AN ACTIVITY SHOWING HOW TO USE HISTORY OF SCIENCE IN TEACHING NATURE OF SCIENCE[1]

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ABSTRACT

The purpose of this study is to develop a history of science activity which can be used to improve middle school students' nature of science views. The activity was designed and implemented based on an explicit-reflective approach within the context of the circulatory system. The activity was designed for grade 6 students and implemented during the 3-hour class period. During the implementation, most of the students successfully participated in the whole class discussion and established a connection between historical material and the corresponding nature of science aspect. Since the history of science activities in teaching key aspects of nature of science are still insufficient, the activity might both contribute to filling this gap in the literature and provide an example for science teachers to teach nature of science.
Keywords: science education, history of science, nature of science, science activity.

BİLİMİN DOĞASI ÖĞRETİMİNDE BİLİM TARİHİNİN NASIL KULLANILABİLECEĞİNİ GÖSTEREN BİR ETKİNLİK

ÖZ

Bu çalışmada ortaokul öğrencilerinin bilimin doğasına yönelik görüşlerini geliştirmek için kullanılabilecek bir bilim tarihi etkinliği ortaya koymak amaçlanmıştır. Etkinlik dolaşım sistemi bağlamında açık-yansıtıcı yaklaşıma dayalı olarak tasarlanmış ve uygulanmıştır. Geliştirilen etkinlik 6. sınıf öğrencilerine uygulanmış ve toplamda 3 ders saati sürmüştür. Etkinlik; tarihsel materyali deneyimleme, düşündürücü soruları yanıtlama, tüm sınıf tartışması ve genellemelere ulaşma şeklinde 4 temel basamak kullanılarak tasarlanmış ve uygulanmıştır. Uygulama sırasında öğrencilerin çoğu başarılı bir şekilde sınıf tartışmalarına katılmış ve aktivite ile bilimin doğasının ilgili boyutu arasında bağlantı kurabilmişlerdir. Bilimin doğası öğretiminde bilim tarihi etkinliklerinin kullanımı halen yetersiz olduğundan, etkinlik literatürdeki bu boşluğu doldurmaya katkı sağlayabileceği gibi, fen bilimleri öğretmenlerine de biliminin doğasını nasıl öğretebileceklerine yönelik bir örnek teşkil eder.
Anahtar kelimeler: fen eğitimi, bilim tarihi, bilimin doğası, fen etkinliği.

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INTRODUCTION

The view that scientific literacy is the ultimate goal of science education is widely accepted among science educators (e.g., Bybee & McCrae, 2011; Hodson, 2008; Van Dijk, 2014). Scientific literacy requires not only having science content knowledge, but also having knowledge about the nature of science (NOS) (Bell & Lederman, 2003; DeBoer, 2000; Driver, Leach, Millar, & Scott, 1996; Zeidler & Kahn; 2014). In other words, in addition to science content knowledge, NOS is accepted as one of the significant components of scientific literacy. According to the commonly accepted definition, NOS refers to the "epistemology of science, science as a way of knowing, or the values and beliefs of scientific knowledge and its development" (Lederman, 1992, p. 331). NOS is important for every individual to develop an understanding of several important issues such as "what science is, how it works …, how scientists operate as a social group, and how society itself both influences and reacts to scientific endeavors" (Clough, 2006, p. 464). It is also important to develop a more holistic understanding of scientific discipline (Next Generation Science Standards [NGSS] Lead States, 2013).

There are some widely accepted aspects of NOS in the literature. These aspects include the characteristics of scientific knowledge. As the literature on NOS indicates, scientific knowledge is reliable yet tentative (subject to change); empirically based (consistent with evidence which comes from the observation of the natural world); subjective (theory-laden); involves human inference, imagination, and creativity (it is not the copies of reality); is influenced by the culture of a society in which it is practiced (culturally embedded); does not require any absolute way so-called scientific method; perceives scientific theories and laws as different yet significant (Abd-El-Khalick & Lederman, 2000; Bell, 2006; Lederman, 2007).

Regarding the translation of NOS aspects into classroom practice, there are two general approaches, namely the implicit and explicit approach. Abd-El-Khalick and Lederman (2000, p. 673) stated that the former approach considers NOS as a "learning outcome that can be facilitated through process skill instruction, science content coursework, and doing science." Khishfe and Abd-El-Khalick (2002) criticized implicit NOS instruction by advocating that it is very unlikely to attain a more adequate understanding of NOS by merely "doing science". Several studies provided the support that an explicit approach is more effective than an implicit approach (e.g., Duschl & Grandy, 2013; Moss, 2001; Quigley, Pongsanon, & Akerson, 2011; Wahbeh, 2009; Walls, Buck, & Akerson, 2013). Although the implicit approach advocates that engaging in inquiry activities is sufficient to learn about NOS, the explicit approach requires utilizing from "history and philosophy of science and/or instruction geared toward the various aspects of NOS" (Abd-El-Khalich & Lederman, 2000, p. 673). During the explicit approach, teachers are required to direct students' attention to the targeted aspect of NOS by means of in-class activities such as whole-class discussion and questioning (Schwartz & Lederman, 2002). Besides, some researchers suggested adding reflective components to the explicit approach (Khishfe & Abd-El-Khalick, 2002). In NOS literature, reflective means "providing students with opportunities to analyze the activities in which they are engaged from various perspectives (e.g., a NOS framework), to map connections between their activities and ones undertaken by others (e.g., scientists), and to draw generalizations about a domain" (Khishfe & Abd-El-Khalick, 2002, p. 555). An important amount of studies indicated that students do not automatically develop an understanding of the complex epistemology of science just by "doing science" (i.e., implicit approach); rather, an explicit-reflective approach appears to be the most appropriate method (Clough, 1997; Khishfe & Abd-El-Khalick, 2002; Lederman, 2006; Moss, 2001; Schwartz & Crawford, 2006; Smith & Scharmann, 2008). In this approach, the classroom activities should be prepared in such a way that they should explicitly be centered around one or more NOS aspects. It is important to remind that *explicit* does not mean "didactic" or "direct instruction". Rather, it "entails the inclusion of specific NOS learning outcomes in any instructional sequence aimed at developing learners' NOS understandings" (Abd-El-Khalick, 2013, p. 2091). The "reflective", on the other hand, refers to "structured opportunities designed to help learners examine their science learning experiences from within an epistemological framework" (Abd-El-Khalick, 2013, p. 2091).

Although a lot of studies showed that explicit-reflective approach is an effective way of improving both students' and teachers' NOS conceptions (e.g., Abd-El-Khalick & Akerson, 2009; Lederman, 2007; Schwartz, Lederman, & Crawford, 2004), few researchers have been able to develop historical material using explicit-reflective approach (Maramante, 2018). In this study, therefore, a history of science (HOS) activity was developed with the aim of enhancing middle school students' nature of science views through the explicit-reflective approach. There are two important areas where this study makes a contribution to the existing literature. First, although some studies provided evidence that teaching science with history develops students' NOS views (Bauer, 1992; Irwin, 2000; Kolstø, 2008; Lonsbury & Ellis, 2002; Matthews, 1998; Monk & Osborne 1997), a critical review of current NOS literature indicates that the history of science activities to be used in teaching key aspects of NOS are still insufficient (Diem & Yuenyong, 2018; Maramante, 2018; Wolfensberger & Canella 2015). Therefore, the HOS activity developed in this study may contribute to the existing literature by adding an alternative source which helps to support middle school students' NOS understandings. Second, there is a concern about the availability of HOS activities in varied disciplines of science. For example, McComas (2008) stated that most of the HOS activities have been prepared for the discipline of physics. Therefore, it is important to develop HOS activities in other disciplines such as biology and chemistry. This study is also important because the HOS activity was developed for the circulatory system, a biology topic.

A SUMMARY OF IMPLEMENTATION STEPS

The implementation process consists of four main steps. These steps have been recommended for the first time within the course of the author's doctoral dissertation (Cansız, 2014). The general information about the implementation of each step is explained first, and the details of the implementation of the activity are presented next.

Step 1: Experiencing Historical Material

This is the first step in the implementation. In this step, the teacher provides students with historical material. Relevant to the purpose, students might work individually or as a group. In this step, the teacher allows students to work on the historical material and s/he actively observes students that they work on the material. The teacher gives enough time to the students considering the extent of the historical material.

Step 2: Engaging in Probing Questions

In this step, the teacher provides students with a handout that includes some probing questions related to the historical material. The students are expected to reflect on the historical material and write their thoughts on the handout to be used in the next step. The important point is that students should support their ideas with evidence when responding to the questions. They are also expected to organize their opinions regarding the historical material, which is critical to be prepared for the whole class discussion.

Step 3. Whole-class Discussion

In this step, the teacher encourages students to share their ideas using historical evidence. During the whole-class discussion, the role of the teacher is quite important. The teacher should moderate the interaction between students well so that the discussion remains on the topic of the interest. Although the discussion should be student-centered, the teacher makes sure that students establish a connection between historical material and corresponding NOS aspects. During this process, students should share their ideas, express their judgments about emerging ideas, challenge with opposing views, and use evidence from historical material. The teacher needs to encourage all students to participate in the discussion.

Step 4. Creating Generalization

Compared to the previous step, this one is more teacher-centered. In this step, the teacher guides students to generalize what historical material indicates to the complex epistemology of science. In order to do this, the teacher gives students an opportunity to make a connection between key points in historical material and scientific enterprise.

ACTIVITY IMPLEMENTATION

This activity was developed to help middle school students improve their NOS views. The targeted group was grade six students and the targeted topic was *F.6.2.3 Circulatory System.* This topic consists of five objectives. In the current science curriculum in Turkey, the Ministry of National Education (MoNE) (2018) recommended 6 class-hours to cover the topic Circulatory System. It is better to use the activity suggested in this paper right before the circulatory system topic. Three class-hours are needed to fully cover the activity; one for reading and comprehending the story, two for an in-depth discussion of corresponding NOS aspects. In addition to developing students' NOS views, the activity has the potential to overcome students' possible misconceptions about the circulatory system. Researchers defended that some students' misconceptions are quite similar to those of prior scientists (e.g., Matthews, 1994). Providing students with earlier scientists' misconceptions may prevent them from developing similar misconceptions.

This activity is also expected to be useful in achieving the specific goal of the curriculum since it states that "The main goals of the science curriculum, which aims to educate all individuals as scientifically literate, are as follows: ... to help understand how scientific knowledge is created by scientists, in which processes has it passed…" (MoNE, 2018, p. 9). Although the activity was primarily developed for the sixth graders to emphasize NOS right before the circulatory system, it may also be used as a stand-alone activity in the following grades when the spiral structure of the curriculum is considered. For instance, the objective F.7.1.1.5 states that *"[Students] make inference about the importance of telescope in the development of astrology."* (MoNE, 2018, p. 39). Similarly, in the explanation of the objective F.7.2.1.2, it was underlined that *"it is emphasized [to students] that scientific knowledge is not definitive but can change and develop."* (MoNE, 2018, p. 40). This activity can also be used to attain the following objective in grade 7 (objective F.7.4.1.2): "*[Students] question how the ideas about the concept of the atom changed from past to present."* (MoNE, 2018, p. 41).

The activity "About Circulatory System" was developed and implemented to improve middle school students' views on certain aspects of NOS. These aspects are "there is not a fixed scientific method that all scientists have to follow", "scientific knowledge is not objective", and "scientific knowledge is subject to change". The activity also focuses on "creative and imaginative nature of science", and "empirical nature of science". The activity was implemented to sixth grade students attending a public school located in Çankaya, a district of Ankara. Two classes and a total of 51 students (26 boys and 25 girls) engaged in the activity. All required ethical and legal permissions were obtained before the implementation.

Step 1: Experiencing Historical Material

At the beginning of this step, a handout including the following historical story (About the Circulatory System) was distributed to the students. The story was adapted from Ozkaynak (2006), Ribatti (2009), Schultz (2002), Shank (1985), and Westfall (1977). The teacher provided students with enough time to read the whole story.

About the Circulatory System

In order to fully appreciate Harvey's discoveries in the circulatory system, it is necessary to return back to 400 BC, the golden age of Greece. In those years, the Hellenic civilization rejected the idea that everyday events, such as rain or disease, were in the hands of various souls. They thought that these events should be connected to a critical and rational analysis by emphasizing that these phenomena are not supernatural; on the contrary, they are natural. In this respect, they separated logic from legend and they always searched for reasons.

In the medical field, prior to William Harvey, Galen's views on heart and blood circulation had been effective for more than 1600 years. One of the most important contributions of Galen to medicine is Blood Distribution Theory. According to Galen's theory, blood was produced in the liver from the food which comes from the stomach and intestines.

This blood was delivered to the body through the vessels to feed the body or to transform into soft tissues such as meat. The rest of the blood was coming to the right ventricle. A portion of this blood was sent to the lungs to feed them, and the remaining blood poured into the left ventricle from the pores in the ventricle wall. Here, this blood was combined with air coming from the lungs and it was believed that this "inspired air" contains the basic principles of life. During the heart expansion (in diastole), the hearth was believed to absorb the blood to the right ventricle and air to the left ventricle. According to this view, when the heart contracted (in systole), the blood in the right ventricle was sent to the lung and in the left ventricle to the body. It was thought that when the heart expanded and filled with blood (in diastole), it was actively doing its job and the heartbeats occur during this process. Galen's Blood Distribution Theory also postulated that blood was constantly consumed in the body and it was instantly reproduced from digested foods.

William Harvey was born in 1578 in Folkestone, England. He received his first medical education at Padua, a famous medical school of the time. In 1615, he was appointed as a faculty member to the chair of anatomy and surgery of the Royal School of Medicine. In 1616 when Harvey was a professor at the Royal Medical School, he began to describe blood circulation based on his experiments and observations on animals. He used various methods to describe blood circulation. One of them is the vivisection (examination and research on live animals for medical purposes). With the help of vivisection, he observed that the heart continued to beat for a while when it is separated from the body of a living animal. Thus he proved that the hearth does not suck blood when it expands as Galen thought. Rather, the heart works as a pump. He observed the heart until it begins to die and concluded that, in contrast to what Galen had said, the active movement of the heart is in systole and when the hearth is in diastole, it is resting. Using vivisection, Harvey also demonstrated that the blood is transferred to the ventricles by contraction of the auricles. When Harvey cut the hearth of a living animal from a specific point with the help of scissors, he observed that the blood was flowing out of the ventricles each time the auricles contracted. In this way, he proved that the blood came into the ventricles by the impulsion of the auricles.

Other conclusions Harvey reached to describe the circulatory system using vivisection can be summarized as follows:

- *When he cut a fish's vessel which leads from the hearth to the gills, he observed that blood was spouting out of the cut in each heartbeat and the expansion of the arteries followed the heart's contraction.*
- *When he cut the veins of a sheep, he observed that there was constant blood flow in the veins leading to the hearth and there was no blood flow in the opposite direction. In this way, he proved that the direction of the flow of blood in the veins is from the body to the heart. When he conducted the same procedure for arteries, he observed just the opposite and concluded that the direction of the flow of blood in the arteries is from the heart to the body.*

A second method Harvey used to describe the circulatory system was dissection (examination of the parts of the dead body for experimental purposes). What he found using dissection may be summarized as follows:

- *He dissected a mammalian heart and observed that the ventricular walls are thick, hard, and dense. He also examined that there are no pores on these walls.*
- *He demonstrated that there are valves in the veins and these valves function to keep blood moving in one direction and prevent the blood to move backward. Based on this he inferred that, contrary to what Galen thought, the blood cannot ebb and flow in the veins.*
- *Harvey also used a quantitative-mathematical method as proof of his blood circulation theory. This is important since nobody had used the quantitative method before to support her/his arguments in medicine. With the help of this, he postulated that the blood cannot be consumed in the body and reproduced from the food. Therefore, it necessarily circulates in the body. The essence of this method is as follows:*
    - *Harvey measured the volume of the blood in the left ventricle. Then he calculated the amount of blood that passes through the human heart within half an hour. Based on his*

calculations, this amount was more than the total blood in the body. If the blood was consumed in the body and reproduced from the food, then we would have to eat earlier than every thirty minutes. This was the evidence gained through the quantitative-mathematical method.

Harvey also used the perfusion method (the process of intravenous delivery of a fluid to an organ or tissue) in his studies related to circulatory system theory. For instance, he tied all the blood vessels of the hearth and observed that the right ventricle swelled when water delivered from the vena cava. Moreover, when the right ventricle filled with water, he cut the left ventricle and observed that no water was coming out. If there were pores between the ventricles, water would outflow from the left ventricle.

Eventually, by putting all his findings together, Harvey introduced his theory of circulation. It is still accepted almost unchanged.

During the first step, the teacher wandered around the classroom and answered the questions of students about the story. He also assured that everyone is working on the story. When all students completed reading the historical story individually, the teacher asked several students to summarize the main parts of the historical story. The aim here is to make sure that students understand the story.

Step 2: Engaging in Probing Questions

At this step, students were given another handout which included the following questions:

- Why might Harvey and Galen think differently about the circulatory system?
- Why might Galen's theory remain unchanged over 1600 years?
- What methods did Harvey use to develop his theory of the circulatory system?
- Why might Harvey's theory of the circulatory system be accepted in the scientific community instead of Galen's theory?
- Considering the story, do scientists use the same methods when trying to solve a problem? Why?
- Many people imagine scientists as working in the laboratory. Based on the story, how is Harvey different from these scientists?
- Figure 1 shows the steps of the scientific method in most of the written documents. What do you think about the accuracy of these steps after reading the historical story?

Students are given enough time to answer the questions in the handout. With the help of these questions, students are expected to reflect on the history of the circulatory system and arrange their ideas for the whole classroom discussion.

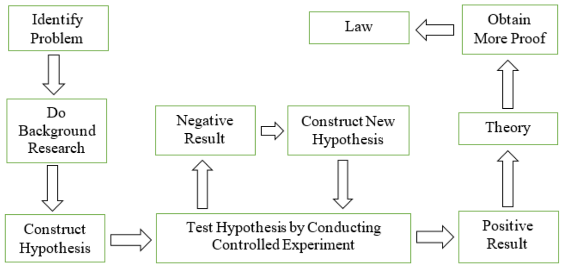

Figure 1. A Stereotypical View about Scientific Method

Step 3 and Step 4: Whole-class Discussion and Creating Generalization

Since several aspects of NOS are targeted to develop using the history of science story, step 3 and step 4 are presented together. After each student completed answering the probing questions in the handout, the teacher starts the whole class discussion by listening to students' thoughts about probing questions.

First of all, the teacher-directed the whole class discussion into a single-method fallacy in science with reference to Harvey's investigations. He started the discussion with the following direction: "Let's first look at Figure 1. What do you think about it? Is it true or false? Is it the only way to do science?" At the beginning of the discussion, most of the students seemed to consider that there is only one legitimate way to do science, which is called *the scientific method*. For example, one student stated that "it is obviously true!" When she was asked the reason why she thinks so, she replied: “Because it is written so in books!” When the teacher asked her to briefly summarize through which stages Harvey carried out his work, she seemed to be uncomfortable with her existing idea. When other students questioned the way Harvey conducted his studies, they were first seemed to perceive their understanding of “unique scientific method” as inadequate. Toward the end of the discussion, they were seemed to comprehend that there is no unique scientific method. For example, one of the students expressed during the discussion:

> I read about Mendel who studied in his garden with pees and made observations in most parts of his study. He was trying to find the inheritance of the pea plant. He did not follow any stepwise method throughout his study.

The discussion on single-method fallacy in science using the history of the circulatory system was generalized into science by underlining that there is no only one legitimate way to do science.

After completing the discussion on single-method fallacy in science, the teacher-directed students' attention to the subjective nature of science. In the history of science story, it was highlighted that Galen’s theory dominated studies on medicine over 16 centuries. Although it was almost completely wrong, Galen’s Blood Distribution Theory was accepted for such a long time. Scientists of those times provided more evidence, which supported Galen’s opinion since it was explaining the complex physiology of the circulatory system. Taking this as a reference point, the teacher asked students the following question: When the theory of Galen was almost completely wrong, how come the scientists, who came after the Galen, didn't realize it for many years? Students are directed to discuss that scientists’ beliefs shape their observations and inferences. During the discussion, the statement of a student was worth mentioning:

> Most of the ancient scientists believed that earth was the center of the universe. Therefore, they inaccurately observed that stars and planets orbit the earth every day!

The whole class discussion was ended with creating generalization that the scientists’ existing theories and their mindset influence all scientific processes such as making observations, collecting data, or interpreting data. That is, it was underlined that science is not objective.

After finishing the discussion on the subjective nature of science, the teacher went ahead with the tentative and empirical nature of science. In this part of the whole class discussion, the teacher focused on how Harvey’s Theory of Circulation replaced Galen's Blood Distribution Theory. He asked that “Why might Harvey's theory of the circulatory system be accepted in the scientific community instead of Galen's theory?” The students discussed that Galen’s theory did not satisfy Harvey. Therefore, he conducted a series of studies to satisfy his curiosity and refute Galen’s theory. For instance, Galen thought that there are small holes on the ventricle walls that allow the blood to pass from the right ventricle to the left one. Harvey invalidated the existence of those small holes by dissecting the hearth of some mammalian animal and by conducting perfusion experiments. By referring to this knowledge, students discussed that science requires evidence and the teacher stated that this is the empirical nature of science. Moreover, having obtained a piece of new evidence on the circulatory system and failing to explain the complex structure of the circulatory system provided a good context for students to discuss the critical role of evidence in science.

In this part, the teacher also guided students to discuss how new empirical evidence resulted in the change of scientific knowledge on the circulatory system (i.e., the tentative nature of science). He initiated the discussion with a general question: “What do you think, does scientific knowledge ever change?” At the beginning of the discussion, with their stereotypical view, most of them stated that scientific knowledge cannot be changed! Later in the discussion, the teacher stated that “Let’s go back to handout and read the following question again: Why might Harvey's theory of the circulatory system be accepted in the scientific community instead of Galen's theory?” Students paused immediately after asking this question again. After a while, they seemed to be convinced that science might change.

The nature of Harvey’s attempts to discover the theory of circulation offered several worthy contexts for discussing creative and imaginative NOS. For example, the teacher asked, “Although Harvey had not been able to directly observe certain events in circulation, how could he come up with conclusions about them?” During students’ whole-class discussion, the teacher underlined some of Harvey’s smart approaches to circulation by referring to the story including the calculation of how often does somebody need to eat if the human body would consume blood as Galen asserted or performing perfusion experiment to show if there are pores between the ventricles. The teacher completed the whole class discussion by referring to that as opposed to what some people believe, scientists use their creativity and imagination all the time, as did Harvey in his seminal work.

DISCUSSION and CONCLUSION

In this study, a history of science activity was developed and implemented based on an explicit-reflective approach to improve middle school students’ understanding of NOS aspects within the context of the circulatory system. An important body of literature suggested that history of science (HOS) instruction has a potential to improve students’ NOS understanding (Clough, 2006; Duschl 2000; Irwin, 2000; Kolstø, 2008; Lin & Chen, 2002; Lonsbury & Ellis, 2002; Matthews, 1994; Maramante, 2018; Wolfensberger & Canella 2015). Although empirical support of the benefits of HOS on students' NOS views, implementation of HOS in classroom settings are inadequate in practice. Höttecke and Silve (2010) described four major obstacles of implementing HOS in school settings as teachers' tendency of content-driven teaching, teachers' inadequate epistemological belief, insufficient support of curriculum developers, and more importantly lack of sufficient historical materials. This study is important to add one more historical material to the literature. It is important to share similar HOS activities that target to teach NOS. In this way teaching NOS aspect using HOS become widespread in the literature.

Although providing results on how students’ NOS views changed during the implementation is out of the scope of this paper, it is important to note that most of the participants successfully participated in the whole class discussion and articulated more adequate views. During the whole class discussion, it was observed that few students could not discuss the corresponding NOS aspect deeply and could not express themselves well. In order to improve students’ deep understanding of NOS and self-expression capacity, they should be provided with structured opportunities as in this activity.

Based on the classroom observation during the implementation of the activity and personal experience, it is valuable to make some suggestions to educators who plan to use the history of science as a method to emphasize the aspects of NOS. First, as Matthews (1994, p. 50) defended “history is necessary to understand the nature of science” because it is one of the best ways to show students how science and scientists work. Therefore, diverse historical materials from physical science, earth science as well as life science should be developed and implemented in the science classrooms at earlier school years to prevent possible misconceptions related to the nature of science. Otherwise, as Wandersee, Mintzes, and Novak (1994) emphasized, it is highly difficult to change inconsistent conceptions through traditional teaching in the following years of schooling. Second, the history of science activity is limited to the circulatory system in this study. The circulatory system is an abstract topic and students could not directly observe some concepts of it. Therefore, we suggest that historical materials also need to be developed for more concrete topics in future research. Finally, in this study, we utilized from historical short story to discuss NOS aspect. Although students exhibited productive whole discussion based on it, some of the experiments Harvey used to discover the circulatory system may be repeated during HOS instruction. For example, the teacher may let students dissect the hearth of a sheep similar to Harvey did. In this way, the students may internalize the activity better.

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