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# A Modified H-R Diagram Activity to Introduce the Nature of Science

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**Abstract:** The purpose of this study is to suggest the modification of activities to introduce the nature of science in earth science classrooms. A small modification can turn ordinary textbook activities into the nature of science activities. Since earth science could provide a good basis for the tentative, creative, and socially and culturally embedded nature of science, as well as appropriate understanding about scientific methods, careful modification of earth science activities could be effective for students to understand the nature of science. Considering which aspects of the nature of science are appropriate, along with the possible change in the activity, teachers will be able to modify textbook activities effectively. An example modification of H-R diagram activity was also suggested.

Keywords: the nature of science, earth science activities, nature of science activities, modification of earth science activities.

## Introduction

Today, the importance of understanding the nature of science is highly regarded in science education. In fact, many of science education standards from various countries explicitly state the importance of understanding the nature of science (McComas and Olson, 1998). In spite of such emphases, however, students' inadequate understanding of the nature of science has been repeatedly reported by researchers (Lederman, 1992; Lederman *et al.* 2002). This discrepancy between the goal and the achievement suggests that we need to invest more efforts on how to teach the nature of science to students in science classrooms.

The nature of science should be taught explicitly, because "just doing science" does not help much in understanding the nature of science (Bell *et al.*, 2003). Moreover, learning science without clear understanding of the nature of science often leads students to mistaken notions (Clough and Olson, 2004). Fortunately, many strategies to help teachers to deliver accurate notion of the nature of science are already available. For example, pictorial gestalt switches such as old/young lady and rabbit/duck images are engaging way to help students to understand that observations are not strictly objective (Michaels and Bell, 2003). Card-exchange activity (Cobern and Loving, 1998) can help both students and teachers to explore their previous understanding and to introduce accurate notions of the nature of science. Black-box activity (Lederman and Abd-El-Khalick, 1998) can provide students an understanding about how science works.

Nevertheless, difficulties of teaching the nature of science are still present in today's science classrooms. Although these activities are excellent to teach the nature of science, they are not woven into science contents and cannot be used repeatedly in teaching various science subjects. For instance, earth science teachers could use these activities to introduce the nature of science once, but they cannot use them repeatedly in earth science classroom. If the nature of science is introduced to students once or twice, with specially designed activities, then not mentioned for the rest of the science course, students might not fully understand the nature of science. While the mistaken notion of the nature of science can be easily given in teaching any science subject, introducing accurate notion of it in teach-

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ing each science subject seems difficult. Thus we need different strategies which are simple for applying but subtle for affecting in the science classrooms.

A few alternative strategies were provided by some researchers. The core idea was 'modification in activities'. Colburn (2004) suggested that typical cookbook lab can be changed by making small modification. He gave students more choice and stopped the procedure at certain points to bring up the discussions. By this modification, students could learn about the nature of science as well as the chromatography. Lederman and Lederman (2004) also demonstrated how the notion of the nature of science can be introduced in the typical biology activity. They placed some reflective questions regarding the nature of science in several crucial points of the procedure. By this simple modification, the typical cell cycle activity turned into the nature of science/biology activity.

The modification in activities could be a good strategy to introduce the nature of science in earth science, too. Therefore, this study will focus on suggesting the way to introduce the nature of science in high school earth science class through modified activities. With this strategy, the nature of science could be explicitly taught in earth science classroom without making a big change.

### The Aspects of the Nature of Science

The nature of science typically refers to the values and assumptions inherent scientific knowledge and the development of scientific knowledge (Lederman and Lederman, 2004). Naturally, the specific aspects and issues about the nature of science are not unanimously agreed among historians and philosophers in science, because the nature of science itself is tentative (Lederman *et al.*, 2002). But a consensus of key ideas of the nature of science appropriate for K-12 students has been agreed in some degree. Lederman and Lederman (2004) suggested seven key aspects of the nature of science as follows.

First, students should understand that there is the crucial distinction between observation and inference (Lederman and Lederman, 2004). Second, students should understand the distinction between scientific laws and scientific theories (Lederman and Lederman, 2004; McComas, 2004). Scientific laws are descriptive statements about the patterns or relationships among the natural phenomena, while scientific theories are inferred explanation about the natural phenomena (Lederman *et al.*, 2002). Thus it is closely related to understanding the distinction between observation and inference. Third, students should understand the empirical nature of science. Science demands and relies on empirical evidence (McComas, 2004). Fourth, students should understand that scientific knowledge involves creativity and imagination (Chiappetta and Koballa, 2004; Lederman and Lederman, 2004; McComas, 2004). Fifth, scientific knowledge is at least partially subjective. It refers the influence of accepted theories in the scientific community as well as the individual backgrounds of researchers (Lederman and Lederman, 2004). Sixth, students should understand that science is socially and culturally embedded (Lederman and Lederman, 2004; McComas, 2004). In other words, there are historical, cultural and social influences on science and science is neither independent nor objective from human social system. Seventh, students should know that scientific knowledge is subject to change. It is called the tentative nature of science (Lederman and Lederman, 2004; McComas, 2004).

In addition to these seven aspects of the nature of science, a few more important aspects have been repeatedly pointed. The myth of the scientific method is one of them (Chiappetta and Koballa, 2004; Lederman et al., 2002; McComas, 1998, 2004). Students should know that controlled experiments are not the only and the most credible scientific method, and there is no single, standard scientific procedure that every scientific investigation should follow. In fact, various methods are, and have been, available for scientific investigations.

The relationship between science and technology is another significant aspect of the nature of science. Students should know that science and technology impact each other, but they are not the same (McComas, 2004). Another aspect that student should notice is that science and its methods cannot answer all questions (McComas, 2004). This aspect also relates to the tentative nature of science and the misunderstanding about the scientific method. These aspects and some related aspects are usually addressed in k-12 science curriculum (AAAS, 1993; NRC, 1996), thus how to convey these aspects to k-12 students will be the concern in each science classroom.

## Introducing the Nature of Science in Earth Science Classrooms

Earth science can be a good subject to introduce the nature of science. As Mayer (1995) explained, earth science with earth system approach could contribute to science education in three ways: philosophical contribution, methodological contribution, and conceptual contribution.

Methodological contribution is, perhaps, the most obvious one among them. There has been persistent misconception about "the scientific method". Many students believe that there is "the scientific method" to obtain scientific evidence and it should be the experimental method (Chiappetta and Koballa, 2004; Lederman et al., 2002; McComas, 1998, 2004). In earth science, historical methods and descriptive methods are often used. Since earth science takes many different methods outside the experimental method, students may be able to understand that there are many ways to do science by studying earth science.

But this methodological contribution seems like a double-edged sword, because, without accurate view of the nature of science, it can lead students to another misconception. There is a likely chance that students regard earth science less developed because it often uses non-experimental methods. Thus, teachers must be cautious when they do earth science activities with students. Many of earth science activities in the textbooks are using non-experimental methods. Students' positive understanding of the nature of science depends on how teachers deliver the nature of science view through these activities.

Other aspects of the nature of science can be effectively introduced in the earth science class. Earth science concerns natural phenomena which occur in and around the earth. Some parts of earth science demand understanding about locality and other parts of it demands global prospect. In both cases, earth science is closely related to human life and societies and it does not only affect them but also is affected by them. Thus, students can learn that science is socially and culturally embedded.

Creative nature of science can also be introduced in the earth science class. Lack of tangibility is one of the aspects of earth science. In many cases, direct observation or collecting data is impossible. In other cases, invisible perspectives are explored. For example, we cannot go and collect data directly from the inside of the earth, or outside of the solar system. Because of this lack of tangibility, studying earth science requires researchers' creativity and imagination more than others. Therefore, students could learn how creativity and imagination contribute in science.

Learning earth science can also be a good chance to understand the tentative nature of science. Recently, earth science has dramatically changed with the help of advanced technology. Moreover, the change never stops. The new ideas and the new discoveries are being reported almost every day, and it changes our view about the earth, the life, and the universe. It also captures a great deal of public attention. While teachers teach these incessant changes in the earth science class, they can also remind students of the tentative nature of science.

Introducing the nature of science in the earth science class can be done in various ways. As mentioned above, earth science provides several good bases. Teachers can remind students of the nature of science through the lecture, ask questions or they

**Table 1.** The absolute magnitudes and the spectral types of thirty, well-known stars

| Name | Magnitude | Spectral Type | Name | Magnitude | Spectral Type |
|---|---|---|---|---|---|
| The Sun | 4.8 | G | Polaris | -4.5 | F |
| Centaur A | 4.7 | G | Algol | -0.5 | B |
| Centaur B | 4.1 | K | Aldebaran | -0.8 | K |
| Centaur C | 15.4 | M | Capella | -0.6 | G |
| Barnard's Star | 13.2 | M | Rigel | -7.0 | B |
| Sirius A | 1.3 | A | Begelgeuse | -5.9 | M |
| Sirius B | 11.3 | A | Regulus | -0.8 | B |
| Cygnus A | 7.5 | K | Mizar | -0.0 | A |
| Cygnus B | 8.3 | K | Spika | -3.1 | B |
| Procyon | 2.8 | F | Arcturus | -0.2 | K |
| Kapteyn's Star | 8.6 | M | Antares | -4.7 | M |
| Luyten | 11.9 | M | Vega | 0.5 | A |
| Kruger 60 A | 13.4 | M | Altair | 2.3 | A |
| Kruger 60 B | 11.9 | M | Deneb | -7.2 | A |
| Groombridge1618 | 8.5 | K | Mintaka | -6.0 | O |

can engage discussion among students. One of the ways would be conducting activities. Developing new nature of science/earth science activities can be good. Using activities in the textbooks with small modification, however, seems to be a simpler and easier way.

To modify ordinary earth science activities, teachers should be well aware of aspects of the nature of science. Then, the following two questions could be considered.

- Which aspects of the nature of science could be brought into this activity?
- What change is available?

With these questions in mind, teachers can modify activities to become the nature of science activities. Tentative nature, creative nature, socially/culturally embedded nature of science along with dispelling the myth of 'the scientific method' could be considered first for modification, because these aspects can be easily related to earth science as explained before. In general, choosing appropriate aspects for the activity entirely depends on teachers' decision, since each activity has particular advantage/disadvantage for introducing the nature of science. How to make a change also depends on teachers. Some of frequently used ways are asking reflective questions about the nature of science or engaging students' discussion at certain steps during the procedure (Colburn, 2004; Lederman and Lederman, 2004). Teachers are encouraged to make various changes. In any case, small modifications can make a big change. Students will learn about the nature of science through earth science, if teachers are willing to do it.

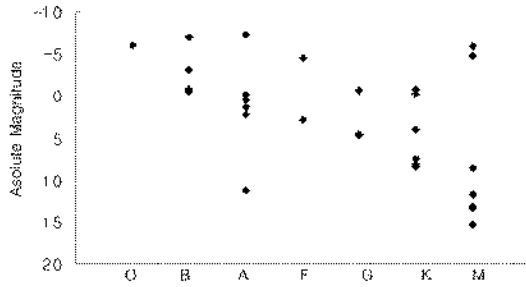


**Fig. 1.** H-R diagram of stars in Table 1.

## The H-R Diagram: An Example of Modified Earth Science Activities for the Nature of Science

The H-R diagram activity is one of the popular activities in earth science classes. Table 1 shows a list of stars from one of the earth science textbooks (Woo et al., 2002). The original activity from the textbook is not linked to the nature of science. Students are provided with the data and asked to draw the H-R diagram by plotting all data on the chart. Then, they are asked to group stars in the diagram. Fig. 1 shows the diagram produced from

**Table 2.** The absolute magnitudes and spectral types of twenty, well-known stars

| Name | Magnitude | Spectral Type | Name | Magnitude | Spectral Type |
|---|---|---|---|---|---|
| Rigel | -7.0 | B | Barnard's Star | 13.2 | M |
| Betelgeuse | -5.9 | M | Kruger 60 A | 13.4 | M |
| Deneb | -7.2 | A | Kruger 60 B | 11.9 | M |
| Sirius A | 1.3 | A | Mizar | -0.0 | A |
| Sirius B | 11.3 | A | Mintaka | -6.0 | O |
| The Sun | 4.8 | G | Kapteyn's Star | 8.6 | M |
| Aldebaran | -0.8 | K | Luyten | 11.9 | M |
| Arcturus | -0.2 | K | Centaur A | 4.7 | G |
| Antares | -4.7 | M | Centaur B | 4.1 | K |
| Groombridge1618 | 8.5 | K | Centaur C | 15.4 | M |

the data in the Table 1. In this diagram, the main sequence is clearly shown therefore, any student would easily identify it. There are two questions to conclude this activity: 'How can you group stars in the H-R diagram?' and 'Describe the brightness and surface temperature of each group.' In this activity, students only follow procedures as directed, and the result is so clear that there is no room for questions or arguments.

Nevertheless, small modification can bring the notion of the nature of science into this activity. The modified activity consists of two parts. In the first part, incomplete data set is provided to students instead of whole set of data which will produce clear main sequence in the diagram (see Table 2). In Table 2, there are only twenty of stars from original data set, and the result is not so obvious to identify the main sequence as shown in Fig. 2.

Students can work as an individual or as a group to draw the H-R diagram. Then, the teacher can ask students to group the stars and to explain why they grouped them in that way. Since the main sequence is not clearly shown, students' answers would not be unanimous. At this point, the teacher can bring up the subjective nature and creative nature of science with following questions:

- How did you group stars in that way?
- How do you think scientists would group stars with such a result?

Students can have a chance to talk about that analyzing data and producing outcome might not be totally objective. They might highly depend on

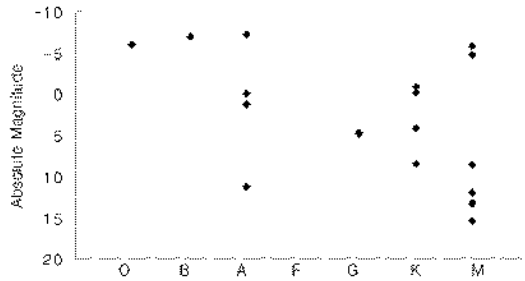


**Fig. 2.** H-R diagram of twenty stars in Table 2.

researchers. Thus different analysis and outcome could be possible even among scientists. This is the subjective nature of science. Students can also talk about creative nature of science. Science is not completely procedural and at certain step, researchers need creativity to produce outcome just as students did to group the stars in this activity.

Then, the teachers can ask the next question: "What would you need to do next?" If students point the lack of data, then it is easier to go to the second part. Also, the teacher can remind students of the empirical nature of science. Science demands and relies on empirical evidence.

In second part of this activity, students as an individual or as a group should choose their own data to complete the H-R diagram. Many textbook provide information about well-known stars as an appendix. Usually, the list of some bright stars and/or the list of some near stars are provided. Students can use this appendix as a resource. Otherwise, teachers can provide resources. When students completed their diagrams, they should identify

groups of stars. The teacher can ask following questions:

- How and why did you choose these data?
- How did you know that the diagram is completed?
- How and why did you group stars in that way?

At this point, tentative nature and subjective nature of science can be discussed. At the end of the first part, students had various results, then, at the end of the second part, they may reach different results from their former results. Thus, students can discuss about the tentative nature of science contemplating that scientific knowledge always changes with more evidence. Students can also learn more about subjective nature of science. Sometimes choosing improper data leads to improper result. And it happens among scientists. Students can discuss about the similarity among their H-R diagrams as well as the difference among them. They can also compare their procedures, mainly what data they chose, to one another to discuss how it affected their results.

Giving incomplete data set and letting students choose more data would be nothing but a small modification. Combined with a few questions regarding the nature of science, however, this small modification can change the ordinary activity into the nature of science activity in earth science. With this modified activity, students may learn not only about H-R diagram but also about subjective nature, creative nature, tentative nature, and empirical nature of science.

## Conclusion and Implication

The nature of science must be taught in all science classrooms with every subject of science. Learning scientific knowledge does not automatically bring the understanding of the nature of science. Moreover, possessing scientific knowledge without appropriate understanding of the nature of science might mislead students toward biased views. Thus, teachers should consider how to teach the nature of science within the subject they teach.

Earth science has its own merit to introduce the nature of science. The non-experimental methodology that is frequently used in earth science could provide a good basis to introduce accurate understanding about scientific methods. Tentative nature, creative nature, and socially and culturally embedded nature of science can also be easily introduced in the earth science class.

As shown in this study, modifying textbook activities could be one of the simple and easy ways to teach the nature of science in the earth science class. Teachers could do it without changing curriculum, or developing new programs. Therefore, there is less risk in modifying activities than trying whole new strategies. It is a small step and might not bring significant outcome. Nevertheless, it could be, at least, the starting point for both teachers and students to understand the nature of science in more practical way.

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