A Lesson on the Arbitrary Nature of Thermometer Scales Using the Historical Case of the Creation of the Fahrenheit Temperature Scale

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ABSTRACT: The historical case study of Daniel Gabriel Fahrenheit's creation of the first mercury thermometer with reliable scales is used as the basis for a lesson that is designed to provide students with a richer insight into the arbitrary nature of thermometer scales. The lesson attempts to move students beyond a level of understanding that is based simply on knowing how to read and use a thermometer, to a level of understanding that is based on knowing the very procedures and principles used to create thermometric scales. By studying the criteria that Fahrenheit used to create his scale, students should begin to obtain a richer insight into the arbitrary nature of thermometer scales in general. It is argued that it is insufficient to teach students how to read and use thermometers without giving them some notion of how a scale came into existence because no real insight is being provided into the nature of science. Students must be introduced to the actual procedures used by scientists if they are to understand how scientists have obtained their knowledge. The use of the historical example moves the teaching of science beyond the "cold" facts of science to the dynamic processes that are behind the facts. The extreme of teaching science as infallible is avoided by focusing on the idea that science is a human product that is subject to change. This paper does not advocate teaching science as a historical discipline, but rather argues that part of the science curriculum should include historical cases, such as the creation of the Fahrenheit temperature scale, in order to bring out the specific characteristics of science.

PART I: HISTORICAL BACKGROUND

By the end of the 16th century, scientists were becoming increasingly aware that many of the speculations about the atmosphere were inadequate and erroneous. Much of this failure was due to the absence of precise meteorological instruments. Science as it is practiced today did not yet fully exist. Intellectual thought about the nature of the universe was dominated by the conclusions of natural philosophers who interpreted observations in ways that supported their preconceived notions (Frisinger, 1977). This is epitomized by Aristotle's *Meteorologica*, published around 340 BC, which examined atmospheric phenomena such as rainfall, cloud formation, hail, long-term climate patterns, thunderstorms, and temperature (Aristotle, 1952). Aristotle believed that weather phenomena could be explained by the mixing of four basic elements – namely earth, water, ice, and fire – between different levels. *Meteorologica*, which became the standard resource on atmospheric phenomena until the 17th century, used qualitative observations to support its conclusions rather than the quantitative procedures that modern meteorologists would consider to be consistent with experimental scientific methods (Nutter, 2001). Frustration over the inadequacies of the qualitative approach lead scientists of the 17th century to yearn for quantitative instruments that would provide precise methods for measuring atmospheric phenomena.

Galileo Galilei helped to lead the way when he created the first known thermometer at the tail end of the 16th century. This gave rise to the field of thermometry and to numerous attempts at expanding upon Galileo's work. Robert Hooke published a document in 1664 that described his creation of a four-foot long thermometers filled with wine (Frisinger, 1977). Christian Huygens introduced the idea in 1665 of using the boiling point and the freezing point of water as fixed reference points on the thermometric scale (Zinszer, 1944). Sir Isaac Newton published a paper in 1701 which described the creation of a thermometer that was three feet long and that had a two inch diameter bulb filled with oil (Newton, 1701). None of the above mentioned scales, however, became widely accepted as a standard for measuring temperature. A young instrument maker by the name of Daniel Gabriel Fahrenheit therefore saw an opportunity.

Fahrenheit was born in Danzig, Poland in 1686. He lived most of his life in Holland. When both of his parents died in 1701, Fahrenheit was sent by his guardian to study business in Amsterdam where he took a special interest in scientific instruments (Rozell, 1996). His primary desire was to go into business as a successful instrument maker, and it is believed that he was more interested in being a tradesman than he was in being a natural philosopher (Middleton, 1966). Fahrenheit combined business skills with instrument making skills in such a way that he was able to widely market his thermometers. The widespread availability of his thermometers explains why both scientists and society quickly embraced his scale as a standard. The scientific community, however, would for the most part eventually reject Fahrenheit's scale in favor of the centigrade scale, which was created by Anders Celsius around 1740. Celsius suggested using the fixed points of 0 degrees and 100 degrees to represent the boiling point of water and the freezing point of water respectively. The scale was later inverted because placing the colder value at 100 degrees did not make intuitive sense to most scientists (Rozell, 1996). The eventual acceptance of the centigrade scale as a scientific standard was seen as a logical choice because it was consistent with the decimal based counting system that had been adopted by society (Middleton, 1977). Multiples and powers of ten are considered to be the round numbers in such a counting system. The centigrade scale with 100 degrees between two fixed points was therefore seen by scientists as more reasonable than Fahrenheit's scale which was not consistent with a decimal based counting system.

Fahrenheit was greatly influenced by a Danish astronomer by the name of Olaus Roemer who, around 1702, developed an alcohol thermometer to record daily atmospheric temperatures. Roemer set one of his fixed points at the boiling point of water, which he labeled 60 degrees, and the other fixed point at the melting point of snow, which he labeled 7.5 degrees (Cohen, 1944). Fahrenheit met Roemer in 1708 and eventually based his own thermometers on the fundamental principles of Roemer's thermometer. Fahrenheit did make some changes, however. He used mercury instead of alcohol. He also modified Roemer's scale because, according to Fahrenheit's letters, he had no desire to work with "inconvenient and awkward fractions" (Rozell, 1996). Fahrenheit also was not initially concerned with using the boiling point of water as a fixed point because his primary interest was to use thermometers to measure atmospheric temperatures. A thermometer graduated as high as the boiling point of water is not very useful in a meteorological context (Middleton, 1977). Fahrenheit therefore used fixed points that were similar to temperatures that could be observed in the atmosphere.

Fahrenheit designed and crafted the first mercury thermometer with trustworthy scales in 1714 (Frisinger, 1977) and divided his degrees into quarters (Middleton, 1966). An interesting account of how Fahrenheit arrived at the fixed points for the scale on his thermometers can be found in a document that he published in an issue of *Philosophical Transactions* (Fahrenheit, 1724). In this work, Fahrenheit stated that the length of his thermometers varied with the temperature range needed for a given task, but the distance between the scaled degrees did not deviate from one thermometer to another. The scale could be lengthened by adding more spaces of equal length whenever the situation required the use of higher values. The partitioning of the scale on all his thermometers was based on three fixed points. The first point was fixed at 0 degrees, which he considered the beginning of the scale, and was obtained by placing a thermometer into a mixture of ice, water, and sal-ammoniac, or also sea salt. This was an experiment that Fahrenheit claimed worked better in the winter.

It produced what was essentially the coldest temperature that Fahrenheit could obtain with the materials and tools that were available to him. The temperature obtained from the mixture was therefore seen by Fahrenheit as a logical point to begin his thermometer scale.

The second fixed point on Fahrenheit's scale, also explained in the 1724 document that he published in *Philosophical Transactions*, was set by placing a thermometer in a mixture of water and ice without the salts (as Roemer had similarly done). Fahrenheit set this at a value of 32 degrees and referred to this point as "the beginning of congelation, for in winter stagnant waters are already covered with a very thin layer of ice when the liquid in the thermometer reaches this degree (Middleton, 1966). The third fixed point on Fahrenheit's scale was obtained by placing the thermometer in the mouth or under the armpit of a healthy man. Roemer had done something similar and had placed the value of "blood heat" at 22.5 degrees (Cohen, 1944). Fahrenheit, however, set the value at 96 degrees. The boiling point of water, or 212 degrees, replaced 96 degrees as the upper fixed point shortly after Fahrenheit's death. It was discovered that 98.6 degrees, and not 96 degrees, was the actual average temperature of a healthy human body. Once Fahrenheit's scale was recalibrated to reflect this knowledge, scientists realized that the boiling point of water fortuitously lined up exactly with 212 degrees on the Fahrenheit scale (Middleton, 1977). It therefore became a common practice to use 212 degrees as the upper fixed point rather than either the erroneous 96 degrees or the corrected 98.6 degrees temperature of a healthy human body. The melting point of ice, or 32 degrees, was maintained as the lower fixed point. However, 0 degrees is no longer considered a fixed point on Fahrenheit's scale most likely because it cannot be established that 0 degrees will always result if Fahrenheit's method is used. As one author notes, "The mere fact that either of two salts was to be used in his freezing mixture, and the note that 'the experiment succeeds better in winter than in summer,' should have warned readers that such a zero would not be even approximately a fixed point" (Middleton, 1977).

Fahrenheit died in 1736 at the young age of 50. He left behind a legacy that would influence society for centuries to come. His scale, while no longer in use by most countries of the world or by the general scientific community, continues to reign as the thermometric scale of choice within American culture.

PART II: THE LESSON

The lesson outlined in this section is intended for introductory earth science, physical geography, and meteorology courses that are taught at the university level. All such courses have extensive sections that deal with the phenomena of temperature, especially as it relates to the atmosphere. Several class sessions have been dedicated to this topic in every introductory earth science, physical geography, and meteorology course that I have either taught as an instructor or attended as a student.

A dilemma that is encountered in introductory earth science, physical geography, and meteorology courses (at least, within my own teaching experience) is that students sometimes have difficulty understanding the significance of temperature scales. Some students express frustration over the fact that lab experiments usually require the use of the centigrade temperature scale, which they are generally unfamiliar with, rather than the Fahrenheit temperature scale, which they are more thoroughly familiar with. Students sometimes complain that they do not understand what the numbers on the centigrade scale mean unless they convert them to Fahrenheit values, and they wonder why they cannot do everything using the Fahrenheit scale. The intent of this lesson, therefore, is to create an exercise that responds to these concerns by helping students understand why one scale can be preferred over another in the context of science. It is the goal of the lesson to provide students, by means of the historical case study of Fahrenheit creating the first mercury thermometer with reliable scales, with a richer insight into the significance of the arbitrary nature of thermometer scales in general. After examining the historical account, students should begin to understand that the arbitrary nature of temperature scales could make some scales more useful when the fixed values are placed at logically convenient points. In the context of a decimal based counting system, for example, it is more reasonable to have a temperature scale with 100 degrees between the two fixed points than it is to have 180 degrees between the two fixed points (as it is on the Fahrenheit scale).

The lesson will begin with students individually reading the account that is found in Part I of this paper (or a similar account that could be written later) that describes the background of Fahrenheit creating his mercury thermometer and temperature scale. Students will be asked the following questions to help them think more thoroughly about the nature of temperature scales:

> How did Fahrenheit arrive at the "0" point of his scale?
>
> What were the other two fixed points that he chose?
>
> Define the terms "objective" and "arbitrary."
>
> Was Fahrenheit’s scale based on "objective" standards or "arbitrary" standards?
>
> What is a "decimal based" counting system?

> What are some possible disadvantages of Fahrenheit's temperature scale?
>
> What might be the advantages of using the centigrade scale (which places the melting point of ice at a value of "0" degrees and the boiling point of water at a value "100" degrees)?
>
> Which scale is consistent with a decimal based counting system?

Students will work in small groups of two to four to answer these questions.

After students have spent adequate time constructing various responses to the above questions, the instructor will initiate a class-wide discussion. Groups will be asked to present their ideas to the rest of the class. Students will also be asked to evaluate the comments made by other students. The instructor should encourage students to think carefully about what the questions are asking before constructing appropriate responses. It is hoped that the students themselves (with as little suggestion from the instructor as possible) will begin to recognize the arbitrary nature of temperature scales. Once this has been accomplished, it is hoped that students will also recognize that the centigrade scale is a more reasonable scale in the context of a decimal based counting system.

Following this introductory exercise, students will work with a thermometer that uses the Fahrenheit scale and a thermometer that uses the centigrade scale. Students will be asked to record the air temperature in the classroom with both a centigrade thermometer and a Fahrenheit thermometer. The temperatures found by both thermometers should be recorded on paper. Students will also be asked to go out of the building and record the outside temperature using both thermometers. As with the indoor temperatures, the outside temperature found by both thermometers should be recorded on paper. Students will return to the lab where they will perform an experiment using water and ice. Students will be asked to fill a small container with tap water. (It is up the instructor's discretion as to whether to have "room temperature" water prepared or to allow students to use cooler water from the sink.) Students will record the initial temperature of the water. They will slowly add chunks of ice to the water and, using both the centigrade and Fahrenheit thermometers, observe what happens to the temperature of the water as increasing amounts of ice are added to the water. Students should notice that the temperature of the water approaches 0 degrees on the Celsius scale and 32 degrees on the Fahrenheit scale. Students will be asked the following follow-up questions that are again designed to stimulate thought about the arbitrary nature of temperature scales:

> What is the melting point of ice on the centigrade scale?
>
> What is the melting point of ice on the Fahrenheit scale?
>
> The melting point of ice is different from one scale to another. What does this tell us about the nature of thermometer scales?
>
> What would the possible benefits be of placing the melting point of ice at 0 degrees rather than 32 degrees?

It has already been noted that having 100 degrees between the fixed points is consistent with a decimal based counting system. There are also other advantages to the centigrade scale. For example, the melting point of water is extremely significant in meteorology because it is a transitional point between very different kinds of weather (namely, frozen verses wet). Depending upon whether or not the temperatures at various levels in the atmosphere are above, below, or equal to this point will determines whether or not precipitation will fall in the form of snow, sleet, freezing rain, or rain. Above or below freezing temperatures will determine whether there will be dew or frost in someone's garden on a spring morning, and they will determine whether conditions on the highways will be made more hazardous by icy pavement or less hazardous by wet pavement. Thus, it may extremely beneficial to understand the temperature in terms of whether it is above the melting point of ice (positive values) or below the melting point of ice (negative values). Therefore, the following questions will be included in order to stimulate further thought about this idea:

> Why is the melting point of ice a significant value for meteorology and weather forecasting?
>
> What temperature did the water approach (on both scales) as you continued to put increasing amounts of ice into a container of water?
>
> What temperature (on both scales) did you record both inside and outside?
>
> What temperature values would you except outside (on both scales) during the day in the middle of January? Are these values positive or negative?

> What temperature values would you expect outside (on both scales) during the middle of July? Are these values positive or negative?
>
> Why would it be more useful to meteorologists to use a scale that places the "0" point at the melting point of ice?

As with the previous questions, the instructor will initiate a class-wide discussion after students have spent adequate time constructing various responses. Groups will again be asked to present their ideas to the rest of the class and will be asked to evaluate the statements made by other students.

A final discussion will take place between the students and the instructor that will be based on the following two questions related to student's personal reactions to the historical account:

> Did the historical account of Fahrenheit creating his thermometer scale make the discussion of thermometers more interesting to you?
>
> Did the historical account help you to gain a better understanding of the concepts that were being discussed? If so, in what ways did reading this historical account benefit your understanding of thermometer scales?

These questions are meant as a reminder to the students that their thoughts and opinions are valuable and important. Instructors could also use students' responses to these questions as somewhat of a gauge of the lesson's effectiveness.

The lesson that has been outlined in this section is potentially effective in teaching only a small amount of the content that students should be learning about temperature and thermometers. Instructors should also explain what thermometers are actually measuring, and they should explain the difference between temperature and heat.

This lesson could serve as a foundation for teaching other topics related to temperature such as isotherms, wind chill factor, mathematical conversion between temperature scales, and atmospheric lapse rates.

PART III: PHILOSOPHICAL JUSTIFICATION

It is not enough to teach students how to read and use various thermometer scales without giving them at least some notion of how these scales cane into existence. The use of historical case studies in the science classroom has been advocated by many researchers and philosophers of science education for quite some time. Defenders of its use as a pedagogical tool believe that the growth of science should be examined more closely, giving special considering not only to the paths that have been taken by scientists, but also to the paths that have not been taken by scientists (Duschl, 1994). Various arguments have been made in defense of this type of belief. Three of the stronger arguments for the use of history in science classrooms are summarized in a paper by Jenkins (1991) that described the use of history in science classrooms in Great Britain. First, history can be seen as providing a "humanizing" aspect to what is usually a "dehumanizing" science education structure. This argument was primarily used in Great Britain after the end of World War I. Second, science can be seen as offering "common ground" between the specialists in arts and the specialists of science. This argument was dominant in Great Britain during the 1950's and 1960's. Third (and likely the most enduring argument), the inclusion of history in the science classroom can provide students with a richer insight into the "nature of science" itself. I have stated that the goal of the lesson presented in Part II of this paper is to provide students, by means of the historical case study of Fahrenheit creating his thermometer scale, with a richer insight into the significance of the arbitrary nature of thermometer scales in general. It is therefore Jenkins's third argument (the use of history in science can be used to provide a richer insight into the "nature of science" itself) that provides the basis for the lesson that has been presented in this paper.

It has been argued that the teaching of science without an emphasis on the rich history of its development leaves students with a superficial and inadequate understanding of the nature of science. Matthews (1994) uses Boyle's Law to illustrate this point. It is inadequate to teach Boyle's Law without considering what the definition of a "law" is, who Boyle was, what Boyle did, and what kind of cultural environment and background influenced Boyle's work. So too, it is inadequate to teach temperature without considering how temperature scales were arbitrarily created, who the creators were, what they did, and what kind of cultural environments and backgrounds influenced the creators' work. In short, it is not enough simply to teach students how to read and use a thermometer because no real insight is being provided into the nature of science itself. Instead, students must be introduced to the very procedures that have governed scientific progress. In order to gain such insights, students must see science as being part of a larger surrounding cultural heritage (Jenkins, 1989). It is therefore imperative for science educators to furnish students (at least somewhat) with the richness of the influential history of science and to involve them in some of the questions that scientists have engaged in (Matthews, 1994). Students should realize that science does not create itself. In other words, science does not exist in a cultural vacuum. Much to the contrary, real people engaging in real activities have molded science into the vast field of knowledge that it is today. *Benchmarks* asserts a similar idea when it states, "History provides another avenue to the understanding of how science works. Students should come to realize that much of the growth of science has resulted from the gradual accumulation of knowledge over many centuries" (American Association for the Advancement of Science, 1993).

Similar ideas have been expressed by other researchers and philosophers of science education. Brush (1989) argued that the focus of a historical approach to the teaching of science is not merely on the ***conclusions*** reached by the scientists, but rather it is on the ***processes*** that were used by the scientists to reach those conclusions. In short, the historical approach to the teaching of science requires ***thinking*** on the part of the students. Brush goes on to argue that traditional science teaching has focused far too much on the "objective facts" of science, and that this has resulted in the inaccurate but common notion of the arrogant scientist who has obtained infallible knowledge. However, the use of history in the teaching of science avoids this extreme by demonstrating that science is a human product that is subject to change. One researcher argued that a broad cultural approach to science that includes historical elements should replace the traditional focus on "correct-for-now" contents with history-based instruction that reveals the non-linear processes by which scientists have attained their knowledge (Galili. 2000).

It is important to note, however, that the presentation of historical material ***will not necessarily guarantee*** an improved understanding of science (Russel, 1981). I am therefore not advocating replacing the teaching of science content with the teaching of science as a historical discipline. Rather, I am arguing that part of the science curriculum should include historical case studies that can provide students with a richer insight into the procedures and nature of science. There is evidence that indicates that the portrayal of history in science classrooms is most effective when it is used to bring out the "specific characteristics" of science (Russel, 1981). Thus, instructors are not advised to teach the history of science as merely a series of cold, hard historical events; rather instructors are advised to focus on specific historical cases and events that emphasize the explicit concepts and procedures that provide insights into the very nature of science. It is with the above considerations in mind that the lesson developed in Part II of this paper was created. It is my hope that the procedures and principles that determine the nature of thermometers will come alive for students after they read the historical account of Fahrenheit's creation of the first mercury thermometer with reliable scales. Students are doing more than simply using a thermometer to measure temperature, and they are going beyond simply learning the abstract principle that thermometer scales are chosen in an arbitrary manner. They are seeing a concrete example of the principle in action. By studying this particular example students should begin to realize that arbitrary standards are used to determine the fixed values on a thermometric scale, and that this arbitrary nature can make some scales more useful than others when the fixed values are placed at logical points.

It was noted in Part II of this paper that students sometimes have difficulty understanding the significance of temperature scales. Students may express frustration because they are using the centigrade scale instead of the Fahrenheit temperature scale that they are more thoroughly familiar with. It was therefore stated that it is important that this lesson responds to these concerns. Monk and Osborne argue that there are two modes of support for introducing historical accounts into the classroom (1997). They argue that it is comforting to students to realize that others have thought in the same way that they do and that they are therefore not stupid for thinking in the ways that they do. Secondly, it allows students to realize that some modes of thought are part of the past and that the current line of thought offers an improvement. These two principles can be easily applied to the teaching of thermometers. Students should begin to understand that the Fahrenheit scale is primarily a thing of the past in science because the centigrade scale offers an improvement. Students should understand that they are not stupid for wanting to hold on the Fahrenheit scale. In fact, the scale was created by a brilliant man, was adapted by society, and was used at times by the scientific community. This will hopefully address students concerns about using a scale that they are unfamiliar with. It should help them to understand that it is reasonable for the scientific community to develop and use a temperature scale that is consistent with the decimal based counting system that governs society.

In summary, I have argued that it is possible for students to gain a richer insight into the arbitrary nature of thermometer scales in general by examining the specific historical case study of Fahrenheit creating his thermometer scale. Knowledge is not simply about the "products" of science; it must include the ‘processes" of science as well which can be defined as the technical and intellectual ways that science develops its ways of understanding the world around us (Matthews, 1994). If students are only aware of the "products" of science, then science may seem distant to them. This is why it is beneficial to discuss the historical example of Fahrenheit’s thermometer. Students will not only know what a thermometer is and how to use it, but they will also know how it was developed. Knowing how it was developed will help them to understand the processes by which scientists can develop thermometer scales in general, and this may open the door for them to understand why using different fixed points may be more useful to scientists. Hopefully, this recognition will result in their not being so hesitant in using the centigrade scale for their experiments in class. They may begin to understand the value of the centigrade scale.

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