Kugel von 1.2 bis 1.3 zoll Durchmesser endigt. Die untern 3 Zoll der Röhre werden an der Lampe so umgebogen, dass die Kugel nicht über 0.7 Zoll weit von dem Rohre absteht. Dieser geringe Abstand ist nötig, um den Kohlensaeuremesser in ein enges Glass mit Wasser tauchen zu können. Die übrigen Dimensionen sind gleichgueltig. Es kommt nur darauf an, dass die Röhre in dem obern Teile ab durch Kalibration gleich weit gefunden und nicht zu enge ist, um sich bequem zu füllen. Verengerungen oder Erweiterungen in c und d sind für den Gebrauch ganz gleichgültig, wenn zur Ersparung der Reagentien die ganze Capacität des Instruments nur nicht über 2 bis 2,5 Kubikzoll beträgt. Die Röhre abc ist in der mitte bei e dergestalt zerschnitten, dass der obere teil a e etwa 7 Zoll Länge behält. Beide Teile sind in Metall gefasst (geküttet) und können so fest auf einander geschroben werden, dass Glas auf Glas passt und auch ohne dazwischen gelegtes Leder keine Flüssigkeit bei e ausdringt. Das obere Ende der Röhre ist in einen, etwa 6 linien hohen metallen Cylinder geküttet, der von aussen bei 8-9 sehr enge Schraubengänge hat und an der Mündung kegelförmig ausgedreht ist. In diese Mündung nun passt ein konisches

Muschelventil g von 1.2 Linien dicke. Ein zweiter Cylinder von Metall h, der bei 5 Linien höhe oben durch eine Platte verschlossen und inwendig als Schraubenmutter ausgehölt ist, passt als Deckel auf die Röhre und drückt, indem er aufeschroben wird, auf das Muschelventil. Um diesen Druck zu vermehren, ist die Platte k l in der mitte durchbohrt und eine zweite Schraube m presst das Ventil auf die Mündung der Röhre.

Diesen Verschluss, der überaus luftdicht ist und jeden Stoss aushält, kann ich überall empfehlen, wo die Dünnigkeit des Glases den Gebrauch eingeriebener Stöpsel untersagt, oder, wo es darauf ankommt, das zu erreichen, was der schieber des Fontanaschen Eudiometermasses erreicht, nämlich, genau gleiche Volumen einer luftförmigen oder tropfbaren Flüssigkeit abzuschneiden. Herr Kleinsteuber zu Weimar und der verfertigen Luftmagazine, welche mit diesen doppelt angeschrobenen Muschelventilen versehen sind.

Der Gebrauch des beschriebenen Absorptionsgefässes ist sehr einfach. Soll es, z.B. als Kohlensäuremesser benutzt werden, so füllt man das ganze Gefäss mit flüssigem ätzenden Ammoniak. Um die Luft aus der Kugel auszutreiben, fasse man das Instrument mit 3 Fingern so, dass der Zeigefinger auf dem Ventile aufdrückt. Die gebogene Röhre acd muss so gehalten werden, dass sie in eine durch den Arm senkrecht gelegte Fläche fällt und dass die Kugel nach aussen gekehrt ist. Indem man nun die Hand herabbeugt und das Instrument schnell nach innen gegen den Ellenbogen bewegt, so dass a senkrecht unter c zu stehen kommt und nun e einen halben Kreis beschreibt, so sinkt die Flüssigkeit aus der Röhre abec in die Kugel herab und verdrängt die Luft daraus, welche, indem man die Hand wieder aufwärts beugt, in die Röhre hinauf steigt. Ich gebe diesen Handgriff vorsetzlich mit pedantische Genauigkeit an, weil ich Personen kenne, die ihn von selbst nicht aufgefunden haben, und den Kohlensäuremesser, der in 2 Minuten vollkommen gefüllt werden kann, so halten, dass neue Luftblasen in die Kugel dringen, wenn sie bereits ganz mit Ammoniak gefüllt ist.

Will man die Kohlensäure untersuchen, welche in der Abendluft enthalten ist, so giesse man an einem freien Orte einige Tropfen Ammoniak aus der Röhre aus, so dass die Flüssigkeit nur bis b steht. Ist der obere Teil der Röhre eingeteilt, so kann man sogleich die zu prüfenden Luftmengen ablesen. Ist sie es nicht (und ich ziehe den letztern Fall vor, weil das Instrument sonst unnötig kostbar wird) so fasse man mit dem Cirkel die Länge der Luftsäule ab und trage sie auf einen Masstab. An dem ein Zoll wenigstens in 50 Teile geteilt ist. Richer in Paris und Renard in Berlin, verfertigen dergleichen Masstäbe sehr scharf in Glas mit dem Demant geschnitten. Gesetzt, die Luftmenge betrage 206 Teile. Man schliesse das Ventil durch die Schrauben und lasse die 206 Teile mittelst des vorher angegebenen Handgriffes in die Kugel steigen. Hier befinden sie sich in einer vorteilhaften Lage zur Absorption. Wenig Luft ist mit vielem, eine grosse Oberfläche darbietenden Ammoniak in Berührung. Die Säule ac macht selbst einen kleinen Druck, der unter dem Ventil einen luftleren Raum veranlasst. Man findet eine kleine Schwierigkeit, das Ventil aufzuheben, und indem man die äussere Luft hineindringen und den Spiegel der Flüssigkeit um 0.01 bis 0.02 sinken sieht, ist man geneigt einer anfangenden Absorption zuzuschreiben, was bloss von dem hydrostatischen Drucke abhängt.

Indem nun die Absorption in der weiten Kugel so unmerklich ist, dass kein steigen beobachtet werden kann, so sinkt das Ammoniak in den engen Röhre sehr sichtbar. Glaubt man die Absorption vollendet (was durch einen Stillstand im Sinken angedeutet wird) so fülle man die Röhren abc wiederum gänzlich und schliesse sie mit dem Ventile. Durch einen Handgriff, der den vorbeschriebenen gerade entgegengesetzt ist, durch ein drehen des

Instuments um e, indem die Kugel gegen den Körper des Physikers hin gehalten wird, steigt nun die verminderte Luft aus der Kugel in die Röhre zurück. Wollte man hier unmittelbar ihre Länge mit dem Cirkel messen, so würde man sehr irren, da aus der Construction und Behandlung des Instruments leicht einzusehen ist, dass die Luft nunmehr nicht dieselbe Elasticität haben kann, in der sie zuerst gemessen ward. Sie ist comprimiert, und ihre geringere Menge ist daher nicht der Absorption allein zuzuschreiben. Um diesen Irrthum zu vermeiden, habe ich die Schraube bei e angebracht. Ich tauche das ganze Instrument in ein Glas mit Wasser, so dass der Wasserspiegel über e reicht. Indem nun die von Kohlensäure gereinigte Luft unter dem Ventile steht, schraube ich e auf und halte den obern Teil der Röhre senkrecht so tief unter Wasser, dass die äussere und innere Oberfläche der Flüssigkeit in einer horizontalen Fläche liegen. Die eingeschlossene Luftmenge setzt sich nun in das Gleichgewicht mit der Atmosphäre und wird in diesem Zustande gemessen. Bleiben von 206 Teilen nur 202.5 übrig, so war demnach die Menge der Kohlensäure genau 0.017.

Diese Berechnung ist unter der Voraussetzung gemacht, dass Temperatur und Elasticität der Atmosphäre, während der Absorption keine Veränderung erlittern hat. Um auf diese beiden Verhältnisse Rücksicht nehmen zu können, ist das Instrument sehr bequem eingerichtet. Die Eröffnung der Schraube e giebt der geprüften Luftsäule sogleich die Elasticität der äussern Athmosphäre, und will man nicht zugleich auch die veränderte Temperatur in Rechnung bringen (sondern nur für das Barometer corrigieren) so macht das Eintauchen des Instruments im Wasser, diese Arbeit entbehrlich. Flüssigkeiten verändern ihre Temperatur zu einer Jahrszeit nur wenig, und selbst der bestimmte Wärmgrad von 10 Degree Reaumur (wenn man gerade diesen wählen sollte) ist durch Mischungen leicht hervorzubringen. Neben dem aufgeschrobenen Kohlensäuremesser hat ein Thermometer noch immer auch in dem kleinsten Wasserglase platz. Die Bestimmung der verschluckten Luftmengen und die Correction nach dem Barometer- und Thermometerstande ist die Arbeit weniger Minuten.

Da die Genauigkeit der Mischung von dem Verhältnis der Kapacität der Kugel zu der der Röhre abhängt, so würde es bei andern Dimensionen leicht sein, nach den 0.0001 Teil, der zu prüfenden Luftmenge sichtbar zu machen. Wenn indess die Feinheit der Messung keine grenzen hat, so ist jedoch bei allen physikalischen Arbeiten ein gewisses Maximum anzugeben, über welches hinaus den zahlen nicht mehr zu trauen ist. Wenn ich die Polhöhe eines Orts, mehrere Tage hinter einander, mit einem zweizöllingen Dosensextanten bestimme; so kann ich durch mittelzahlen die Bestimmung bis auf die zehnten Teil einer Sekunde treiben. Wenn ich die im Fontanaschen Eudiometer geprüfte Luft in ein Senebiersches konisches Glas übergehen lasse, so kann ich die Absorption bis auf Hundertteile eines Grades angeben. Was hilft aber diese scheinbare Genauigkeit, da ich weiss, dass ich bei dem Nivellieren des allzukleinen Horizonts, in welchem die Sonnenhöhe genommen wurde, um 30-45 Sekunden, in dem Schütteln der Gasarten über Wasser, um 1 bis 1.5 Grade irren kann? Man muss bei jedem astronomischen oder physikalischen Instrument genau untersuchen, welches die kleinsten Teile sind auf deren Bestimmung man sich verlassen darf. Bei dem oben beschriebenen Absorptionsgefässe, glaube ich, diese Gränzen bei Tausendteilen festsetzen zu können versuche mit einerlei Luft in verschiedenen Röhren haben nie über halbe Hunderteile von einander abgewichen. Die Ausdrücke 0.016, oder 0.009 darf man sich daher nur insofern erlauben, als sie blos etwas mehr, als anderthalb, oder weniger als Einhundertteil ausdrücken. Nicht 0.001 aber wohl 0.003 mehr oder minder, glaube ich, bei reinlicher und sorgfältiger arbeit unterscheiden zu können.

Zur Bestimmung der Kohlensäure ist auf physikalischen Gebürgsreisen, Kalkwasser dem Ammoniak weit vorzuziehen. Es absorbiert eben so schnell, es ist leichter zu bereiten und (was am wichtigsten) das blosse Auge entscheidet über seine Güte. Aetzende Schwererde wirkt oft weniger, als Ammoniak und Kalkwasser. Bei dem wichtigten Versuche über den Demant, welchen Herr Guyton vor wenigen Wochen in der Ecole polytechnique anstellte, wurde die Luft, welche nach dem Volumen übrig blieb, mit Schwererde in Berührung gesetzt. Nach mehreren Tagen sollte ich die nun von den Kohlensäure befreiten Gasarten, in Rücksicht auf ihren Sauerstoffgehalt prüfen. Ich wusch sie aus Vorsicht vorher mit Ammoniak und fand noch 0.03 Kohlensäure, welche die ätzende Erde übrig gelassen hatte. Viele Chemisten ziehen überhaupt die Absorption der Kohlensäure durch feste Substanzen der durch Flüssige vor. Auf Bestimmungen nach der Gewichtszunahme ist dabei zwar nicht zu rechnen, weil die hygroskopischen Veränderungen jeden Calcul fehlerhaft machen. Aber man entbindet die Kohlensäure selbst aus den kohlengesäurten Stoffen und misst sie so, wenn sie einzeln dargestellt ist. Die Vorzüge dieser Methode scheinen mir aber darum nur sehr geringe, weil man beim austreiben der Kohlensäure die Luft der entbindungsflasche ohne Verlust an Kohlensäure, nicht rein absondern kann und also, wenn man alles zugleich aufsammelt, entweder zu einer unsichern Schätzung der Capacität der Gefässe, oder doch gar zu einem absondern der Kohlensäure durch Kalkwasser schreiten muss. Man gelangt also auf einem weitläuftigen Wege dahin, wohin ein kürzerer unmittelbar führt.

Dass der Kohlensäuremesser, als allgemeines Absorptionsgefäss, z.B. zur Abscheidung des Stickgases von dem Salpetergas durch die Auflösung von schwefelsaurem Eisen (sulfate de fer) zur Verschluckung des Atmosphärischen Sauerstoffs, durch aufgelöstes Schwefelalkali, durch die Solution von salzsaurem Zinn, durch Wasser mit einer Alaunerde, oder Dammerde gemengt, durch den Aufguss von Alkohol auf frische Baumbläter u.s.w. gebraucht werden kann, bedarf hier keine Ausführung. Als acheelsches Eudimeter mit Schwefelalkali habe ich es und haben es andere besonders mit grossem Vorteil benutzt. Da man das kleine Instrument sehr bequem in ein Glas mit heissem Wasser tauchen kann, und da alle Affinitäten bei erhöhter Temperatur schneller wirken, so habe ich oft bei 40 Degree Reaumur in 6-8 Stunden schon 0.14 Oxygen verschwinden sehen. In 18-24 Stunden ist die ganze Absorption, zu der Scheele mehrer Tage brauchte, bereits vollendet. Bei dem Erwärmen des Instruments muss natürlich das Ventil bei a aufgeschroben werden. Dass die zu prüfende Luft in der Kugel sich weit ausdehnen sollte, dass sie durch den gekrümmten Hals dc aufwärts stiege, ist, da sie kaum ein 3 bis 400 Kubik-linien beträgt, nicht zu fürchten.

Die Herren Mossy, Betailly, Dumotiez zu Paris verfertigen mit vorzüglicher Genauigkeit das hier beschriebene Absorptionsgefäss. Zwei, oder auch vier davon lassen sich bequem in ein 10 Zoll langes, 6 Zoll breits und kaum 1.5 Zoll hohes Futterall packen, das man auf Bergreisen nicht unbequemer als ein Seaussüresches Hygrometer, bei sich führen kann. Statt der messingenen, oder eisernen gefirnissten Schraube bei e, sollte man versuchen, die obere Röhre in die untere, etwas weiter einzuschleifen. Bei der Arbeit mit Schefelalkali würde man dadurch an Reinlichkeit gewinnen. Wird eine geringere Genauigkeit der Messung gesucht, so kann man die Röhre abc ganz unzerschnitten lassen. Man rechnet dann so viel Teile, als man von der absorbierenden Flüssigkeit zugiesst, indem die Luft beim ersten eintreten in die Kugel ihre Elasticität verändert, von der gefundenen Absorption ab, und verwandelt dadurch die scheinbare Luftveränderung in die Wahre. Ja! man kann auch (was noch einfacher ist) die Menge der zu prüfenden Luft erst dann bestimmen, wenn man sie nach dem zugiessen, oder gänzlichen füllen der Röhre, sogleich in dieselbe zurücksteigen lässt und in diesem verdichteten Zustande misst. Alsdann ist beim Messen nach der Absorption, wenn die Luft zum zweiten Male aus der Kugel in die Röhre tritt, jede Correktion entbehrlich. Wer nur einigermassen mit den ersten Grundsätzen der Hydrostatik bekannt ist, wird das Maximum des Fehlers, welcher bei dieser letztern Methode begangen ward, leicht von selbst auffinden„

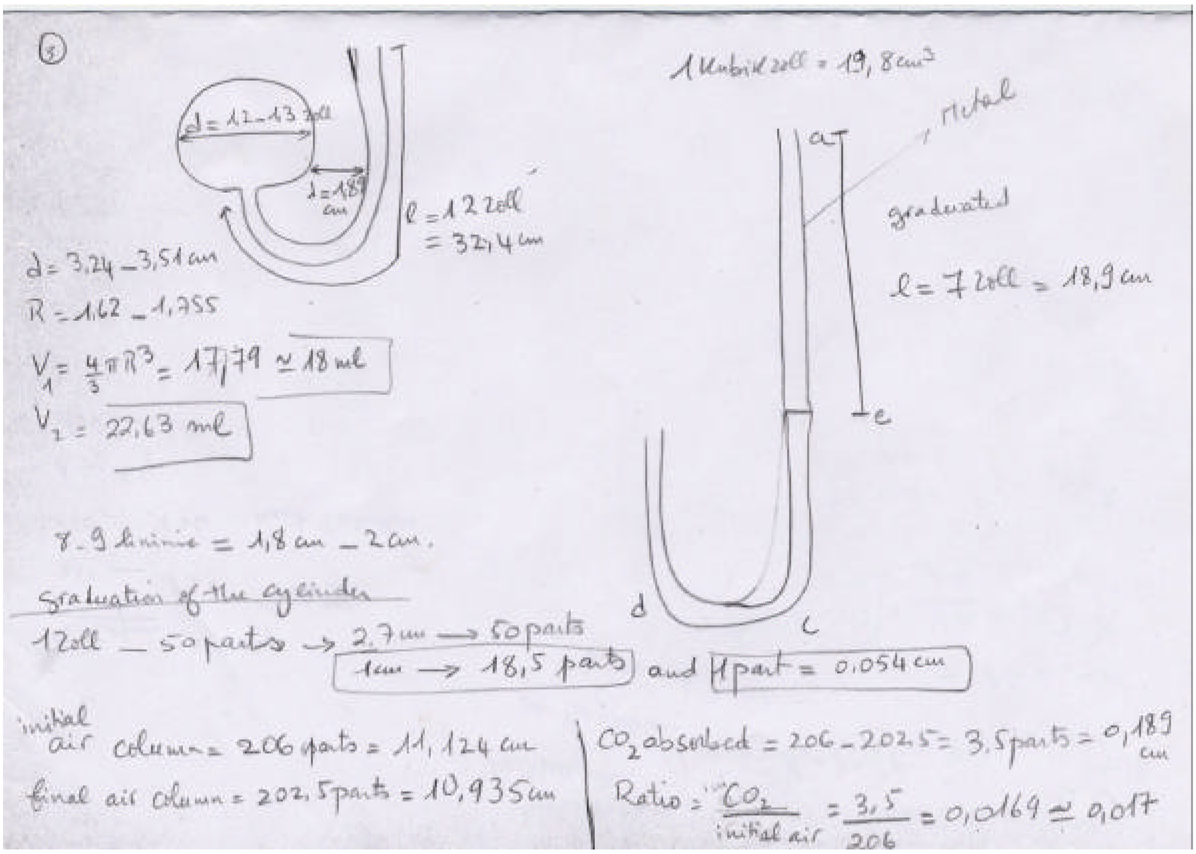

Figure 3: represents the detailed calculations that I’ve decoded in Humboldt’s description of the Anthracometer.

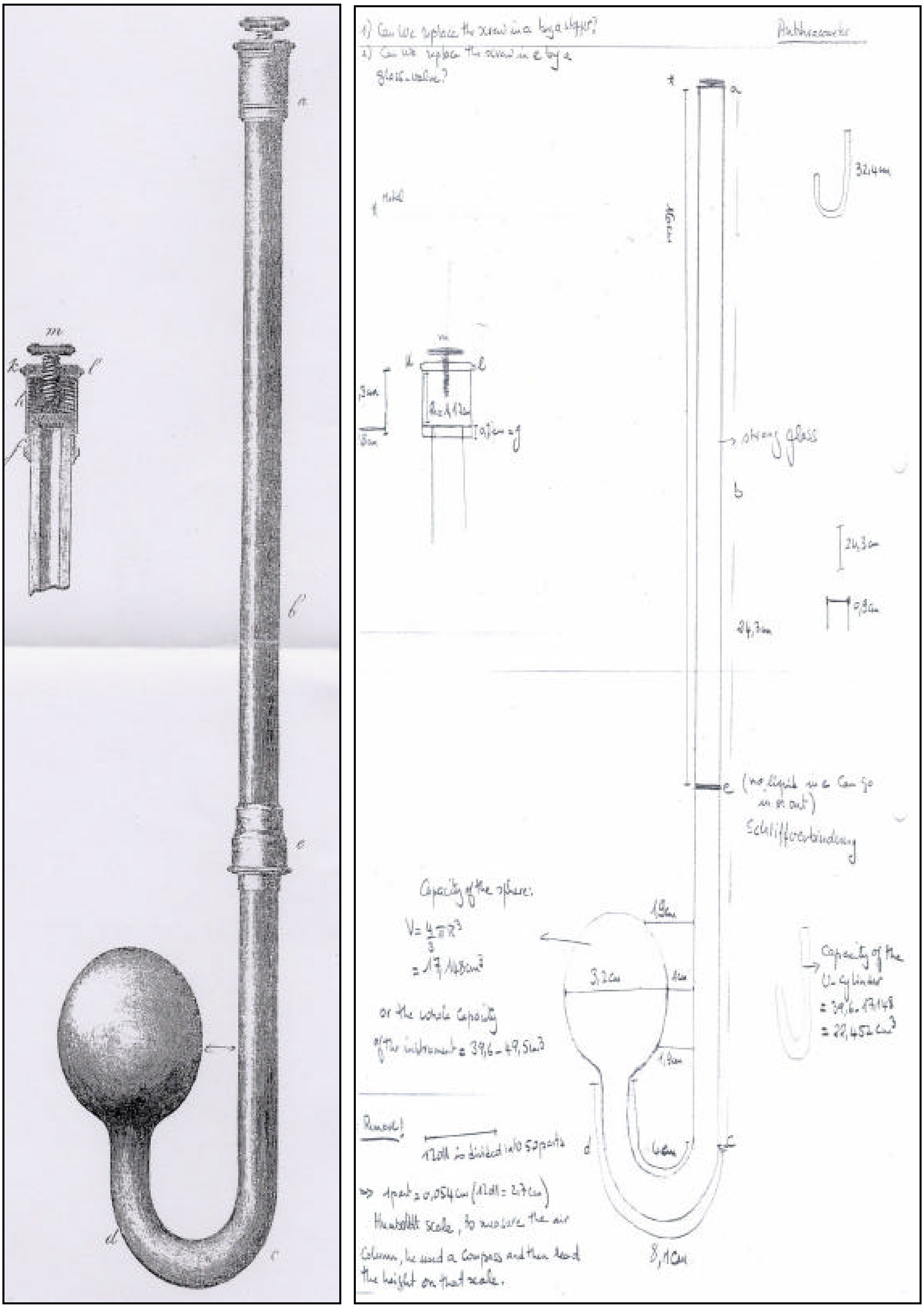

Figure 4: represents the Anthracometer sketch in Table 1 in *Versuche über die chemische Zerlegung des Luftkreises und über einige andere Gegenstände der Naturlehre* (Alexander von Humboldt, 1799) and my sketch with the Antrachometer's precise dimensions.

9. 4 Reflections on Humboldt's journey and the main difficulties faced during the bibliographical research.

🔹 Humboldt presented all the time brilliant ideas. In his *Voyage in the equinoctial regions*, he wrote about the increase in temperature of our planet, and he talked about it also in his public lectures in Berlin; in his *Voyage*, Humboldt wrote: "does the quantity of free calorific remain the same during thousands of years? have the mean temperatures corresponding to different parallels augmented, or diminished, since the last revolution that altered the surface of the Globe? We cannot answer these questions in the present state of our knowledge; we are ignorant of every thing that relates to a general change of the climates, as we know not whether the barometric pressure of the atmosphere, the quantity of oxygen , the intensity of the magnetic powers, and a great number of other phenomena, have undergone any change since the time of Noah…. It is only by the comparison of a great number of observations, made in different parallels of latitude, and at different degrees of longitude, that we shall be able to solve the important problem of the increase of the heat of the Earth… As a preparation for this work, we must carefully determine, at a given period, the *maximum* of the temperature of the waters of the sea under the tropics, and in the *parallel of the warmest waters*. We have proved, that this maximum is at present, in places and the most remote from each other, from 28º to 29º of the centigrade thermometer. Very distant posterity will one day decide, whether, as Mr. Leslie has endeavoured to prove by ingenious hypothesis, two thousand four hundred are sufficient to augment the mean temperature of the atmosphere a single degree. However, slow this increment may be, we must admit, that an hypothesis, according to which organic life seems gradually to augment on the Globe, occupies more agreably our imagination, than the old system of the cooling of our planet, and the accumulation of the polar ice. Some parts of physics and geology are merely conjectural; and it might be said, that science would lose much ot its attraction, if we endeavoured to confine this conjectural part within too narrow limits" (Personal narrative of travels translated to English by Helena Maria Williams, 1818-1829, pp. 83-84).

🔹 In sum, Humboldt's *scientific* observations collected from Alexander von Humboldt's letters and from his daily observations in his *Voyage aux régions équinoxiales* were:

a. botanical and zoological observations (some examples):

1. composition of air circulating in the *clusea*
2. composition of the mushrooms milk
3. study of the respiration of crocodiles

b. physical, chemical and geophysical observations:

1. air temperature
2. sea temperature
3. hygrometrical state of air
4. colour of the sky and sea colour at its surface
5. inclination of the magnified needle. Intensity of magnetic forces
6. electricity of the air
7. determination of longitudes and latitudes
8. determination of the height of mountains
9. determination of the quantity of the rainfall
10. chemical composition of the air

🔹 During my biographical research, I was so deeply involved in Humboldt's life that I was even telling my surrounding about him and his achievements. I was interested in his letters, especially because one could follow his thinking and feelings day by day and one could know lots about his scientific, social, and political correspondence and subsequently about the European society in his time. Indeed, he never stopped corresponding with his friends; he even wrote a letter to his friend Varnhagen von Ense three days after his brother's death.

- Because of the rarity of the original publications of Humboldt, I was allowed only to use them inside the library; this costs more time and especially with copying and scanning.
- The old used terms, especially in chemistry (e.g., adipoccre or ozmazome) as well as all his botanical publications in Botanic, and most of all, the different unit system (Toise, pariser Foot, etc ..) nowadays and the search for many formulas, such as Laplace and Ramond coefficent, made the search more difficult and coasted more time.
- Moreover, before their trip in 1799, there was not yet a unified measure although the metric system was established in 1798, but not commonly used. Furthermore, there was not yet a conventional meridian, so Humboldt was making his measurements with reference to the Parisian one.
- I knew little about geodesy nor astronomy; I lacked the knowledge of many specific terms, such as an austral and a boreal altitude, or the sun azimuth... so the more I was reading about Humboldt's achievements, the more I was learning about different disciplines in science.
- Not only I was collecting what Humboldt discovered or did, I had to look also for the methods he used for collecting his data; for example, the trigonometric method used to measure a height of a distance or the different methods at his time to measure longitudes and latitudes. So I had additional bibliographical search about history of scientific methods and discoveries. In a short time I was overloaded with lots of information!
- Humboldt's instruments are scattered in different museums between Berlin, Munich and Paris. I had lots of questions concerning their functioning, such as, how is the Quadrant of Bird used or the Borda compass, or the eudiometer, etc.. So, on one hand, I had only to read about them in books and on the other hand I had to look for the modern ones suitable for the same measurements, in case I would do similar measurements with students.
- Humboldt was generous in communicating his ideas; his books were like personal portfolios that depicted his thoughts and emotions. Moreover, he introduced especially his observations and measurements by giving a historical synopsis of previous work in the similar domain. For instance, Humboldt noted in his *Voyage* that the intensity of magnetic forces had been a very important phenomenon and that had captured little attention from physicists so far. Before him, Graham and Muschenbroek had tried to measure the diurnal variations of this force by the speed of horizontal variations of a magnetic bar. But before them, Borda had the idea to use the inclination compass in different places of the earth… Humboldt, himself, used to measure the terrestrial magnetic forces by the number of oscillations of a horizontal or a vertical needle! (Alexander von Humboldt, Voyage aux Regions Equinoxiales, pp. 134-154).
- Humboldt's work presented a valuable source for designing activities for students. For instance, Humboldt analyzed the composition of vegetable milk: the juice of a mushroom *agricus piperatus* that contains albumen, which renders them so hard when boiled. He could prove also that when (morchella esulenta) is converted into a (sbaceous) and (adipcerous) matter, it can be used in the fabrication of soap.
- Although his publications about Botany were in Latin, it was clear that Humboldt sticked to one method in describing the plant. In his *Révision des Graminées*, I had the

impression that I leafed through a book for children, because everything about the plant was presented and classified in an easy and colorful way.

9. 5 Proceeding with Humboldt monumental work.

Humboldt used a descriptive and narrative way in writing. Sometimes, he could write pages describing an event (when he spent the night in the governor place) or an accident: for example, during the Chimborazo ascension, he narrated how very difficult it was to handle the barometer and at the end, it was broken. So, now, he had to reproduce the Toricelli barometer and had to carry mercury in his hand etc. Even the Humboldt's biographies when dealing with his different observations, they used the same monotonous way of narration. As Minguet (1969) remarked:*"… la plupart du temps, les biographes Humboldtiens accompagnent le voyageur pas à pas en mentionnant au fil des jours les innombrables faits observés par Humboldt, et qui vont de l'énumération de phénomènes météorologiques, d'observations astronomiques, botaniques, zoologiques, à des considérations politiques, ethnographiques, sociales, historiques, etc.. Le lecteur éprouve une pénible impression de monotonie et de lourdeur…",* and that " *Humboldt had taken immense pains to discipline his inclination to discursiveness, which often gave his writing a certain lack of logical coherence"* (Britannica, 1991).

For these reasons, I found it easier and more functional to rely on his letters, his only way to communicate his findings to his colleagues in Europe at every step of his journey, because that's how he let them know of his discoveries and observations, as well as his thoughts were immediately recorded.

Furthermore, it contained interesting thoughts such as when he remarked on 23 September 1799: *"… les singes sont d'autant plus tristes qu'ils ressemblent plus à l'homme. Leur gaieté pétulante diminue à mesure que leurs facultés intellectuelles paraissent plus dévelopées"* and when he studied in Cumana the "sommeil des plantes" (Minguet, 1969, p. 118), or when he expressed his hope that the *"… nous apprenons ici que Bonaparte, Berthollet et Monge sont retournés en France; que l'armée d'Orient reste toujours victorieuse… Jugez quelle joie nous ont cause ces nouvelles"* (letter addressed to Comte Fourcroy, from La Guaira, on 25. 1. 1800, in Moheit, 1993).

In a letter to Jean Claude de Lamétherie (from Cumana, on 18. 7. 1799), Humboldt wrote:

> Vous vous souvenez des dernières belles observations du cit. *Coulomb* sur l'air[27] qui sort avec explosion des troncs d'arbres lorsqu'on les perce. J'ai fait ici des expériences sur le *clusea rosea*, dans lequel (c'est dans l'intérieur des vaisseaux pneumato-chimifères de Hedwig[28], *vasa cochleata* de Malpighi[29]), circule une immense quantité d'air. Cet air contient jusqu'à $\frac{35}{100}$ d'oxigène. Les feuilles du même arbre, exposées au soleil sous l'eau, ne donnent pas un millimètre cube d'air. Cet air qui circule sert certainement (comme dans le corps animal), pour coaguler, par l'absorption d'oxigène, la partie fibreuse. Le *clusea* est une plante laiteuse, et il s'y forme un gluten élastique.
>
> Quoique la pureté de l'air atmosphérique monte ici, principalement la nuit, au-delà de 0.305 d'oxigène, j'ai trouvé que l'air contenu dans les siliques et capsules des plantes équinoxiales, par exemple, des *paullinia*, est plus azoté que notre air atmosphérique. Il ne monte guère au-dessus de 0.24 à 0.25 d'oxi[111]gène. L'air dans les *culmi geniculati* n'a ici que 0.15 d'oxigène. Tout cela prouve que l'air qui circule est plus pur; et que l'air qui est en repos, déposé dans des capsules ou *utriculi*, est moins pur que l'air atmosphérique. Le premier est récemment produit par les organes qui décomposent l'eau; il se porte là où il doit servir, par son abondance d'oxigène, à précipiter la fibrine, à former le tissu fibreux; l'autre est le résidu d'un gaz qui a déjà achevé de faire ces fonctions.
>
> Salut, etc. *Sign.* ALEX. HUMBOLDT.

a. What I thought and did after reading this letter:

1. I looked for this plant.
2. I searched for the Coulomb method (I could not find out what it is).
3. I looked for the method that was used in those times to prove that plant leaves produced gas (it is Ingenhousz method).

b. What I thought as students' activities:

1. I can show that leaves are like *factories* of oxygen. And since Humboldt proved that the clusea contains more Nitrogen that the surrounding air, it means that plants purified the air that we breathe (air pollution).
2. to prove that leaves produce gas ; pupils can follow the same Ingenhousz method, by plunging the leaves of a plant in water and exposed to sun. Then in the night. To repeat this experience with river and boiled water. They will record every time their observations.

10 The yield for the classroom.

10. 1 The main objective of the study is using the history of science to promote the understanding of the nature of science.

1. Humboldt's main objective was to demonstrate the unity of nature within the multiplicity of sense experience. For this he used **the comparative method**. At the same time for him facts, measurements and number were the cornerstone of science. So data collection in nature was a substantial part of his science. He believed in **universal harmony and equilibrium in nature**, and was unable to perceive the importance of oppositional forces in any development (Biermann, Kurt-R., in Dictionary of scientific biography, p. 549). Furthermore, being a lifelong bachelor and thus being able to dedicate every minute of his life to very many fields in Science he developed an **encyclopaedic thinking.** His basic scientific attitudes were close to those of Goethe and Schelling. In the beginning of the 21st century the attitudes of "normal science" (T.S.Kuhn) are, of course, different. Empiricism and analytical consciousness have vanquished romantic natural philosophy, and encyclopaedism is being replaced by interdisciplinarity. The question here is: should I communicate his 19th century aims, objectives and methods to students or should I simply use his discoveries to design some activities? (This was my approach in the pilot study.) Is it acceptable to reduce Humboldt's science to the common grounds it shares with modern science? Should Humboldt' 19th century Nature of Science (NOS) be in the focus of my teaching or nowadays' NOS? What decisions have other science teaching approaches taken that use the History of Science (HOS) to promote the nature of science?
2. Lin, 2002, in Taiwan, used HOS to emphasize the development of a scientific concept or theory; students were provided historical-rich supplementary materials as hands-on activities analogous to previous scientists' experiments or ideas, such as, Toricelli's mercury- and Boyle's J-tube experiments. In this way, students were put in the same situation as these scientists and went more or less through the same steps of their scientific speculations and inquiries. In this way, they are taught implicitly about the nature of science. Should I do similar research? Indeed, based on my teaching experience, I think that this procedure would not be suitable, because many students would not be interested in it at all; they could read simply about it.
3. Wagenschein, on a couple of occasions insisted on studying the basic problems (and experiments) at the bottom of modern science such as Galileo's swinging

candelabrum, Blaise Pascal's mounting of the Puy de Dôme to measure its height or repeating Faraday famous lecture-experiments on the chemistry of a candle. He argued (very similar as Piaget did) that genuine understanding of a problem in physics or mathematics may parallel the historical road of argument. Wagenscheins objective of "Ursprüngliches Verstehen und Exaktes Denken" in his "genetic-socratic-exemplaric" teaching, indeed, explicitly aimed at understand the nature of science. His way of teaching is highly demanding (Buck, 2003). Will I, as a guest-teacher in few lesson-periods, be able to live up to such demands?

4. A third approach is by the means of the used instruments for his different investigations, students can perceive how science knowledge has developed historically. For this approach, in my opinion, students can simply go to the museum to see the collections of different apparatus exposed chronologically. There is a more sophisticated method, however, that makes use of historical instruments in promoting both history of science and nature of science (Höttecke, 2001): It is the process of reconstructing historical apparatus that yields insight in the process of Science. Thus reconstructing a given apparatus, say Faraday's induction apparatus, is a method of reconstructing both the historical process of discovery important in science history and the pattern and path of scientific reasoning. Again: Will I be, as a guest-teacher in few lesson-periods, able to live up to such demands?
5. A forth approach is by starting the unit to be taught by telling a story (Solomon, 1992) and then for a definite time, implementing a ready teaching unit about a specific topic, like how was a sextant developed and performed. The objections made against this approach can be summarized under the name of the "quarry-reproach": HOS is used as a stone pit for motivation or content; it is a surrogate to "closeness to life".
6. So, what is needed is a stronger justification, than the one that argues with science content or with motivation. To formulate again my objectives: it is making students learn implicitly by themselves about NOS starting from ideas based on historical investigations (scientific literacy aspects: Knowledge of science, investigative nature of science, science as a way of knowing and interaction of science, technology and society). In this way, students would be able to understand science as **a human activity**.
7. **My concept as I see it is the following:** starting with students by telling them about Humboldt's life and his passion for expedition as a story. The main target, here, would be to contribute to the identity formation of the students by confronting them with persons that were important in the development of culture and civilization. Then, I will ask them to look for information that interests them about his discoveries. After that, students are asked to raise a question and then to design an experiment with reference to Humboldt's investigations. History of science will, here, be a kind of reference, a kind of obstacle to peel off the nature of science nucleus within the teaching and learning period. Later they can collect, check and communicate their data (Figure 5). All their knowledge development process as well as their thinking will be recorded in portfolios. In addition, a pre- and a post-test (or interview) will be applied at the beginning and at the end of the add-on activities, to seek their change in their attitudes toward science and all the sessions will be video taped.

Observing a phenomenon of interest

Developing ideas and raising questions

To explain a phenomenon or to find answers to the questions. This would be done by:

a. Learning about previous work in the domain.
b. Collecting data with the proper instruments.
c. Recording and interpreting the data.
d. Communicating the findings and thoughts with friends and experts to get wider perspectives and to share their knowledge on the phenomenon.
e. Drawing conclusions.
f. As evidence of his findings, record his findings in journals and books.

Figure 5: summarizes Humboldt's scientific method of research and application in scientific investigations and serves to communicate it to students.