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Analysing Vee Diagram Reflections to Explore Pre-service Science Teachers' Understanding the Nature of Science in Biology

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Vee diagrams have been a metacognitive tool to help in learning the nature and structure of knowledge by reflecting on the scientific process and making knowledge much more explicit to learners during the practical work. This study aimed to assess pre-service science teachers' understanding some aspects of NOS by analyzing their reflections on the Vee diagrams constructed during the general biology laboratory course. In this single case study, elementary pre-service science teachers who cited mainly "the cell theory" in their Vee diagrams while building around the cell concepts were asked to participate in focus group reflective interviews. These interviews compared the patterns of the nature of scientific knowledge to the ways their constructed the cell related concepts. The content analysis of transcripts revealed that pre-service teachers gained a superficial understanding of history of scientific ideas in the development of the cell biology, not a deeper epistemological understanding in conceptualizing a contemporary understanding of the aspects of NOS. The emergent categories of naive understandings and misconceptions held by the participants were demonstrated and discussed in the light of NOS related literature.

Keywords: nature of science, Vee diagrams, biology teaching, cell theory

INTRODUCTION

A contemporary epistemological view of science emphasized in any reform efforts in science education has inspired an understanding of the Nature of Science (NOS) (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). In the similar vein, current changes in K-12 science curriculum documents by Ministry of National Education (MoNE) in Turkey, which is the context of this study, imply students' conceptions of NOS as an educational goal (MoNE, 2013). On the other hand, nurturing science teachers with appropriate NOS pedagogical content knowledge remains as an unattainable goal in teacher education programs (Sarieddine & Boujaoude, 2014). Abd-El-Khalick (2012) emphasized the importance of content situatedness as a domain of teacher pedagogies for both effective teaching about NOS and with NOS. However, there is lack of cases indicating teaching NOS as content-situated in teacher education programs. In an attempt to address this gap, this study anticipated that Vee diagrams in biology concepts would provide a context for teaching and learning of NOS because of the extent to which has a potential to integrate philosophical and methodological underpinnings of scientific knowledge. Then, this study aimed to assess pre-service science teachers' understanding some aspects of NOS by

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State of the literature

- A contemporary epistemological view of science emphasized in any reform efforts in science education has inspired an understanding of NOS; hence, nurturing science teachers with appropriate NOS pedagogical content knowledge for effective science teaching is still a major endeavor in teacher education programs.
- Beyond its definition, there has been recently a perceived dichotomy in domain-general versus domain-specific NOS, but huge amount of the literature has converged on its generic meaning across all scientific disciplines.

Contribution of this paper to the literature

- Vee diagrams can be a pedagogical approach in forming theories to relate scientific concepts and events with their historical development for NOS understanding in a more clear and probative way.
- Vee diagrams would provide a valuable context for conveying explicitly NOS understanding into classroom practice in relation to any science content courses.
- There is a need to refocus on the biological knowledge beyond memorizing the extent to which aspire the contemporary views of NOS in improving teachers and students' ability to debate contextualized issues.

analyzing their reflections on Vee diagrams constructed during the general biology laboratory-I course.

Nature of Science in Biology

Beyond its definition, there has been recently a perceived dichotomy in domain-general versus domain-specific NOS, but huge amount of the l has converged on its generic meaning across all scientific disciplines (Lederman, 2007). So, it was not the aim of this study to define nature of biology different from the general NOS understanding. Rather, the following discussion was a framework to construct the theoretical underpinnings of the study about how NOS would be typified in biology as a specific content domain.

While there is no succinct definition for the NOS in the philosophy of science literature, there seems to be a consensus to a somewhat broader array of explanatory understanding of natural phenomena as a way of knowing in science education (Carey, et al., 1989; Lederman et al., 2002). So, it has been widely accepted that teaching the NOS as an accomplishing educational goal in science classes involves the major epistemic elements of scientific knowledge which is subject to change (tentative), creative, based on empirical evidence, socially and culturally embedded, subjective (theory-laden), based on observations and inferences, theories and laws (Lederman et al., 2002). It needs to make clear the differences between observation and inference, similarly the functions and relationships of theory and law. Observations are descriptive in nature made directly with our own senses or indirectly through the use of tools whereas inferences are statements about phenomena that are not observable by our own senses. Similar relationship exists between a law and a theory. A scientific law explains the relationships among observable phenomena whereas a scientific theory refers to inferred explanations for observable phenomena derived from human interpretation, imagination, and creativity (Lederman et al., 2002).

Hurd (2001) pointed out the image of modern biology as a scientific domain extended from the physical evolution of living organisms to the more ethical, legal, and moral aspects of human beings and social contexts. This needs to refocus on the biological knowledge in science education the extent to which aspire the contemporary view of NOS and its social implications in improving teachers and students' ability to debate contextualized issues through personal and cultural needs of human beings (Hurd, 2001; Nickels, Nelson, & Beard, 1996). However, this cultural dimension of biology has been neglected in reform efforts in science education while biological studies have dominated in today's science (Hurd, 2001; Mayr, 1997; McComas, 2003; Simpson, 1963).

It may be due to the fact that the underpinnings of scientific methods and NOS conceptions historically have inherited from physical sciences that are perceived comparatively more rigid, mathematical and mechanical in nature, even the birth of NOS refers to beginning with ancient physics (McComas, 2003; Simpson, 1963). For instance, many laws in biology do not contain universal mathematical relationships like in the law of gravity or the laws of thermodynamics. The universality would explain the more deterministic nature of physical sciences that inspires a cause and effect relation, while laws in the life sciences are delineated by the rules/regularities with exceptions in their probabilistic nature such as the law of independent assortment which is limited to genes on separate chromosomes (Hurd, 2001; Kampourakis 2013; Mayr, 1997; McComas, 2003).

On the contrary to the perceived rigidity of physical laws in the past, the issue of universality in today's conception of physical science also restrict the generalizations of some physical laws such as Newton's laws of motion restricted to speeds less than the speed of light and Boyle's gas law to a certain range of temperatures like in Mendelian laws (McComas, 2003). In fact, Simpson (1963) postulated that rigid conception of physical sciences had been abandoned with the scientific revolution in the last century that was initiated by quantum theory and its principle of indeterminacy. Hence, causality for laws in modern science are acceptable as long as their predictions are based on repeated observations and measurements as far as encompassing a confidence in a range of probability; then the prediction would not be expected as the only precise way to confirm a hypothesis (Simpson, 1963).

Similarly, theory formation on the philosophy of science reflects the certainty of physical theories that are the scientific explanations based on universal laws. Therefore, it is worth of examining theory construction in biology by considering the factors of chance, pluralism and history that make it alive and/or unique for a case instead of seeing all phenomena by lenses of invariable and universal laws in physical sciences. In fact, biological principals or generalizations provide explanations and predictively accurate (e.g., natural selection in evolutionary biology) as driven by our observations instead of laws in physics (Kampourakis, 2013; Mayr, 1997). Thus, Kampourakis (2013) notifies that there is no need to use overly emphasized laws in building explanations and theories of biology.

Vee Diagrams as a Laboratory Instrument

Laboratory experiences have a high potential in aiding learning scientific knowledge and the ways of constructing this knowledge. However, laboratory or practical experiences in science education has been valued to the extent in which the investigation strikes on both substantive understanding and procedural understanding of science (Lunetta, Hofstein, & Clough, 2007). The substantive structure of science requires conceptual understanding of concepts, laws and theories. The procedural understanding acknowledges developing skills and concepts of evidence which implies scientific process (Duggan, Johnson, & Gott, 1996; Sahin-Pekmez, Johnson, & Gott, 2005). As a consequence, the more effective way of laboratory experiences requires an intersection in which learners "understand the epistemological [how knowledge is constructed and justified] and ontological [nature of reality] assumptions underlying scientific knowledge and the rationale for holding those assumptions while doing science" (Lunetta et al., 2007, p. 410).

In fulfilling this epistemological aim, Vee heuristic proposed by Gowin (Novak & Gowin, 1984) can help learners make connections between conceptual and procedural understanding in structuring scientific knowledge and the process through which this knowledge is generated. Then, Vee diagrams are an instructional strategy to enable learners to link the content and process in making knowledge much more explicit to learners (Alvarez and Risko, 2007; Novak & Gowin, 1984). Beyond providing conceptual connections, the educating philosophy of Gowin entails a non-absolute knowledge that depends on the epistemological elements constituted of it and prepositions about what learners already know into cognitive structure (Alvarez & Risko, 2007; Novak and Gowin, 1984; Novak, 2002). While learners are constructing a simple V shape in laboratory applications besides the practical work of gathering data, on the right side they are expected to cite philosophy, theories, principles and concepts related to the focus question in the center as well as transfer this data to make claims to the left side involving events or objects at the point of the Vee (Alvarez & Risko 2007; Novak 2002).

Gowin's Vee and its extensions have been employed as a heuristic tool at various disciplines from K-12 to post-graduate levels for learning science concepts (e.g., Alvarez & Risko, 2007), structuring argumentations (e.g., Nussbaum, Winsor, Aqui, & Poliquin, 2007) and integrating research philosophy and methodology (e.g., Fox, 2007). For teaching history of science, Chamizo (2012) used the restructured heuristic to enhance in-service teachers' understanding scientific investigation in chemistry from past to present. However, the historical studies mainly refer to the field of physics education rather than biology (Heering, 2014). Actually, no study has appreciated the role of Vee diagrams in understanding the aspects of NOS by reflecting on both the history of science and scientific process.

As a rationale, Vee diagrams can be a pedagogical approach in forming theories to relate scientific concepts and events with their historical development for NOS understanding in a more clear and probative way. Therefore, it was the underpinning of this paper to discuss how the interrelated relationship between substantive and procedural understanding can nurture theory-laden nature of scientific knowledge; specifically, what about pre-service teachers' understanding NOS in biology through the reflections of Vee diagrams developed for the cell laboratory investigations.

METHODS

Research Design

This qualitative research study followed a case design as defined by Merriam (1998) "an intensive, holistic description and analysis of a single, bounded unit" (p.193). In this single case study, therefore, the case was defined as the NOS learning by reflecting Vee diagrams in the general biology laboratory course with the multiple focus groups as unit of analysis. The study was bounded within the scope of general biology laboratory course offered in the elementary science teacher education program at a large university placed in the western part of Turkey.

In Turkey, teacher education programs usually have centralized and structured curriculum. In the first year of science teacher education program pre-service science teachers take general science and educational courses while more specialized science teaching courses are beginning in the second year. It is important to emphasize the course of "Nature of Science and History" offered in the third year. This course explicitly addresses the aspects of NOS and science history. Because of the participants of this study in their second year there were no potential impacts of this course on the results of the study.

Context

The one-credit compulsory introductory level biology lab course was offered in the second year of the program at fall term and scheduled to meet two hours a week for the term of 14 weeks. The course was delivered by the researcher in two sections in which approximately 104 pre-service science teachers enrolled. Concurrently, they involved in the theoretical general biology course. The basic objectives of the applied laboratory course were to continue improving pre-service science teachers' conceptual understanding about biology and basic science process skills throughout the practical works. The whole term scientific investigations conducted in the laboratory course involving the use of microscope, plant cells and tissues, cytoplasmic streaming, plastids, the structure of stem, leaf and flower, cell transport, mitotic cell division, photosynthesis, respiration, and fermentation. The laboratory text book guided the procedure of each week's scientific investigation. The laboratory course was designed by the researcher as to provide pre-service science teachers build Vee diagram for each laboratory investigation. Each scientific investigation consisted of four stages. The first stage required pre-service teachers to determine focus question and complete individually the conceptual part (left side) of Vee diagram before each week's assigned scientific investigation. The second stage involved doing investigation as hands-on activity in a group work for the laboratory class. The third stage required pre-service science teachers to individually complete methodological part (right side) of Vee diagram, and the last involved writing a reflective journal related to that week's assigned investigation.

The participants for the study were purposefully selected. Because, at the end of the lab course, pre-service science teachers' Vee diagrams were collected to identify pre-service teachers who cited scientific theories as a reference such as "the cell theory", "the endosymbiotic theory" and "the fluid mosaic model of membrane structures". Next, pre-service science teachers who referred mainly above theories were asked to voluntarily participate in focus group discussions from each section. The three groups of five to seven pre-service teachers were formed for focus group discussions. Then, the total number of participants was 18 pre-service science teachers with the average age of 20 years old. Except from two participants they were all female. This was not deliberate and but also the number of females in the original population was dominant. The focus groups were abbreviated as FG1, FG2, and FG3 and pre-service science teachers in the groups were presented as PST with the given numbers for everyone.

Data Collection and Analysis

The focus group interviews were used to assess pre-service science teachers' understanding some aspects of the NOS by reflecting on their Vee diagrams constructed around the cell related concepts in biology. Focus groups were preferred due its advantageous to get more data from limited questions throughout an interaction among interviewees who have similar experiences and cooperative with each other (Creswell, 2007). Specifically, semi-structured reflective interview questions were focused mainly on the discovery of the cell and development of the cell theory to reveal their perceptions through conceptualizing and processing their ideas for the cell development. Instead of using a general language in the questions, the cell related terminology were used including historical and evolutionary development of the cell concept and the scientific process in the development of the cell theory like observation, inference, data and evidence. The questions were validated by another science educator's views and piloted in the previous year classes before its last version. The questions to reflect on the cell theory for NOS understanding were illustrated in the Appendix. During the focus group, participants were asked to utilize the knowledge and data in their Vee diagrams to contribute the discussions. The discussions in each group approximately took two hours. The interviews were transcribed for the data analysis.

Marriam (1998) values the case study to gain an in-depth understanding and interpreting of the educational phenomenon within its real-life context. Thus, data transcripts from focus group discussions were subjected to holistic analysis to reach a deep understanding on the conceptual categories of pre-service teachers' views about the NOS and scientific process (Creswell, 2007). The qualitative data throughout a holistic approach were entirely examined and interpreted around the interview questions of this study and the pre-defined framework in the literature for the aspects of NOS to describe the whole case (Patton, 1987; Yin, 2003). The emergent outcomes of analyzing Vee diagrams reflections were categorized to represent the depth of the aspects of NOS understanding as informed and naïve as set by the pioneering researchers (e.g, Lederman et al., 2002). Finally, the emerged issues which were mostly naïve understandings and misconceptions held by the participants were exemplified and discussed in the light of the NOS related literature.

RESULTS

The analysis of reflective transcripts revealed that the six emergent categories of more naïve understandings of the NOS and scientific process held by the participants identified as coexisting meanings and images of scientific knowledge and scientist, lack of understanding of the distinction between experiments and observations, lack of understanding of the nature of hypothesis, lack of understanding of the nature of theories, lack of understanding of the distinction between theories and laws, and lack of understanding of the distinction between data and evidences. In the following subsections, each category was being described and exemplified with direct quotations.

Coexisting Meanings and Images of Scientific Knowledge and Scientist

The analysis of the participants' talking about the historical ideas cited in their Vee diagrams for the cell discovery indicated that they had difficulty in empathizing with the images and thoughts of scientists involved in the development of cell biology. When the question of "What did Robert Hooke observe under the microscope?" was asked, they imagined that Robert Hooke could think of his first view of cell in cork as the smallest unit of living organisms as what we understand today. In fact, he observed tiny hollow boxes that are actually walls of dead cells of oak bark. But, Hook only named the structures as cells in cork without thinking of them as being dead cells. Because, he did not know that these cells could be alive as a meristematic cell (Mayr 1997; Starr and Taggart 1992). The following excerpt from FG1 exemplifies the participants' coexisting meanings and images of scientific knowledge in the cell biology.

Facilitator: What did Robert Hooke view under the microscope?
PST1: He saw empty rooms made up cork.
PST3: It was a cell, when he searched for them; he got more knowledge about it.
Facilitator: You called the cell. But what do you mean by the cell at that time?
PST6: It is the smallest building blocks of living things.
Facilitator: My question is why Robert Hooke named the structures as "cells"?
PST1: He displayed the living activity. (Focus Group Interview, Group 1, 1/11/ 2013)

Lack of Understanding of the Distinction between Experiments and Observations

When pre-service science teachers discussed the development of the cell theory initiated by the question, "Can you think of how scientists developed the cell theory?" they used the words of experiments and observations interchangeable. This indicates that they hold naive views about the function of experiments because they perceived an experiment that is anything that scientist do to investigate including making observation (Schwartz, Lederman, & Lederman, 2008). Actually, an experiment as a specific scientific procedure means a controlled way to test and manipulate the factors (McComas, 1998; Lederman et al., 2002; Schwartz et al., 2008). The following example from FG2's discussion indicates their lack of understanding of the distinction between experiments and observations.

Facilitator: Let's talk more about the cell theory. How did scientists develop the cell theory? What about things or data makes the cell theory?
PST10: Experiments, observations.
Facilitator: What you mean experiments and observations?
PST10: It began with the observation of cork.
Facilitator: What is the difference between observation and experiment?
PST10: An experiment involves an observation.
PST13: Yes. It was an experiment.
PST11: Firstly, he did an experiment, and then he observed the experiment. (Focus Group Interview, Group 2, 1/14/ 2013)

Lack of Understanding of the Nature of Hypothesis

Almost all participants' views on the development of cell theory clearly indicated that they held common misconceptions on the nature of a hypothesis. Based on the first observations about the cell mentioned in the previous section, pre-service teachers described the next step as emerging hypotheses exemplified by 'even cells are independent units, they work as a whole'. Actually, this hypothesis/idea would be developed by interpreting or evaluating the empirical evidences, but by not directly observing the cell. Then, hypotheses are defined as reasoned and inferred explanations mainly both derive from and inform prior experiences and observations for a narrow set of phenomena (Carey et al. 1989; Understanding Science 2013, "Hypothesis" para. 1). Even few of them called a hypothesis as an idea or claim based on observations, when the facilitator probed the discussion to extract their understanding for a hypothesis, they considered hypothesis as refutable and uncertain knowledge. The below excerpt from FG2 typically exemplify their naïve understanding about the nature of hypothesis.

PST13: Even cells are independent, they serve their purpose together.

Facilitator: How you describe this knowledge of cell?
PST13: It is an observation.
PST11: It is a claim.
PST12: It is a hypothesis.
PST10: It is a hypothesis.
Facilitator: How do you describe a hypothesis?
PST11: It has indeterminate accuracy.
PST10: It would be change later.
Facilitator: What do you mean?
PST10: I think it is hypothesis that has validity now. But this knowledge can change later.
PST11: We accept it as correct now because we do not have any knowledge that would disprove it.
PST13: When the new knowledge comes, it takes place the old one. (Focus Group Interview, Group 2, 1/14/ 2013)

Lack of Understanding of the Nature of Theories

Most of the participants seemed to perceive the cell theory emerged over a period of time as on the availability of supporting evidences for the hypotheses of 'all organisms are composed of one or more cells', 'the cell is the basic living unit of structure and organization of organisms', 'all cells come from pre-existing cells'. It was an ossified misconception such that pre-service teachers stated a hierarchical relationship between the hypotheses and theories (McComas, 1998; Lederman et al., 2002). They perceived first hypotheses about the cell had been put forward, and then hypotheses became theories on the availability of supporting evidence over a period of time in the development of the cell theory. Actually, hypothesis, theories, and laws are all scientific explanations but they differ in breadth, not in level of support, so theories often integrate and generalize many hypotheses (Understanding Science, "Theories" para. 1). In the following excerpt from FG1 participants were discussing to rationale the emerging cell theory as a result of being supported hypotheses based on their misconceptions on the development of hypotheses into the cell theory.

Facilitator: Which one is hypothesis?
PST3: The hypothesis is that from single cell organisms to oak trees and human beings all living things are composed of cells.
PST5: Yeah. This is hypothesis.
PST3: There are three assumptions for the cell theory including; the cell is the basic unit of structure of organisms, cell division provide passing copies of parental genetic materials on to their offspring, and even cells are independent they work as a whole.
Facilitator: What you mean with these assumptions?
PST3: These three things are the assumptions covered by the cell theory.
PST5: The arising of cell concept would encompass hypotheses about the cell. The taking roots of these hypotheses leaded to be formed as the cell theory.
Facilitator: Let's continue to talk about the theory. What is a theory?
PST1: Something is to become a theory. Firstly, someone developed a hypothesis. If we can repeat this one again and again by experiments with unchanging outcomes, it is to be proved. I mean that those are named as theories that we read now, they were previously hypotheses. Because the results are not change or the same results reach in each experiment in everywhere, it turns into a theory. (Focus Group Interview, Group 1, 1/11/ 2013)

This expert also includes another example for the section of 'coexisting meaning' of scientific knowledge hold by pre-service teachers. While pre-service teachers refer to Virchow's idea "all cells from cells", one of the participants stated 'cell division provides passing copies of parental genetic materials on to their offspring'. Actually, the cell theory originally had no use for the nucleus or chromosome as a means of including genetic material for the cell division (Mayr, 1997).

Lack of Understanding of the Distinction between Theory and Law

In having to assess pre-service science teachers' understanding the distinction nature of theories and laws firstly the participants were impelled to think of the history of cell science by using the conceptions on their own words as exemplified in the third question of the reflective interview (see Appendix). Then, they were asked to discuss their warrants for the cell theory whether it can become a law or not. There were two emerging perspectives. The participants having the first perspective proposed that the cell theory can become a law because there is no counter-theory so far to refute. The others having the second perspective proposed that the cell theory can not become a law because of further future studies needed to prove the rigidity of the cell theory or it opens still to change by accumulating evidences. In any way, participants in the focus group discussions perceived that the cell theory developed in a sequential manner such that it began with hypotheses and transferred into theories and now can be upgraded to a law on the availability or rigidity of supporting evidences. This indicates that participants have ossified misconceptions in functions and hierarchal relationships of theory and law (McComas 1998; Lederman et al., 2002). The following excerpts from FG2 typically exemplify the preservice teachers' rationales on the development of a theory into a law or not.

Facilitator: Then, over four hundred years have passed that you admit that the cell theory keeps its accuracy. Let's talk *more about laws. Can you think of the cell theory could become a law?*

PST11: Something is to be continued as a theory or not to be upgraded as a law, there should be anti-theories. But, the scientific investigations have been conducted so far based on the cell theory as being accepted. New things have been added to old ones and have not yet changed them. Therefore, I think that it could be a law.

PST13: I do not think so. Because the cells are all different with regard to their functions, shapes and sizes.

PST10: I think that microscopes are able to magnify a definite size or it can be magnify a definite smallness. I mean that it can not be descended for a deeper so that the cell cannot be examined exactly. Therefore, the structure of living matter might be different. So, it cannot be a law.

Facilitator: When can it be a law?

PST10: In any way if cells can be examined deeply by improved microscopes, it might be a law. But, there are different cells as regard to their structures, so something has validity for one cell but not for another.

PST9: I think that it can not be a law. Because it is going on by adding more new things so it has been continuously changing with newer things. (Focus Group Interview, Group 2, 1/14/ 2013)

Lack of Understanding of the Distinction between Data and Evidence

In having to assess pre-service science teachers' understanding the distinction between data and evidence to make a theory, they wanted to give examples from their claims constructed in the procedural part in their Vee diagrams for their scientific investigations in the cell lab. As exemplified in the following excerpt, one of the participant's claim was that "the cell wall in plants gives the shape of the cell" grounded from her observations of elodea leaf under the microscope. This is an example that typifies that the participants mostly indicated a lack of understanding to distinguish their observations from inferences to relate evidences to justify their theories/ideas/claims. In fact, scientific knowledge does not come directly from observations; rather scientific theories/claims are inferred explanations for observable phenomena (Abd-el Khalick, 1998). While data are the observations, evidence is an inferred pattern/outcome as a result of data interpretation (Schwartz, 2007). This failure indicated that pre-service teachers hold a naïve view of empirical NOS. The following excerpts from FG3 typically exemplify the pre-service teachers' lack of understanding of the distinction between observation and inference and in relating empirical evidences to make their theories.

Facilitator: What else your claims/ideas?

PST14: One of my claims was that cell wall in the plants gives the shape of the cell. As such, there are many cells in adjacent with each other…The cell wall in elodea gives its shape.

Facilitator: Is it an observation or inference?

Facilitator: It is my observation

Facilitator: How did you observe?

PST14: I observed under the microscope.

Facilitator: But why do you think the cell wall gives its shape?

PST14: It gives a shape like a bowl that surrounds the water inside it. (Focus Group Interview, Group 3, 1/14/ 2013)

DISCUSSION AND CONCLUSIONS

The reflective focus group interviews conveyed the ways in which pre-service teachers view scientists, scientific knowledge, and the practice of science to the researcher for exploring their personal theories and identifying their misconceptions in this process of knowledge construction. The analysis obtained from focus group discussions gave evidence that participants had only superficial understanding of historical ideas and were not aware of the evolutionary and developmental nature of scientific knowledge in regards to the cell biology from past to present. Even though Vee diagrams compelled the participants to cite the cell discovery and theory, they could not perceive how science has worked and scientists have thought about NOS in biology at different times. In fact, they were not aware of developmental nature of cell biology that has roots back to early microscopists in the seventeenth century. It seemed that participants perceived Hooke and others like Malpighi and Leeuwenhoek as biologist but they were actually keen on lenses and it was a funny job to examine things under their own microscopes without being able to explain what they had seen yet this was mostly an age of exploration not of interpretation (Mayr, 1997; Starr & Taggart, 1992).

Moreover, the participants' talks gave evidence for their misconceptions in understanding some aspects of the NOS and scientific process. Particularly, they are unfamiliar with the nature of hypothesis, theory, law, observation, experiment, inference, data, and evidence; and the relation among these elements as a way of constructing their scientific knowledge in the cell biology. While they were explaining how scientists developed the cell theory, pre-service teachers referred to an application of a universal scientific method which means dealing with hierarchical observations, hypotheses, theories and laws, as a consequence, failure in distinguishing functions and relationships of hypothesis, theories and laws. It is obvious that participants had misconceptions on the nature of hypothesis. They perceived hypotheses as an immature idea or guess about the cell postulated immediately after the first observations of cells under the microscope to be proved with accumulating evidences, then it turned to the cell theory. Actually, the postulated ideas or hypotheses are informed scientific explanations for the phenomena of the cell developed based on the empirical evidence and logic (e.g., life is built from cells) (Understanding Science, 2013, "The logic of argument" para. 1). Yet, they could not realize that these ideas had not been formed over the next 200 years until improvements in microscopes after the first observation of the cell in the 1600's.

The participants demonstrated further a lack of understanding in distinguishing between observation and inference in constructing their personal theories of natural phenomena in regards to cell biology. In fact, they had no empirical view of science relating evidence and theories for reasoning their claims in the cell structure. For this case they hold theories likely to be facts based on their observable evidences evolving independently from their prior knowledge and interpretation of the experimental data, and that was associated with a lack of understanding in theory-laden nature of scientific knowledge. As such observations restricted by our perceptual apparatus, scientific activities become necessarily theory-laden in nature involving imagination and creativity (Abd-el Khalick, 1998; Lederman et al., 2013). When considering this low level of empiricism associated with lack of understanding in relating evidence and theories/ideas/claims, it is obvious that the participants appreciated observable evidences as the sole source to explain natural phenomena without producing the phenomena based on theory-laden nature of empirical science (Carey et al., 1989; Schwartz, 2007; Solomon, Duveen, Scot, & McCarthy, 1992).

Consequently, pre-service teachers did not seem to develop a contemporary understanding of their views on the nature of scientific knowledge and science process. Moreover, the findings obtained from the reflective interviews displayed epistemological weakness in pre-service science teachers' thinking, reasoning, and justification to develop their scientific knowledge and understand the ways in which scientific knowledge generated throughout the time in the cell biology. Therefore, we should discuss such factors that impede enhancing epistemological understanding in conceptualizing a contemporary understanding of NOS. It is seen that participants usually met with the similar written historical studies as in the cell discovery and theory, so it reminds the weak validity of written or internet sources about the history and NOS in biology sources. As such, the content analysis textbooks in biology indicates that they poorly described not only some important aspects of NOS, but also with the same repeating misconceptions including the discriminations among hypothesis, theories and laws, one type hierarchical method of scientific investigations (Irez, 2009; McComas, 2003).

We can not only blame textbook or internet sources for poor understanding of NOS. It is possibly due to the absence of epistemology and history of science content in teacher education programs, too (McComas, 1998). Thus, further emphases with NOS and practicing in the classroom must be part of science teaching as a cognitive rather than affective goal, in particular, outcomes should be planned, explicitly taught, and assessed instead of assuming to develop as a side effect (Lederman et al., 2013). The explicit inclusion of epistemology discussions during not only pre-service courses, but also the integration in primary and secondary curriculum could help pre-service teachers' understanding NOS and their construction of scientific knowledge. At least some aspects of NOS should be taught beginning from kindergarten to K12 as a cognitive outcome by explicitly reflecting on real science activities or experiments.

In addition, misusing the words by many people in daily life might be another factor to misunderstand the scientific terms like "just a theory" to mean something is not true. The other one is "experiment" to mean any scientific investigations and procedures but not all of them include controlled manipulative experiments (McComas, 1998; Scwartz, 2007). It is so similar in Turkish educational context that many science teachers and instructors (e.g., like the researcher), and text book resources use the word of "experiment" to mean any laboratory investigations such the classroom atmosphere of this course that used a language of like "today experiment is …" among the pre-service teachers and the instructor in their talks and writings.

The study has implications for teacher educators delivering science content courses in teacher training program in a way that integrated and enhanced pre-service science teachers' understanding NOS. As a suggestion for science curriculum developers, biology or science textbook writers should include the aspects of NOS beyond content and process by engaging learners to develop understanding across context specific issues. Indeed, science teachers and instructors should be handled history and philosophy of science explicitly in related science content courses about how scientific knowledge has become accepted or how science has functioned at different times in different places.

Furthermore, Vee diagrams would still be a valuable context for explicit reflective approach for functional understandings of NOS and scientific inquiry by combining the historical case study with procedural ideas in the laboratory investigations. As Lederman et al., (2003) notifies that we do not have any evidences among the relative effectiveness of various explicit approaches. Thus, qualitative and quantitative future research can determine the effectiveness of Vee diagrams and other inquiry-based methods in facilitating explicit approaches throughout the direct reflections of both historical and procedural aspects of scientific knowledge to inspire learners for contemporary understandings of NOS.

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APPENDIX

Reflection questions on Vee diagrams of the cell concepts for NOS understanding.

1) Can you describe how the knowledge has been formed about the cell that we know today? [They would be mostly expected to cite to Robert Hooke and Leeuwenhoek for the first discovery of the cell based on their Vee diagrams in the cell concepts laboratory work.]

Who was the first do research about the cell?

What did Robert Hooke view under the microscope?

Who described the cell as a living unit?

2) [If they have mentioned the cell theory already.]. Let's more talk about the cell theory. Can you think of how scientists develop the cell theory, or how they make the cell theory? What about things that make the cell theory?

[If they have not mentioned the cell theory before. First, ask the cell theory.] Can you tell me what the cell theory is?

[If they have referred to words like observation, hypothesis and experiment in the development of the cell theory, probe the meaning of each word. If they use another words except from below ones, probe their meanings, too.]

What is the observation in the cell theory? How do you describe a scientific observation?

What is the hypothesis in the cell theory? How do you describe a hypothesis?

How do you describe a scientific experiment?

How do you describe a theory?

What is the difference between observation and experiment?

What is the difference between hypothesis and theory?

3) As it was usually stated in your resources, the cell theory was nearly postulated after two centuries than the first observations of cells were made in the 1600's by Robert Hooke. Over the next centuries, scientists have greatly improve the cell science as you exemplified "the fluid mosaic model of membrane structure" in the 1950's or "the endosymbiotic theory" in the 1960's. [Prefer studies that participants mentioned before.]

Can you think of the cell theory is still contemporary today? Why? Why not?

Can you think of that the cell theory could become a law today's (after four centuries that it was discovered)? If so, how? If not, why?

4) Can you give me examples from your focus questions that were written in your Vee diagrams for the cell laboratory work?

5) Can you give me examples from your hypotheses/ claims to answer your focus questions in the cell laboratory work?

How did you develop your claims? What are your justifications? [If they have mostly mentioned observations, probe for other words of inference and evidence.]

How do you describe your scientific evidence?

What is the relation between your claim and evidence?

What are your inferences? How do you describe scientific inference?

What is the difference between observation and inference?

What is the difference between data and evidence?