Multidisciplinary Journal for Education, Social and Technological Sciences

http://dx.doi.org/10.4995/muse.2016.3762
EISSN: 2341-2593

Inquiry learning for gender equity using History of Science in Life and Earth Sciences' learning environments

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Received: 2015-03-02; Accepted: 2016-01-03

Abstract
The main objective of the present work is the selection and integration of objectives and methods of education for gender equity within the Life and Earth Sciences' learning environments in the current Portuguese frameworks of middle and high school. My proposal combines inquiry learning-teaching methods with the aim of promoting gender equity, mainly focusing in relevant 20th century women-scientists with a huge contribute to the History of Science. The hands-on and minds-on activities proposed for high school students of Life and Earth Sciences constitute a learning environment enriched in features of science by focusing on the work of two scientists: Lynn Margulis (1938-2011) and her endosymbiosis theory of the origin of life on Earth and Inge Leehman (1888-1993) responsible for a breakthrough regarding the internal structure of Earth, by characterizing a discontinuity within the nucleus, contributing to the current geophysical model. For middle school students the learning environment includes Inge Leehman and Mary Tharp (1920-2006) and her first world map of the ocean floor. My strategy includes features of science, such as: theory-laden nature of scientific knowledge, models, values and socio-scientific issues, technology contributes to science and feminism.
In conclusion, I consider that this study may constitute an example to facilitate the implementation, by other teachers, of active inquiry strategies focused on features of science within a framework of social responsibility of science, as well as the basis for future research.

Keywords
Features of Science, Gender equity, Inquiry.

1. Introduction

One of the fundamental goals of Science Education is the development of scientifically literate citizens (Conant, 1947) who can understand the nature of scientific knowledge, and this should be achieved by the end of high school (K-12 education). According to PISA (2015), science literacy is an understanding of the major facts, concepts and explanatory theories that form the basis of scientific knowledge, including content procedural and epistemic knowledge and also the ability to explain phenomena scientifically and interpret data and evidence scientifically.

This learning proposal considers that students can understand the nature of explanations within the larger context of the construction of scientific explanations of the natural world, such as scientific models and theories, through the use of historical case studies - corresponding to the 18th and 19th centuries for Biology and 19th century for Geology (Conant, 1947) - as well as contemporary case studies (focusing in relevant 20th century female scientists) and of the enterprise itself which "assumes a human face" (NGSS, 2013). In this study I suggest the use of an inclusive inquiry learning strategy focused on the role of female scientists in the scientific enterprise, for implementation within Life and Earth Sciences classes, in middle and high school Portuguese curricula.

In order to promote an inclusive learning environment it is necessary to understand students' interests and backgrounds, as well as to include significant contributions of women and of people from diverse cultures and ethnicities to be able to engage them, for example from areas not evidenced by Nobel lauretes, such as Al Gore, Neil deGrasee, Sagan, and E. O. Wilson (Biodiversity and Science communication) and Margulis (Evolution), Leehman (Seismology), Tharp (Ocean mapping).

Doing science occurs in complex settings of epistemic and social practices so our science learning environments should be designed around these features such as the embeddedness of Science. Since gender equality has been considered both as a human right and a development goal (UNESCO, 2014) this proposal is based on an inclusive science learning environment that promotes gender equity and its main focus is one of the Features of Science - Feminism (Matthews, 2012).

Historical episodes may be read, presented in movies, may involve role-play, simulated debates or problem-solving scenarios and may focus on ideas, individuals, or controversies. This paper summarizes the guidelines to use 3 relevant case studies of Life and Earth Sciences - 3 women scientists and their corresponding outstanding ideas - from History of Science and were designed to be focused on “how we know”. Since a consistent characteristic of scientific knowledge across different disciplines is that scientific knowledge itself is open to revision in light of new evidence (tentativeness) - either due to new technology or novel interpretations - these features are referred in each case study.

2. Teaching-learning strategy proposal

This teaching-learning strategy is based in a novel Philosophy of Science that goes beyond the epistemic role and introduces the social context in which science is conducted (Kourany, 2012). In our current social context one can find social injustices experienced by women, occurring in their workplaces and homes, that may interfere with career choices to be made by middle and high school students.

Therefore, we propose an inclusive and inquiry-based learning environment, promoting the use of gender-neutral language, collaborative work (in small groups of mixed gender with up to 4 students), scientific argumentation, and focused on “how we know”.

In Life and Earth Sciences curricula one can find several male-scientists, that are always studied in Portuguese and world classrooms, such as:

(a) Earth internal structure - Beno Gutenberg, Andrija Mohorovičić,

(b) Evolution - Charles Darwin, Alfred R. Wallace,

(c) continental drift and plate tectonics - Alfred Wegener, Arthur Holmes, John T. Wilson, William Jason Morgan,

(d) Sea floor (spreading and characterization) - Robert S. Dietz, Harry Hess, Frederick Vine, Drummond H. Matthews,

(e) Classification of life on earth - Carl Woese and Robert Whittaker.

Therefore, we propose a learning environment focused on contemporary female-scientists that contributed to the above themes and constitute relevant episodes of History of Science of the 20th century, in order to promote gender equity in the classroom. In Table 1, one can find the summary of the science topic, within the curricula, and the corresponding proposed episode of History of Science (HOS).

Table 1. Overview of science topics and the corresponding episodes of HOS.

Discipline (grade)	Science topic	Episode of HOS for inclusive inquiry learning
Natural Sciences (Middle School)	Understanding the internal structure of Earth (7th grade)	- Inge Leehman and geophysical model
	Understanding the principles of Earth's structure and dynamics (7th grade)	- Mary Tharp and mapping the ocean floor - Technological advances; using Google Earth.
	Understanding Earth as a system able to generate life (8th grade)	- Lynn Margulis and endosymbiotic theory - Earth as a system subdivided in subsystems
Biology & Geology (High School)	Earth subsystems and their interaction (10th grade)	- Earth as a system subdivided in subsystems (Margulis' s Gaia hypothesis) - Lynn Margulis and endosymbiotic theory - Margulis's life classification system
	Biological evolution (11th grade) Classification systems (11th grade)	
	Face of the Earth: continents and ocean floor (10th grade)	- Mary Tharp and mapping the ocean floor - New technological advances and correlation with plate tectonics; using Google Earth.
	Earth internal structure: geophysical model (10th grade)	- Inge Leehman and geophysical model - New technologies: seismic tomography

http://dx.doi.org/10.4995/muse.2016.3762
EISSN: 2341-2593

3. Case-studies: relevant episodes of the History of Science

The historical case studies presented have in common the focus on a feature of science - feminism (Matthews, 2012). However, each case study highlights, not all but a certain set of Features of Science, such as: empirical basis, scientific theories and models, creativity, tentativeness, idealization, values and socio-scientific issues, technology and worldviews. Some guidelines for teachers are presented for each case study focused on a female scientist, in each of the following sections.

3.1. Inge Leehman (1888-1993)

Inge Lehmann was born in 1888 and received her degree in mathematics in 1920. In 1928, she became chief of the Seismological Department of the Geodetical Institute of Denmark, a position she held until retirement in 1953.

Leehman also contributed to the foundation of scientific societies that are important in both promoting studies and public understanding, so it is suggested to discuss with students the role of scientific and professional societies using this episode. Inge co-founded the Danish Geophysical Society in 1936 and served as its chair in 1941 and 1944, and in 1950, she was elected the first president of the European Seismological Federation (Hjortenberg, 2009).

Inge Leehman was the seismologist responsible for a breakthrough regarding the internal structure of Earth, by characterizing a discontinuity within the nucleus, describing an inner core, in 1936, contributing to the current geophysical model. An interesting question teachers should ask high school students is:

> Analyze Leehman's illustration of how seismic rays propagate inside the Earth's inner layers (Lehmann, 1936) and hypothesize about earth internal structure.

Students should suggest something like Leehman's own interpretations, such as that when a P-wave (the first phase to arrive) hits the core-mantle boundary, passes through the core and is detected on the far side of the Earth or is deflected and received in the P-wave shadow zone suggesting the existence of solid inner core.

http://dx.doi.org/10.4995/muse.2016.XXXX
EISSN: 2341-2593

Leehman worked in the reliability of European seismological stations so they could be used in accurate geological inferences and subsequent independent investigations by Birch in 1940 and Bullen in 1946 establish the Lehmann's hypothesis of a solid inner core (Lehmann, 1987), and in 1970 high-angle reflections of seismic P waves were observed unequivocally on seismograms upon underground nuclear explosions (Engdahl *et al.* 1970).

In small groups, students should read selected articles about Inge Lehmann and focus on:

- Discussion of Lehmann's life and work, mainly identifying aspects of her personality and attitudes towards her work that contributed to her success (Bolt, 1997):

  Inge Lehmann experienced her first earthquake when she was growing up in Østerbro, Denmark, at age 15 or 16, and she was educated at a progressive high school where girls and boys were treated equally. Throughout her long career in seismology, Inge maintained a keen physical intuition and in firm support for international collaboration. She had to fight social stereo-types and prejudice: "No difference between the intellect of boys and girls was recognized, a fact that brought some disappointment later in life when I had to recognize that this was not the general attitude." At College, Inge experienced "severe restrictions inflicted on the conduct of young girls" and returned home from exhaustion, but then returned and graduated in 1920.

  She was described as "probably not always very diplomatic", since she said: "You should know how many incompetent men I had to compete with – in vain."

The award of Bowie Medal by the American Geophysical Union, in 1971, to Lehmann was her highest distinction, and at this ceremony it one said that: "The Lehmann discontinuity was discovered through exacting scrutiny of seismic records by a master of a black art for which no amount of computerization is likely to be a complete substitute...". In 1996, the American Geophysical Union established the Inge Lehmann Medal to acknowledge "outstanding contributions toward the understanding of the structure, composition and/or dynamics of the Earth's mantle and core."

http://dx.doi.org/10.4995/muse.2016.3762
EISSN: 2341-2593

Today's advances by seismic tomography allows the creation of colourfull images of Earth's interior using three-dimensional seismic data, improved modeling techniques and powerful supercomputers (Clabby, 2015), that are responsible for increased resolution of seismic waves speed and consequently a higher accuracy of inferences made about Earth's internal layers.

Teachers should ask students to search for information about the project Earth Scope (www.earthscope.org) - that has been installing 20 new seismometers every month, in USA, since 2013 and promote the discussion of the information available, such as:

- Discuss, in small group, of the tectonic significance of one seismic tomography image of their choice; then share the findings and explanations with the class.

3.2. Mary Tharp (1920-2006)

Marie Tharp was born in 1920 in Ypsilanti, Michigan, and graduated from the University of Ohio in 1943 with a bachelor's degree in English and Music After graduating. Then she enrolled in Michigan's geology program, a rare opportunity, normally only open to males, due to the II World War; in 1944 Marie graduated with a master's degree and started her first job at the Standlind Oil & Gas Company in Tulsa, Oklahoma (Tharp, 2006). However female geologists were not allowed to conduct field work, and only office work was available, coordinating maps and data from male colleagues (Tharp, 2006). So while working, she also attended the University of Tulsa and in 1948 she received her bachelor's degree in Mathematics. Then she started to work as a research assistant at Lamont Geological Laboratory in Columbia University, coordinated by Dr. Maurice Ewing, and collaborating with Bruce Heezen (1924-1977).

Ewing did not allowed females to work at sea, so Mary Tharp was responsible for the analysis of thousands of depth measurements obtained by echo sounders in Navy ships, drafting and plotting ocean floor profiles. In 1952 she discovered what came to be called the Mid-Atlantic Rift Valley, but her claims were dismissed by Bruce Heezen: "It cannot be. It looks too much like continental drift." and later her collaborator said in an interview that "I discounted it as girl talk and didn't believe it for a year." (Tharp, 2006).

Due to Mary Tharp perseverance, Bruce Heezen "eventually gave up the idea of an expanding earth for a form of continental drift..." and in 1957, Bruce Heezen presented their model on the mid-ocean rift system, at a conference, at Princeton, and used a globe (made by Heezen and Tharp) that showed how the rift system extended all around the world. After the talk, the Princeton geologist Harry Hess - who later developed the theory of seafloor spreading - stood up and said: "Young man, you have shaken the foundations of geology!" (Tharp, 2006).

Teachers should promote discussion, in small groups, about the social context (e. g. using the above paragraph) and also the scientific context (using text of Earth Institute, 2006) of Tharp's discovery, using texts such as:

> *"I had a blank canvas to fill with extraordinary possibilities, a fascinating jigsaw puzzle to piece together: mapping the world's vast hidden seafloor. It was a once-in-a-lifetime and a once-in-the-history-of-the-world opportunity for anyone, but especially for a woman in the 1940s. The nature of the times, the state of the science, and events large and small, logical and illogical, combined to make it all happen. (...)Establishing the rift valley and the mid-ocean ridge that went all the way around the world for 40 000 miles - that was something important! You could only do that once. You can't find anything bigger than that, at least on this planet."*

Some questions that the students should focus on are:

- In what way the existence of a mid-atlantic rift supports the continental drift theory?
- At some point Tharp's claims were dismissed by her co-workers, and she latter explained her thoughts: "I figured I'd show them a picture of where the rift valley was and where it pulled apart. There's truth to the old cliché that a picture is worth a thousand words and that seeing is believing!". Discuss about Tharp's characteristics that allowed her to succeed as a woman in a field dominated for decades by men. *(teachers should empathize her imagination and creativity, curiosity, perseverance, intelligence and intuition).*

Mary Tharp and Bruce Heezen collaborated for 30 years producing the first maps of the ocean floor, in summary they are co-authors of published in 1959 - North Atlantic physiographic diagram published, in 1961 - South Atlantic physiographic diagram, published in 1964 - Indian Ocean physiographic diagram, in 1967 - Indian Ocean Panorama in National Geographic Magazine and in 1977 - World Ocean Floor panorama published by the Office of Naval Research (Earth Institute, 2006)

Bruce Heezen, died in 1977, but Marie Tharp continued to work at the University of Columbia till 1983, and then she opened a map making business in New York. In 1998, she was honored at the 100th anniversary of the Library of Congress' Geography and Map Division and in 1999, she received the Women Pioneer in Oceanography Award, awarded by the Woods Hole Oceanographic Institution (Earth Institute, 2006). In 2001, Tharp received the Lamont-Doherty Heritage Award and in 2004, the Marie Tharp Visiting Fellowship Program - a financial aid given to promising women researchers - was created by Lamont.

Tharp worked with pens, ink and rulers, drawing underwater details described by thousands of sonar readings taken by several researchers, and her World Ocean Floor panorama has become a modern scientific and popular icon, described as: "a map produced as a supreme act of rigorous creativity", "one of the most remarkable achievements in modern cartography".

State of the art includes satellite altimetry, by missions CryoSat-2 and Jason-1, that allowed high resolution imaging of tectonic structures of the ocean basins (e. g. unknown areas covered by sediments) and represented in novel marine gravity anomaly maps (Sandwell et al., 2014). Teachers should guide high school students through these technological advances by suggesting them to read "Seafloor secrets revealed" in Science (Hwang & Chang, 2014).

For middle school students, I recommend to introduce the theme by watching some movies, such as: "Deep Sea Challenge", by James Cameron and National Geographic, including the Facebook and website (http://www.deepseachallenge.com/) and focusing

http://dx.doi.org/10.4995/muse.2016.XXXX
EISSN: 2341-2593

on the Mariana Trench and "Cosmos: A Space-time Odyssey", episode 9 of 2014, in which Neil deGrasse Tyson talks about Mary Tharp, and includes some animations about her work.

Then, students can be motivated and connected to the real-world using a virtual globe or geobrowser - such as Google Earth, that includes satellite and aerial imagery and ocean bathymetry images - encouraging them to investigate different areas of the sea floor. It is also interesting to connect Tharp's work with Hesse's theory and Vine's work on the ocean floor using paleomagnetism, by using the layer, for Google Earth, "Age-of-Earth-Crust.kmz", that allows the overlay of the age of ocean isochrones. Some hands-on and minds-on activities have been proposed to be performed in small groups of 3 students per computer (Sousa, 2013), including questions to be used to guide students in their investigative activity using Google Earth, such as:

- Explore the overlay "Age-of-Earth- Crust.kmz" and correlate the maximum age of each ocean with the tectonic event responsible for their origin.
- Tharp, Heezen and collaborators were responsible for producing the first topographical maps of the ocean floor and of the first map of oceanic earthquake locations, both created at the same scale. Argue about the importance of their contributes to the Plate Tectonics theory. Suggestion: using the overlay "USGS Magnitude 2.5+ Earthquakes" correlate the occurence of underwater earthquakes with the ocean bathymetry.
- Explore the overlay "global_grav.kmz" corresponding to the suggested literature on global gravity anomaly (Hwang & Chang, 2014). *Note: suggestion for high school students, only.*

3.3. Lynn Margulis (1938-2011)

Lynn Margulis (born Lynn Petra Alexander, former Lynn Sagan) obtained a bachelor degree at age 19 and her master's degree in genetics and zoology at age 22 from the University of Chicago. She received her PhD from the University of California, Berkeley, at age 27. Then, in 1966, she joined the faculty of Boston University. In 1988 she became Distinguished Professor of Botany, and in 1997, Distinguished Professor of Geosciences

http://dx.doi.org/10.4995/muse.2016.3762
EISSN: 2341-2593

at the University of Massachusetts at Amherst. She is Honorary doctorate from 15 universities.

With middle school students, teachers can explore some of Lynn Margulis sentences and discuss the differences in the attributes of men and women and gender-based roles over time in the past and current cultural contexts, and empathizing the importance of equity between genders in the expectations and roles and sharing of responsibilities by men and women, such as:

> *Margulis said about her marriage with Carl Sagan in 1957, and divorce in 1965 and her second marriage in 1967 with Thomas N. Margulis and posterior divorce: "I quit my job as a wife twice!". And also said that "it's not humanly possible to be a good wife, a good mother and a first-class scientist. No one can do it - something has to go."*

Margulis's first paper on endosymbiosis was finally published in 1967 - after being rejected twenty times - in the Journal of Theoretical Biology, she suggested that mitochondria and plastids evolved from bacteria hundreds of millions of years ago, after bacterial cells started to live symbiotically with one another, then named endosymbiosis theory. Her theory is considered one of the "greatest achievements of twentieth-century evolutionary biology" (Richard Dawkins, 1995 in Brockman, 1995).

Teachers should emphasize the role of criticism and controversies in the revision of theories and acceptance of new theories, such as the endosymbiosis theory, by selecting some texts for discussion in the classroom, such as the one bellow (W. Daniel Hillis, 1995 in Brockman, 1995):

> *"Most of the science that gets done gets done within a rigid set of rules, where you know exactly who your peers are, and things get evaluated according to a very strict set of standards. That works, when you're not trying to change the structure. It works in what Stephen Gould calls incremental science. But when you try to change the structure, that system doesn't work very well. When you try to do something that doesn't fit into a discipline or a standard theory, you usually make some enemies. (...)*

> *She had a way of looking at symbiosis which didn't fit into the popular theories and structure. In the minds of many people, she went around the powers that be and took her theories directly to the public, which annoyed them all. It particularly annoyed them because she turned out to be right. If it's a sin to take your theories to the public, then it is a double sin to take your theories to the public and be right."*

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Teachers should ask high school students to discuss the role of the technological advances in the resolution of the scientific controversies about Margulis's theory, by guiding them to answer the following question:

- What evidence could support the hypothesis that mitochondria really did evolve from free-living bacteria?

Students should be able to refer to DNA analysis - such as in phylogenetic studies - that was not available at the time of Margulis's proposal, since DNA sequencing only started at the end 1970s. In fact in 1982, other scientists showed that the plastid DNA was much more similar to the DNA of free-living photosynthetic bacteria than it was to the nuclear DNA of the host cell, and one year later they showed the similarities of mitochondrial DNA and free-living aerobic bacteria DNA (Gray, 1983).

Students should also discuss in small groups, and then in class, the opposing views about evolution, using for guidance adequate sentences, such as:

- "For two centuries, male biologists had emphasized the role of struggle, competition, and war in evolution, and Lynn Margulis was offering a very different view." (Dunn, 2013).

High school students should be able to refer that Lynn Margulis showed that genetic mutations are not the only source of variation and that competition is not the only strategy that drives evolution. Her view - the novel view - is that through symbiosis organisms can cooperate to form a new entity and that with time the relationship can become definitive, named endosymbiosis, in which distinct species become one and that is responsible for the origin of the first eukaryotic organisms.

http://dx.doi.org/10.4995/muse.2016.3762
EISSN: 2341-2593

Margulis contribution to the classification system should also be referred and high school students may be asked to compare different systems such as: Copeland's, Whittaker's, Woese's and Margulis's (that includes 2 domains and 5 kingdmons).

Gaia hypothesis, according to Margulis, defines that all Earth systems are connected, and the biosphere overlaps with the atmosphere, the upper part of the geosphere, and almost all of the hydrosphere (Margulis & Sagan, 2002). While James Lovelock, a chemist, proposed "Gaia" as a kind of living organism, however according to Margulis: Gaia is "an emergent property of interaction among organisms" but "not a organism" (Margulis,1998).

4. Discussion and future perspectives

An inclusive learning environment is important in order to avoid students be led away from science-related careers due to misperceptions that science is difficult, uncreative and "men's world". The use of historical case studies in Science Education has long been shown to be efficient in both motivating students and promoting significate learning (Conant, 1947). However, the necessity of an update of these case studies and the construction of novel ones has been described (Allchin, 2011).

This paper presents a structured inquiry learning strategy that was designed to promote critical thinking, scientific argumentation, problem-solving and communication, in middle and high school classrooms. The construction of these contextualized historical case studies was made upon the study of several materials in order to create historically, philosophically and sociologically well informed case studies that include biographical and social context factors, as well as the gender equity.

The aim was to create significant case studies, and not anecdotes and stories, to facilitate the development of classes focused on History and Philosophy of Science, that may be used by other teachers and constitute the focus of my current research.

http://dx.doi.org/10.4995/muse.2016.XXXX
EISSN: 2341-2593

Acknowledgments

Special thanks to the ones that inspired me. The views expressed in this paper are those of the author. The author would like to thank Universidade do Porto, Portugal, for financial support.

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