# THE EFFECT OF SCIENTIFIC PRACTICE-BASED INSTRUCTION ON SEVENTH GRADERS' PERCEPTIONS OF SCIENTIFIC PRACTICES

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DECLARATION OF ORIGINALITY

I, Nihal Karabaş, certify that

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ABSTRACT

The Effect of Scientific Practice-Based Instruction

on Seventh Graders' Perceptions of Scientific Practices

The purpose of this study was to investigate the effect of scientific practice-based instruction (SPBI) on seventh-grade students' perceptions of scientific practices and conceptual understandings about electric circuit concepts when compared to traditionally designed science instruction (TDSI). Fifty-six seventh-grade students from two classes in a public school in Istanbul participated in this study in the spring semester of 2015-2016. One of the classes was assigned as experimental group and the other one as control group randomly. The experimental group was instructed with SPBI, whereas the control group was instructed with TDSI. Electric Circuit Concept Test (ECCT) and Perceptions of Scientific Practices Questionnaire (PSPQ) were applied to both groups as pre-tests and post-tests. Independent samples t-test was used to compare means of both groups with respect to post-tests of ECCT and PSPQ. The data analysis indicate that the students in the experimental group had higher mean scores in terms of ECCT and PSPQ than the scores of the students in the control group even if the differences between the groups were not statistically significant. The results might have a potential to contribute to science education researchers and science teachers in terms of learning and teaching scientific practices, and conceptual understanding of electric concepts in science classrooms.

# ÖZET

## Bilimsel Pratiklere Dayalı Fen Öğretiminin
## Yedinci Sınıf Öğrencilerinin Bilimsel Pratikler Algılarına Etkisi

Bu çalışmanın amacı bilimsel pratiklere dayalı fen öğretiminin geleneksel fen öğretimiyle karşılaştırıldığında yedinci sınıf öğrencilerinin bilimsel pratiklerin kategorileri hakkındaki algılarına ve elektrik konusunu anlamalarına olan etkisini incelemektir. Bu çalışmaya 2015-2016 bahar döneminde İstanbul'da genel bir ortaokulda öğrenim gören 56 yedinci sınıf öğrencisi katılmıştır. Bu sınıflardan biri rastgele deney grubu olarak diğeri de kontrol grubu olarak seçilmiştir. Deney grubunda bilimsel pratiklere dayalı fen öğretimi kullanılırken, kontrol grubunda geleneksel fen öğretimine dayalı bir öğretim kullanılmıştır. Elektrik Devreleri Kavram Testi ve Bilimsel Pratikler Algı Anketi her iki gruptaki öğrencilere ön test ve son test olarak uygulanmıştır. Test sonuçları iki grubun Elektrik Devreleri Kavram Testi'nin ve Bilimsel Pratikler Algı Anketi'nin son test ortalamalarını karşılaştırmak amacıyla bağımsız iki örnek t-testi kullanılarak analiz edilmiştir. Data analizine göre her ne kadar gruplar arasındaki fark istatistiksel olarak anlamlı çıkmadıysa da deney grubundaki öğrencilerin kontrol grubuna göre her iki ölçekten de aldıkları ortalama puanlarının daha yüksek olduğu bulunmuştur. Çalısmanın sonuçlarının bilimsel pratiklerin ve elektrik konusunun kavramsal olarak öğrenilmesi ve öğretilmesi bakımından fen eğitimi araştırmacılarına ve fen bilimleri öğretmenlerine katkı sağlama potansiyeli bulunmaktadır.

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Dedicated to my dear family,

to my love, Arif Okutan, and to my precious thesis advisor, Ebru Kaya

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| | |
|---|---|
| BRH | Benzene Ring Heuristic |
| CG | Control Group |
| ECCT | Electric Circuit Concept Test |
| EG | Experimental Group |
| NOS | Nature of Science |
| PSPQ | Perceptions of Scientific Practices Questionnaire |
| RFN | Reconceptualized Family Resemblance Approach (FRA)-to-NOS |
| SPBI | Scientific Practice-Based Instruction |
| TDSI | Traditionally Designed Science Instruction |

# CHAPTER 1

# INTRODUCTION

To appreciate the nature of science (NOS), it is important to understand the processes scientists use and to be aware of scientific practices (National Research Council [NRC], 2012). The NOS is also an important outcome in science education, with the aim of having students' become scientifically literate people (The American Association for the Advancement of Science [AAAS], 1989, 1993; DeBoer, 1991; NRC, 1996). Scientific literacy is identified as a principle goal by NRC, (2012). Scientific literacy is an important vision in the science curriculum in many countries, including Turkey. Four areas of science are required to achieve scientific literacy:

1) knowing, using, and interpreting scientific explanations of the natural world,
2) generating and evaluating evidence,
3) understanding the nature of and how scientific knowledge is developed, and
4) participating productively in scientific practice and discourse. (NRC, 2007b, p.2)

As stated above, NOS is currently considered an important educational objective worldwide for developing students' scientific literacy (Lederman, 1999). Research in the literature advocates that both science content and the NOS should be taught to students. It is important to adopt an approach to teaching NOS. According to Lederman (2007), understanding NOS is important because it makes it easier to recognize scientific work and technological mechanisms, make informed decisions about socio-scientific issues (SSI), and it enables understanding scientific concepts. Besides being a valuable aspect of scientific literacy, an understanding of the NOS could help students' act responsibly as adults when faced with complex issues related

to science and make informed decisions (Allchin, 2011; Khishfe, 2012; Sadler, Chambers, & Zeidler, 2004; Zeidler, Walker, Ackett, & Simmons, 2002).

However, there is an argument in the academic world about what NOS is. There are different views to NOS concepts in science education. For example, one of the views is referred to as the consensus view, the science view of some researchers (Abd-El-Khalick, 2012; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002), the second one is referred to as the features of science (FOS) view by Matthews (2012); and the third one is, an alternative view to the consensus view, Irzik and Nola's (2014) family resemblance approach (FRA). For this reason, it is important to know about all views and adapting them for teaching NOS (Irzik & Nola, 2011). Consensus view of science by some researchers such as Lederman, Abd-El-Khalick, and Bell argue that nature of science (NOS) has seven tenets including the fact that it is tentative (scientific knowledge is never absolute, it is subject to change) and theory-laden (scientific knowledge is subjective; scientists come up with different inferences based on previous knowledge by looking at the same data) (Abd-El-Khalick 2004; Abd-El-Khalick & Lederman 2000; Bell, 2004; Khishfe & Lederman 2006; Lederman 2004, 2007).

In features of science (FOS), Matthews (2012) adds new aspects to seven aspects of the NOS in the consensus view and the FRA handles "a higher level of organization involving a class of ideas approximating common characteristics. In contrast, the consensus view addresses individual ideas about science" (Erduran & Dagher, 2014a, p.25).

In the literature, there are some shortcomings of the consensus view (Allchin, 2011; Irzik & Nola, 2011; Matthews, 2012). According to Irzik and Nola (2011), the consensus view does not mention the aims of science or methodological rules in

science. Moreover, this view excludes inquiry and is blind to the differences among scientific disciplines. “It gives the students the impression that science has no history and no room for change in its nature” (Irzik & Nola, 2011, p.593). Finally, the consensus view seems as it has no sufficient systematic unity. According to Allchin (2011), the understanding of NOS should be arranged to the reliability of real-life contexts, and the consensus view ignores motivation, peer review, cognitive biases, and the validation of new methods. Allchin (2011) calls reconstructed NOS as “Whole Science” which is sensitive to all dimensions of reliability in scientific practice. Based on shortcomings of consensus view, Irzik and Nola (2014) developed family resemblance approach (FRA), which systematically and extensively characterizes NOS regarding similarities and overlaps between various scientific disciplines. They suggest that:

> There should be a distinction between science as a cognitive-epistemic system of thought and practice (including processes of inquiry, scientific knowledge with special characteristics, methods, aims and values) science as a social-institutional system (including social, historical and ethical aspects in terms of professional activities, scientific ethos, social certification & dissemination of scientific knowledge and social values). (p.8)

Erduran and Dagher (2014a) define science “as a cognitive-epistemic system encompasses processes of inquiry, aims and values, methods and methodological rules, and scientific knowledge, while science as a social-institutional system encompasses professional activities, scientific ethos, social certification and dissemination of scientific knowledge, and social values” (p.20). Erduran and Dagher (2014a) developed a new sense of content, rationale and application of NOS in science education research, practice and policy. In other words, they suggest that “the

epistemic, cognitive and social dimensions of science should be handled in schools so that learners develop a balanced understanding of what is meant by science in a holistic sense based on FRA" (p.2). Erduran and Dagher (2014a) developed FRA according to the science education perspective and it is called the "Reconceptualized Family Resemblance Approach (FRA)-to-NOS (RFN)" (Kaya & Erduran, 2016a). Erduran and Dagher (2014a) suggest a representation called an "FRA wheel that shows the interaction between the common characteristics of science in terms of "science as a cognitive-epistemic and social-institutional system" (p.28). Social-institutional system includes categories such as professional activities, scientific ethos, social certification and dissemination, and social values, and Erduran and Dagher (2014a) added "social organizations and interactions, political power structures, and financial systems into the social-institutional system" (p.29). These tree aspects of social-institutional system added by Erduran and Dagher (2014a) were limited in the Irzik and Nola's (2014) FRA framework. The cognitive-epistemic system of the RFN includes the following categories: "aims and values", "methods and methodological rules", "knowledge", and "practices" (Erduran & Dagher, 2014a, p.28).

There are very limited studies about RFN. Those studies were concentrated on scientific practices (Akgun, Aksoz, Kaya, & Erduran, 2016; Aksoz, Akgun, Kaya, & Erduran, 2016; Aksoz, Kaya, Erduran, Akgun, & Tas, 2016; Kaya, Erduran, & Cetin, 2016; Sarıbas & Ceyhan; 2015) and curriculum analysis (Erduran & Dagher, 2014b; Kaya & Erduran, 2016a).

Based on the criticisms of the consensus view, this study heads towards the RFN (Kaya & Erduran, 2016a) developed for instructional and learning purposes by Erduran and Dagher (2014a). In other words, the RFN is focused on in terms of

teaching and learning NOS, and scientific practices in the present study. The RFN is a holistic model representation to show how all the components of the cognitive-epistemic and social-institutional systems interact with each other.

Scientific practices is one of the categories developed by Erduran and Dagher (2014a) "for the infusion of the epistemic, cognitive and social-institutional aspects of the scientific enterprise" (p.69). Scientific practices are the ways scientists use during their scientific work, such as observation, classification, and experimenting. It is important to teach scientific practices to students for their knowledge development (Mody, 2015). Stroupe (2015) defines learning scientific practices as shifting from memorization to attending authentic disciplinary work in an advanced manner.

While conducting scientific practices, students engage in activities such as "learning about experiments, data and evidence, social discourse, models and tools, and mathematics and for developing the ability to evaluate knowledge claims, conduct empirical investigations, and develop explanations" (Bybee, 2011, p. 38).

Erduran and Dagher (2014a) examined scientific practices to understand how to teach students about development of science and how scientists work. They (2014a) developed a "Benzene Ring Heuristic (BRH)" as an analogy with a benzene ring in which each carbon atom is represented as a scientific practice (p.82). Scientific practices in the BRH are real world, prediction, explanation, model, data, and activities, and these practices are not confined to a definite location. Representation, reasoning, discourse, social certification float around the practices and interact with them. For example, argumentation can be used as social certification and reasoning. The BRH representation provides science teachers with pedagogical information about scientific practices because it is easy to memorize the

benzene heuristic with a science analogy in terms of being holistic, visual and dynamic (Erduran & Dagher, 2014a; Kaya & Erduran, 2016b).

According to American Association for the Advancement of Science (1993), "by gaining lots of experience doing science, becoming more sophisticated in conducting investigations, and explaining their findings, students will accumulate a set of concrete experiences on which they can draw to reflect on the process" (p. 4). This assertion highlights the importance of scientific practices for students' conceptual understanding and inquiry because scientific practices are handled in terms of classification, observation, and experimentation, and a heuristic that captures the relationships among the cognitive, epistemic and discursive practices of science (Erduran & Dagher, 2014a). If students know and compare what they and scientists do in participating science practices while constructing knowledge, they could get NOS (Sandoval & Reiser, 2004). Therefore, this heuristic may provide students' with appreciation of science based on an understanding of the NOS.

Conceptual understanding is one of the major goals of science education. It is indicated as a principal goal of science education by the National Research Council (1996). It may be defined as ability of students' using learned scientific concepts in everyday life (Nieswandt, 2007) and related concepts (Stevens, Delgado, & Krajcik, 2009). The NRC (2002) suggests that rather than fact-based understanding alone, the conceptual understanding should be developed in science instruction. Moreover, the NRC (1996) suggests that conceptual understanding is required if a person is to be scientifically literate in line with the definition of scientific literacy.

Taking Science to School (TSTS) (NRC, 2007b) suggests that the science instruction should be arranged around conceptual knowledge frameworks and scientific practices. The importance of the learning progression shifts from "what we

know to how we came to know and develop scientific knowledge and on why we believe what we know in contrast to alternatives" (Duschl & Grandy, 2013, p.2114).

Research in the literature shows that students' conceptual understanding is better when they engage in actively in scientific investigations through inquiry based instruction (Minner, Levy, & Century, 2009). In science education, inquiry has three components: "what scientists do, how students learn, and the pedagogical tool used by teachers" (Minner et al., 2009, p.3). The NRC (2000) defines the constituents of the inquiry as learners use evidence to develop explanations for scientific questions and they share explanations by using justifications.

As seen the definition of the NRC for scientific literacy, conceptual understanding is important and engaging in scientific practices develops conceptual understanding in science education. Constituents of inquiry defined by the NRC (2000) shows the importance of components of scientific practices in BRH. In addition, scientific practices develops the understanding of NOS and the understanding of NOS develops content knowledge (Driver, Leach, Millar, & Scott, 1996; Lederman, 1992; Peters, 2006). Scientific practices also lead to procedural knowledge and epistemic understanding of science (Kuhn, Arvidsson, Lesperance, & Corprew, 2017). Thus, scientific practices based on BRH may contribute students' conceptual understanding and studying scientific practices and conceptual understanding is important for science education and science education researchers. This study investigates the effect of scientific practice-based instruction (SPBI) on students' perceptions of scientific practices and electric circuit concepts. For this reason, this study tries to examine the link between scientific practices and conceptual understanding.

Electric circuit concepts are concepts that students may have difficulty with (Garzon, Cock, Zuza, Kampen, & Guisasola, 2014; Gomez & Duran, 1998). The topic may be abstract and therefore difficult to make it concrete in terms of the movement of charges, voltage and current in the circuit. Therefore, students have some misconceptions about electric circuits (Jaakkola & Nurmi, 2008; Kärrqvist, 1985; McDermott & Shaffer, 1992; Osborne, 1983).

There are very few studies conducted about scientific practices and these studies were about pre-service science teachers (e.g. Erduran, Dagher, Mugaloglu, Kaya, Saribas, & Ceyhan, 2015; Erduran, Saribas, Mugaloglu, Kaya, Dagher, & Ceyhan, 2015; Kaya & Erduran, 2015; Kaya, Saribas, & Erduran, 2015; Sarıbas & Ceyhan, 2015). There is rare study about scientific practices based on BRH (Erduran & Dagher, 2014a) in elementary schools to examine conceptual understanding. It seems that students lack knowledge and have misconceptions about electric circuits. Therefore, this study aims to investigate the effect of scientific practice-based instruction on seventh-grade students' perceptions of scientific practices and conceptual understandings about electric circuit concepts when compared to traditionally designed science instruction.

## 1.1 Significance of the study

This study is significant in terms of its using different methodological tools and teaching scientific practices to elementary school students. Quantitative methodological approaches were used in this study. Although there have been some schemes based on theoretical aspects of scientific practices, this study shed light on the practical dimensions of the issue. There is little research examining scientific practices developed by Erduran and Dagher (2014a). These studies were conducted

with pre-service science teachers to investigate their perceptions and representations of scientific practices (e.g. Erduran et al., 2015; Erduran, Saribas, Mugaloglu, Kaya, Dagher, & Ceyhan, 2015; Kaya & Erduran, 2015; Kaya, Saribas, & Erduran, 2015). However, the present study was conducted with elementary school students to investigate their perceptions and understanding of scientific practices and electric circuit concepts. From this aspect, the present study may have contributions in terms of an experimental study conducted in real school context that investigates the link between scientific practices and conceptual understanding by using scientific practices to teach scientific practices and electric circuit concepts.

Moreover, elementary students may have some misconceptions about electric circuits. In order to eliminate these misconceptions, some activities focused on electric circuit concepts and scientific practices were developed. This study will be useful for science educators and science education researchers.

## 1.2 Operational definitions

Definitions of some terms used frequently in the present study are provided here:

Scientific Practice-Based Instruction (SPBI): Using the "Benzene Ring Heuristic (BRH)" (Erduran & Dagher, 2014a), which is a representation of scientific practices having components as real world, prediction, explanation, model, data, activities, and discourse in the middle of scientific practices.

Traditionally Designed Science Instruction (TDSI): Teacher-centered instruction in which teachers generally talk more than students; how time is used is determined by the teacher; the textbook is looked upon by teachers as a guide to instructional decision-making and instruction. (Cuban, 1993).

Conceptual Understanding of Electric Circuits: It is the level of understanding to show the learning outcomes of light bulb connections in electric circuits at the end of the instruction.

Perception of Scientific Practices: It is the understanding about what scientists do, which activities are used during a scientific practice, and the relationship between them, according to benzene ring heuristic (BRH) (Erduran & Dagher, 2014a).

# CHAPTER 2

# LITERATURE REVIEW

In this chapter, NOS in science education, the consensus view of NOS, Reconceptualized FRA-to-NOS (RFN), scientific practices, Turkish science curriculum context, conceptual understanding in science education, and students' misconceptions about electric circuit concepts are handled according to research in the literature.

## 2.1 The nature of science (NOS) in science education

The importance of the nature of science as a learning outcome in science education has been promoted since the 1980s by Rutherford and Ahlgren (1990), the 1990s policy statement of The American Association for the Advancement of Science (1993), and the National Science Education Standards (NRC, 1996). Understanding the nature of science (NOS) is an important factor for people to become scientifically literate (AAAS, 1993; Driver et al., 1996; Rutherford & Ahlgren, 1990). Moreover, an understanding of the NOS is related to understanding what science is in terms of scientific processes, and the generation and evaluation of scientific knowledge (McComas, 2004; McComas, Clough, & Almazroa, 1998). Promoting scientific literacy is also one of the objectives of the Turkish Ministry of Education science curriculum; it specifies "understanding the basic science concepts, utilizing science process skills, making meaningful connections between science, technology and society, developing values and attitudes toward science and knowing the nature of science" (Özdem, Çavaş, Çavaş, Çakıroğlu, & Ertepınar, 2010, p.6). Based on this

definition, a scientifically literate person should be able to evaluate the quality of the scientific information based on evidence.

Understanding NOS is important for the public because it is beneficial for science, economies, individuals, society, democracy and morality (Thomas & Durant, 1987). According to Driver et al. (1996), it is important for students to understand the process of science, make informed decisions on socio-scientific issues, appreciate the importance of science as a part of contemporary culture, to be aware of the norms of the scientific community, and to learn science concepts successfully when economic, utilitarian, democratic, cultural and moral arguments are made. Allchin (2011) states this notion briefly as "students should develop an understanding of how science works with the goal of interpreting the reliability of scientific claims in personal and public decision making" (p. 521).

There is a lot of research about the NOS in terms of students' (Abd-El-Khalick & Dogan, 2008; Khishfe, 2012; Lederman & O'Malley, 1990), teachers' (Akerson & Hanuscin, 2007; Lederman, 2007), and both students' and teachers' understanding of the NOS (Lederman, 1992) and pedagogical content knowledge (PCK) for the NOS (e.g. Schwartz & Lederman 2002; Abd-El-Khalick & Akerson 2003). Based on a review of over 50 years of NOS research, Lederman (2007) makes some generalizations such as K-12 students and teachers do not have enough NOS conceptions, explicit-reflective instruction is required for learning NOS concepts effectively, and teachers' understanding of the NOS is not transferred into practice, and they do not consider the NOS as an instructional aim, unlike subject matter.

Science teachers' own understanding of NOS is "the most obvious and core domain of knowledge relevant to teaching with and about NOS" (Abd-El-Khalick, 2013, p.2099). Understanding of NOS means being aware of NOS aspects, progress

of science and scientists. Taking into account the available literature on PCK, Shulman (1987) considers PCK as an important component of knowledge base systems and defines PCK as interfuse of content knowledge and pedagogy to make possible transformation of subject topic in an organized matter so that learners can better access the content. PCK for the NOS is defined as a knowledge system including knowledge of NOS, subject matter knowledge and pedagogical knowledge for teaching the NOS effectively. Science teachers are supposed to have NOS PCK to teach NOS. According to Shulman (1987), for students to develop the ability to conceptualize new ideas, teachers must have an understanding of the subject matter and of pedagogy, and be able to translate this understanding through their classroom practice (as cited in Hanuscin, Lee, & Akerson, 2011). Much research about science teachers' understanding of NOS shows that science teachers have naïve conceptions of the NOS (Abd-El-Khalick & Dogan, 2008). Moreover, research conducted to elucidate teachers' classroom practices in teaching the NOS reveals that science teachers' NOS PCK is not sufficient (Abd-El-Khalick Bell, & Lederman, 1998; Abd-El-Khalick & Akerson 2003; Bilican, Tekkaya, & Cakıroglu, 2011; Hanuscin, Lee, & Akerson, 2011; Lederman, 1999; Schwartz & Lederman 2002).

There is other research in science education that characterizes the NOS. One of the characterizations of NOS is referred to as the "consensus view" of NOS (Abd-El-Khalick 2012; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; McComas & Olson 1998). There is some research offering alternative ideas on the NOS. These ideas are "whole science" (Allchin, 2011), the "features of science" (Matthews 2012), the "family resemblance approach (FRA)" (Dagher & Erduran 2016; Erduran, 2016, 2014; Erduran & Dagher 2014a; Erduran, Kaya, & Dagher, 2016; Irzik & Nola 2014; Kaya & Erduran, 2016b), and the "Reconceptualized FRA-to-NOS (RFN)"

(Kaya & Erduran, 2016a). There is limited research on curriculum analysis in terms of alternative ideas on the NOS (Erduran & Dagher, 2014b). For this reason, having different ideas about teaching and learning NOS is important.

## 2.2 Consensus view of the NOS

There are different definitions of the NOS in the literature. Several researchers (e.g. Lederman et al., 2002; McComas & Olson, 1998) advocated for the NOS to be characterized by the "consensus view". They defined the NOS as "the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge" (Abd-El-Khalick et al., 1998, p.418).

According to Lederman et al. (2002), the following are the key aspects of the consensus view which are important for K–12 science students:

a. Scientific knowledge is tentative: all scientific knowledge, including facts, theories and law are subject to change.
b. Scientific knowledge is based on empirical evidence or it is derived from observations of the natural world.
c. Scientific knowledge is theory-laden (subjective). Scientists looking at the same data come up with different inferences based on previous knowledge.
d. Scientific knowledge is the product of human imagination and creativity; it necessarily involves human inference, imagination, and creativity necessarily involves a combination of observations and inferences.
e. Scientific knowledge is socially and culturally embedded; it is influenced by society and culture as well as by scientists' values and experiences.
f. Scientific knowledge involves relationships between theory and law.
g. There is no single scientific method.

Lederman and his group believed that these elements of the NOS are accessible to K–12 students and are relevant to their daily lives, so those aspects must meet the following criteria:

(i) accessibility to school students;

(ii) wide enough agreement among historians and philosophers;

(iii) being useful for citizens to know (Mathews, 2012).

In summary, the consensus view defines NOS in seven tenets and it aims to teach students "epistemological understandings about the generation and validation of scientific knowledge, and the nature of the resultant knowledge" (Abd-El-Khalick, 2013, p.2090)

In the literature, there are criticisms of the consensus view of the NOS. One of the criticisms made by Allchin (2011) is about the "reframing current NOS characterizations from selective lists of tenets to the multiple dimensions shaping reliability in scientific practice, from the experimental to the social, namely to "Whole Science" (p. 518). Allchin asserts that only content knowledge is insufficient to ensure individuals' being scientifically literate and, prototype cases are needed to ensure being scientifically literate and to understand the NOS. He also gives importance to the analysis of reliability because it is important for students to learn whom to trust. Students evaluating the evidence on their own is one of the strategies to learn whom to trust. In the consensus view, the understanding of the NOS is declarative but it should be functional. In other words, the understanding of NOS should be arranged to the reliability of real-life contexts. Moreover, the consensus view ignores motivation, peer review, cognitive biases, and the validation of new methods. Allchin (2011) refers to the reconstructed NOS as whole science, which is sensitive to all dimensions of reliability in scientific practice. In addition to

reliability, he criticizes the assessment of NOS understanding. In Lederman et al.'s views of nature of science questionnaire (VNOS), assessment is implicit because it only asks what a student believes (as cited in Allchin, 2011). However, it should ask for understanding from student rather than belief. He suggests an instrument to assess the understanding of the NOS that would have features as authentic contexts, well-informed analysis, adaptability to diagnostic, formative, or summative evaluation contexts, adaptability to single and mass and to local and large-scale comparative use, adaptability to performance-based assessment, and respect for relevant stakeholders. Finally, Allchin (2011) proposes that case- or problem-based learning may be beneficial to teach the NOS.

Matthews (2012) also criticized the consensus view as features of science (FOS) to involve a more comprehensive meaning of science by replacing the NOS with the FOS. According to Matthews (2012), Lederman's definition of the NOS as "the epistemology and sociology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development" (Lederman et al. 2002, p.498) is characteristically widespread. This definition limits the aspects of science in terms of epistemology and sociology. The seven aspects of the NOS prevent students and teachers from analyzing and critical thinking, and it functions as if it was something to be learnt. Based on those criticisms, Matthews (2012) suggests that the seven aspects of the Lederman the NOS list should be thought of as the FOS rather than the NOS. Moreover, those seven aspects are not enough to define epistemological, historical, psychological and social features of science. Those features are required for the fulfillment of the three criteria of accessibility, consensus and usefulness that the Lederman group use to apply NOS matters to classroom size. Matthews (2012) adds new aspects to the consensus view's seven

aspects of the NOS such as experimentation, idealization, models, values and socio-scientific issues, mathematisation, technology, explanation, worldviews and religion, theory choice and rationality, feminism, and realism and constructivism. Matthews (2012) also suggests that students should appreciate the ideas of NOS rather than gain explanatory knowledge of the NOS. According to Erduran and Dagher (2014a) "the expanded list of features present viable ideas around which school science can be discussed from epistemic and historical points of view" (p.6).

There are some criticisms of explicit instruction about the NOS. In the article of Duschl and Grandy (2013), the consensus view of the NOS is said to lack of attention to cognitive, epistemic and methodological practices. In addition, it omits the history of science in teaching and learning about the NOS. Matthews adds three features to the "Lederman Seven": experimentation, idealization and models (2012). Duschl and Grandy (2013) address the issue of explicit instruction on NOS as Version 1 and Version 2. Version 1 is based on "teachers presenting consensus-based heuristic principles" in science lessons and activities, and Version 2 is based on learners experiencing "building and refining model-based scientific practices in critique and communication enactments that occur in longer immersion units and learning progressions" (p.2109). Moreover, Version 1 dismisses science practices during instruction and the teachers point out to students where the NOS features are found in activities, and this means explicit. However, in Version 2, explicit refers to "students' being immersed in the cognitive, epistemic and social enactments and practices of science that involve building and refining questions, measurements, representations, models and explanations" (Duschl & Grandy, 2013, p.2127). All in all, they propose that focusing on how science works requires development of students' capacities for representations, model-building, and casual reasoning.

According to Irzik and Nola (2011), the science view of some researchers (e.g. Abd-El-Khalick 2012; Lederman et al., 2002) which is referred to as the "consensus view", have some weaknesses. First of all, their view entails a narrow image of science. It does not mention the aims of science or the methodological rules of science. Moreover, they exclude inquiry from the NOS. The second weakness is its blindness to differences among scientific disciplines. "It gives the students the impression that science has no history and no room for change in its nature" (Irzik & Nola, 2011, p.593). Finally, the consensus view seems to have no sufficient systematic unity. Irzik and Nola (2011) defend a view referred to as the "family resemblance approach" (FRA) to overcome those weaknesses. They assert that this new view is more comprehensive and systematic than the consensus view. They propose that scientific disciplines should have a number of similarities and differences. They classify those in a systematic way in terms of the following categories, which give a structural definition of NOS: activities, aims and values, methodologies and methodological rules, and products. In addition, the family resemblance approach has some advantages over the consensus view. The first one is the empirical nature of science as a result of cooperation between the aims and values of testability and the activity of observing. Second, science is a special form of critical inquiry. The third one is reliability and objectivity. The fourth advantage is creativity in constructing theory and discovering laws. The fifth one is justice to the differences among scientific disciplines by emphasizing partial overlaps and similarities. Finally, RFN (Erduran & Dagher, 2014a; Kaya & Erduran, 2016a) suggests the open-ended nature of science. This means that science evolves while it develops. The RFN is explained in detail in the next section.

## 2.3 Reconceptualized FRA-to-NOS (RFN)

Irzik and Nola (2011) define a view referred to as the "family resemblance approach (FRA)" and they assert that this new view is more comprehensive and systematic than the consensus view. They define science components in terms of "categories subsumed under epistemic, cognitive and social systems" (Erduran & Dagher, 2014a, p.19). They propose that scientific disciplines have a number of similarities and differences. They classify those in a systematic way in terms of following categories which give a structural definition of the NOS: activities, aims and values, methodologies and methodological rules, and products. Irzik and Nola (2014) explain four systems of science as follows: The processes of inquiry include activities like "posing questions (problems), making observations, collecting and classifying data, designing experiments, formulating hypotheses, constructing theories and models, and comparing alternative theories and models. Aims and values include "prediction, explanation, consistency, simplicity and fruitfulness, viability, testability, and empirical adequacy that function both as aims and values" (Erduran & Dagher, 2014a, p.21). Methods and methodological rules include approaches and the rules that scientists use to get reliable knowledge. Social-institutional system of science includes four categories which are professional activities, social and ethical norms, community aspects of science work, and the relationships of science with technology and society. Moreover, there is enough resemblance between the four systems that make them recognizable as scientific. FRA has no specific philosophical positions. It is philosophically-neutral.

For instructional and learning purposes, Erduran and Dagher (2014a) developed Irzik and Nola's (2011) philosophical model into a functional framework for science education and referred to it as the "Reconceptualized FRA-to-NOS

(RFN)" (Kaya & Erduran, 2016a). To show how all the components of the cognitive-epistemic and social-institutional systems interact with each other, the FRA wheel (Fig. 1), which is a holistic model shows the interaction between the components of the cognitive-epistemic and social-institutional systems and their enhancement scientific activity. The social-institutional system contains categories as professional activities, scientific ethos, social certification and dissemination, social values, social organizations and interactions, political power structures and financial systems. The cognitive-epistemic system of the RFN includes categories as aims and values, methods and methodological rules, knowledge, and practices. In the FRA wheel, science as a cognitive-epistemic system "occupies a space divided into four quadrants that accommodate its four categories in terms of practices, methodologies, aims and values, and knowledge" (Erduran & Dagher, 2014a, p.28). Aims and values in science are consistency, simplicity, objectivity, empirical adequacy and novelty. Epistemic aims and values include knowledge construction, evaluation and revision practices in the classroom, objectivity, novelty, and accuracy. Cognitive aims and values include aspects of reasoning and objectivity. Social aims and values include addressing human needs, decentralizing power, honesty, and equality of intellectual authority. Methodologies in science are observing, making a hypothesis, experimenting, analyzing data, confirming or rejecting the hypothesis and making conclusions. The knowledge domain of the RFN wheel explains knowledge in the coherence of theories, laws and models and their contribution to growth of scientific knowledge. This domain introduces the Theory, Law and Model (TLM) network of relationships between the forms of knowledge (theories, laws and models). It is very important for learners to understand the specific features of each form of knowledge and how they function with one another to explain and predict a phenomenon,

holistic consideration of theories, laws and models. Finally, scientific practices are the one of the four cognitive-epistemic domains (aims and values, methods and methodological rules, scientific practices, and knowledge). Scientific practices are represented as a BRH that includes the real world, prediction, explanation, model, data, and activities, and scientific practices are not confined to a definite location. Representation, reasoning, discourse, and social certification float around the practices and interact with them. Scientific practices are dynamic and interact with each other (Erduran & Dagher, 2014a).

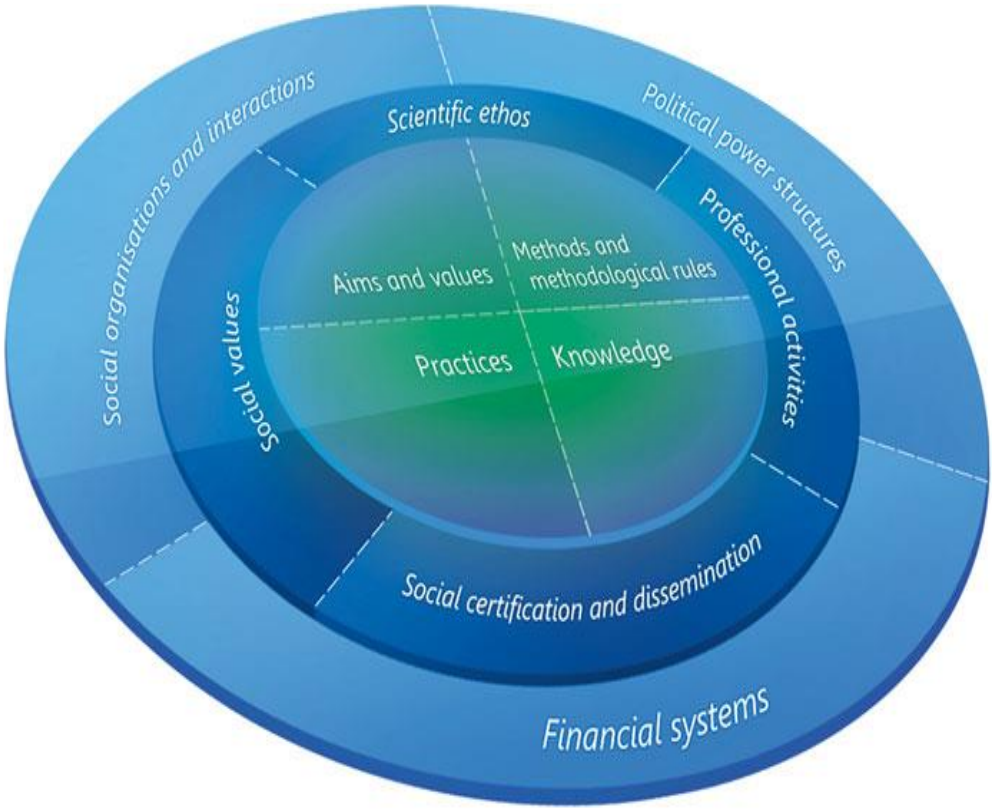



Fig. 1 Family resemblance approach (FRA) wheel

Source: [Erduran & Dagher, 2014a, p.28]

In applying the RFN in science education, it is possible to select ideas in each of the categories of the RFN in a relevant and developmentally appropriate manner to

students of all ages. In addition, Erduran and Dagher (2014a) suggest that "selecting and packaging FRA components to achieve specific NOS goals must be coordinated with other science education goals and with developmentally appropriate NOS content" (p.36). In the literature, there are relatively few studies about the RFN. Some studies are about pre-service teachers' perceptions and understanding of scientific practices (Akgun, Aksoz, Kaya, & Erduran, 2016; Aksoz, Akgun, Kaya, & Erduran, 2016; Aksoz, Kaya, Erduran, Akgun, & Tas, 2016; Kaya, Erduran, & Cetin, 2016; Erduran et al., 2015; Kaya & Erduran, 2015; Kaya et al., 2015; Kaya et al., 2016; Sarıbas & Ceyhan, 2015) and curriculum analysis (Erduran & Dagher, 2014b; Kaya & Erduran, 2016a). The curriculum analysis studies are about alternative ideas on the NOS in the Irish science curriculum (Erduran & Dagher, 2014b) and the transformation of the FRA for the Turkish science curriculum (Kaya & Erduran, 2016a).

Scientific practices constitute one of the categories of the RFN, which guides science educators about what science is composed of and how science is handled by scientists by using scientific practices. In this way, the RFN helps teachers to teach scientific practices. It serves as a pedagogical tool for teaching the NOS and science concepts. Serving as a pedagogical tool, scientific practices are very important in the understanding of the NOS. Scientific practices are explained in detail in the next section.

## 2.4 Scientific practices

Over the past 40 years, scientific practices have been examined by historians, philosophers, cognitive scientists and sociologists (Collins & Pinch, 1993; Conant, 1957; Geison, 1995; Kuhn, 1962; Latour & Woolgar, 1986). Students can understand

how scientists provide credibility for their findings and reach reliable knowledge (Ziman, 1979). Students should engage in scientific practices for the development of their understanding of the epistemology of science (Duschl & Grandy, 2013). The NRC (2007b) states that science should be taught as scientific practices and that instruction methods that develop students' understanding of scientific practices should be used.

According to the NRC (2012), scientific practices are central to science learning and the focus of a science education curriculum shifts from scientific inquiry to scientific and engineering practices. There are two reasons for this shift. The first reason is the difference between the goals of inquiry and science education. For instance, inquiry is used to add new notions to existing scientific knowledge; however, the aim of science education is to teach both the inquiry methods and scientific content. The second reason is that the inquiry is unclear for teachers during instruction from kindergarten to 12$^{th}$ grade students. Instead of inquiry, practices term is used for teachers' better understanding scientific inquiry (Osborne, 2014). The NRC (2012) emphasizes the difference between skills and practices, and both skill and knowledge are necessary for scientific study. Thus, the term "practices" is used rather than the term "skills". There are eight practices proposed by the NRC (2012):

1. Asking questions (for science) and defining problems (for engineering),
2. Developing and using models,
3. Planning and carrying out investigations,
4. Analyzing and interpreting data,
5. Using mathematics and computational thinking,
6. Constructing explanations (for science) and designing solutions (for engineering),
7. Engaging in argument from evidence,
8. Obtaining, evaluating, and communicating information. (p. 49)

Scientific discourse, which is the language used by scientists in their scientific processes, is a main point for students' learning science by using scientific practices. Teachers have an important place in guiding discourse (NRC, 2007a, 2012) and they should guide scientific discourse during the instruction.

There are different perspectives on scientific practices in science education. Mody (2015) points out that students should use the scientific practices of scientists to be qualified in terms of learning of science because students should participate in knowledge development rather than simply consume scientific knowledge. The author underlines that writing, reading and listening in scientific practices should lead to a "more democratic, hands-on, and engaged classroom" in science education (2015, p.1030). Stroupe (2015) defines learning scientific practices as shifting from memorization to attending authentic disciplinary work. He maintains that scientific practice is both implicit and explicit dimensions of disciplinary work and it is enhanced over time in a place such as a laboratory or classroom. Stroupe (2015) used two overlapping points to define scientific practice. Those points are "the dimensions of disciplinary work and descriptions of how novices learn to participate in valued community activities" (p.1034). There are four dimensions of disciplinary work: conceptual, social, epistemic, and material dimensions. Stroupe (2015) recommends that studies are needed to explore how to ensure educators with scientific practice-based science learning and how to plan science learning environment for students. Moreover, Ford (2015) argues that scientific practices are based on evaluation and critique rather than rules. He explains that is important to understand the whole in science, and the whole can be understood through evaluation and critique in an explanatory proceeding.

These perspectives on scientific practices shows that there is a shift in emphasis on scientific practices in science education. That shift should find a place in real school contexts for more authentic scientific practices representations (Erduran, 2015).

Erduran and Dagher (2014a) discuss the range of scientific practices that scientists use. They (2014a), explored scientific practices by asking these questions that "What are the key epistemic, cognitive and social practices of science?" and "How are these practices generated, evaluated and revised?" (p.35). Scientific practices are handled in terms of classification, observation, and experimentation, and a heuristic that captures the relationships among the cognitive, epistemic and discursive practices of science is mentioned. Erduran and Dagher (2014a) also focus on problems between school science and scientific practices such as "reinforcement of an artificial separation between scientific products and processes, and oversimplification of the nature of scientific knowledge and practices" (p.68). The authors propose a heuristic which represents scientific practices and synthesizes them into a whole based on the family resemblance approach (FRA). The heuristic is formed as an analogy with a benzene ring (Fig. 2). In this analogy, each carbon atom represents as a scientific practice: "real world, prediction, explanation, model, data, and activities", and these practices are not confined to a definite location (Erduran & Dagher, 2014a, p.82).

"Representation, reasoning, discourse, social certification" are discursive component of BRH and they float around the practices and interact with practices (Erduran & Dagher, 2014a, p.82).

BRH is important for presenting dynamic interaction between models, data, activities, explanations and predictions based on real world, and those interactions

are combined with social-institutional and cognitive processes through discursive component of BRH (Erduran & Dagher, 2014a).

Two primary purposes are served by the heuristic: exemplifying a holistic to portray scientific practices and ensuring a pedagogical tool for scientific practices (Erduran & Dagher, 2014a; Kaya & Erduran, 2016b). All in all, BRH makes it easier for teachers to remember practices due to its useful analogy with the benzene molecule and it prevents conceptualizing science as a step-wise and linear process, as it is often represented through the conventional scientific method approaches (Erduran & Dagher, 2014a).

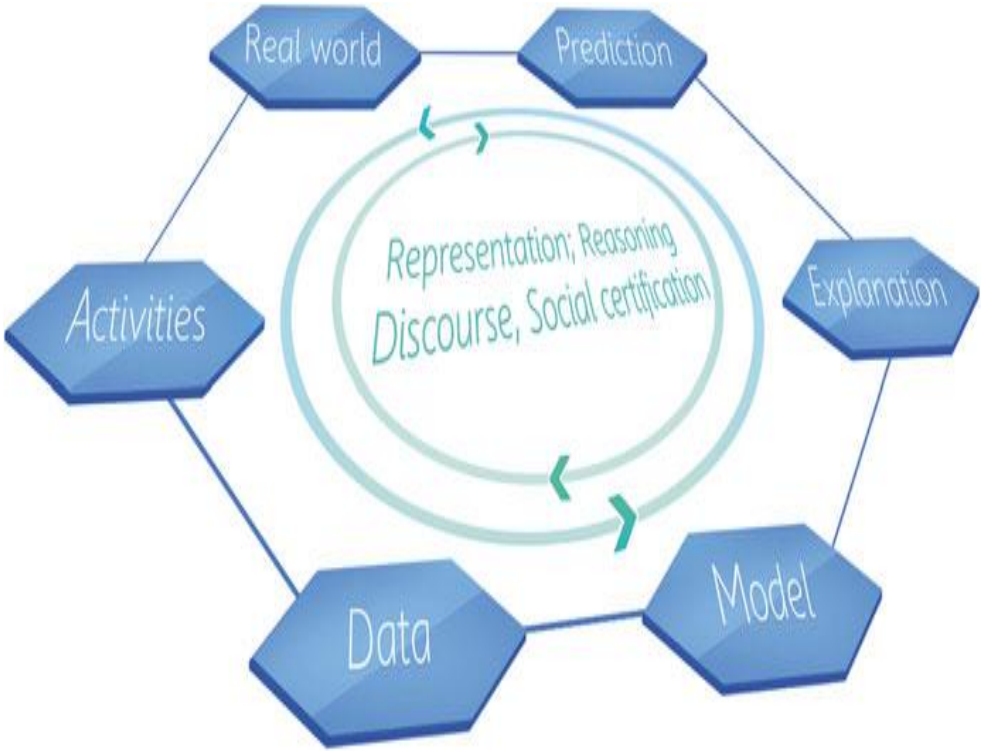



Fig. 2 Benzene ring heuristic (BRH) of scientific practices

Source: [Erduran & Dagher, 2014a, p.28]

When BRH and NRC practices (referred to as P1, P2, P3, etc., in Table 1) are compared, there are similarities such as notions of activities, models, reasoning, data, and explanations. However, the benzene ring heuristic puts the emphasis on prediction, social certification and representation (see Table 1).

Table 1. Comparison of Benzene Ring Heuristic with NRC (2012) Practices

| Feature of Benzene Ring Heuristic | NRC practices |
|---|---|
| Real world | ? |
| Activities | P1, 2, 3 |
| Data | P4, 5 |
| Model | P2 |
| Explanation | P6 |
| Prediction | ? |
| Reasoning, discourse | P7, 8 |
| Representation, social certification | ? |

Source: [Erduran & Dagher, 2014a, p.84]

Thus, BRH is valuable for including representation and social certification in all scientific practices. It is not linear like NRC (2012) practices. Rather, it is dynamic and there is a continued connection between scientific practices. It is important to teach students that science is not linear for their understanding of the progress of science practice (Duschl, 2008; Warren & Rosebery, 1995; Warren, Ballenger, Ogonowski, Rosebery, & Josiane, 2001; Windschitl, Thompson, & Braaten, 2008).

In the literature, there are some studies that have been conducted with preservice and inservice science teachers (Barriea, Moorea & Roig, 2015; Bowen & Roth, 2005; Davis, Petish, & Smithey, 2006; Smith & Anderson, 1999) which show that teachers have inadequate knowledge about scientific practices. Some studies about scientific practices were conducted with students (Duschl, 2008; Hsu, Eijck, &

Roth, 2010; Lehrer & Schauble, 2006). However, there is limited empirical research about scientific practices based on BRH (Erduran et al., 2015; Kaya & Erduran, 2015; Kaya et al., 2015). One of them was conducted by Sarıbas and Ceyhan (2015). This research is an auto-ethnographic study conducted in a science teacher education program at a state university in Turkey where a laboratory applications course had been taught the four previous years. The aim of the study was to investigate the impact of a treatment based on a heuristic of scientific processes on pre-service teachers' perceptions and reasoning in improving their understanding of scientific practices (SPs) using a model known as the BRH (Erduran & Dagher, 2014a). Data was collected from various sources, including pre- and post-interviews, audio recordings of lessons, pre-service teachers' lesson plans and reflections, and the researchers' reflections after teaching. The result of the study suggests that pre-service teachers' understanding of scientific practices improved, but their understanding of domain specificity, ethics, and utility in science, or with their beliefs about the roles and responsibilities of students during science lessons were not satisfactory for the researchers (Sarıbas & Ceyhan, 2015).

Since scientific practices (SPs) are important to teach progress of science (e.g. Duschl, 2008; Warren & Rosebery, 1995) and realizing the process that scientists follow is included in conceptual understanding (Gabel, 2003), the effectiveness of scientific practices on conceptual understanding was investigated in the present study.

## 2.5 Conceptual understanding and scientific practices

Conceptual understanding is a complex phenomenon. Alao and Guthrie (1999) define conceptual understanding as the "breadth and depth of knowledge" and

breadth is about “the extent of knowledge that is distributed and represents the major sectors of a specific domain” and depth is about the “knowledge of scientific principles that describes the relationship among concepts” (p. 244). Conceptual understanding includes declarative knowledge (rules and models about single or complex concepts), procedural knowledge (concepts, rules, algorithms) and conditional knowledge (being aware of importance of conditional knowledge and when to use procedural knowledge) (Paris, Cross, & Lipson, 1984).

If students have an understanding of a concept, they can get some abilities such as thinking with concepts, using concepts in other areas, defining concepts in their own words, coming up with an analogy and a model for a concept (Konicek-Moran & Keeley, 2015). According to Gabel (2003), conceptual understanding in science is a complicated matter. It includes learning a phenomenon’s macroscopic features, clarifying the macroscopic phenomena and operations while using models, symbol usage while solving mathematical problems, and realizing the operations that scientists follow in inquiry. Gabel (1999) defined some strategies for learning in science in her previous research such as the learning cycle approach, science/technology/society, real-life situations, discrepant events, analogies, collaborative learning, and inquiry. Gabel (2003) suggests that those strategies are effective in science learning and that they promote conceptual understanding of science. He maintains there should be an organized hierarchy presenting science for building one concept upon another. Considering those points, the construct of scientific practices seems to include those strategies and it represents the processes scientists use.

According to the NRC (1996), conceptual understanding is important for students to become scientifically literate. The main goal of science instruction shifts

to how knowledge is learned and developed (Duschl & Grandy, 2013). The NRC (2007b) suggests that both conceptual knowledge and scientific practices should be diffused into science instruction. Research shows that participating in scientific investigations develops students' conceptual understanding better (Minner, Levy, & Century, 2009). Conceptual knowledge is developed when students engage in critiquing (Ames & Murray, 1982; Hynd & Alvermann, 1986; Schwarz, Neuman, & Biezuner, 2000). When the discursive part of BRH is considered, it is based on critical techniques such as argumentation. Argumentation is important in science education (Toulmin, 1958) and it is an important goal of science education to teach students how scientists construct scientific knowledge by supporting their claims through evidence (Erduran & Jimenez-Aleixandre, 2008, 2012). There are studies on argumentation in science education which constitute a basis for discursive component of BRH in educational environments (e.g. Erduran, Simon, & Osborne, 2004; Jimenez- Aleixandre, Rodriguez, & Duschl, 2000; Kelly & Takao, 2002; Sandoval & Reiser, 2004; Zohar & Nemet, 2002). However, argumentation should be based on an epistemological foundation for it to be meaningful for students. It is important to examine students' engagement in scientific practices, including reflection and investigating consequences by taking into consideration understanding scientific practices and including debate of alternative claims based on evidences (Kuhn et al., 2017). It is important for students to realize that the scientific claims needs evaluation in the frame of evidence (Greene, Sandoval, & Braten, 2016; Moshman, 2015; Ricco, 2015). BRH may enhance conceptual understanding because it encourages students to reflect on the scientific concepts based on evidence. They can engage in discussions with different evidence-based claims. Moreover, scientific practices are required for the understanding of NOS and the understanding of NOS

should develop students' content knowledge (Driver et al., 1996; Lederman, 1992; Peters, 2006). It seems that conceptual understanding and knowledge of NOS affect each other. Thus, scientific practices based on BRH may contribute to students' conceptual understanding and knowledge of NOS.

BRH is an organized representation so it may contribute to the building of one concept upon another. BRH is a dynamic representation in that it shows that there is no one order to follow and that there are connections between all aspects of scientific practices. Students' first hand engagement in activities in terms of interconnected aspects of scientific practices which have continued connection between each practice is more efficient than engaging in isolated activities (Ford, 2012; Kuhn, 2010; Lehrer & Schauble, 2015; Manz, 2014; Sandoval, 2014). In BRH, cognitive-epistemic and social aspects of science are represented. There are scientific practices as real world, prediction, explanation, data, model, and activities in cognitive epistemic part of BRH. Discourse, reasoning, and representation constitutes the social aspect of science. Thus, scientific concepts map in all parts of BRH. Students engage in their own learning by collecting data during the activities and they make evidence-based explanations of the phenomena in the real world. They construct models and make the concept concrete, using the collected data.

Students' engagement in activities that include scientific practices is important because scientific practices lead to procedural knowledge and an epistemic understanding of science (Kuhn et al., 2017). However, teachers focus on content learning if they do not appreciate the epistemic understanding of scientific practices or have an inadequate understanding of procedures (Kuhn, 2016). BRH (Erduran & Dagher, 2016a) has the potential to eliminate this problem because it represents

every scientific practice and serves as a pedagogic tool for teachers. For this reason, BRH can promote understanding of both scientific concepts and scientific practices.

## 2.6 Misconceptions about electric circuits

Electric circuit concepts are abstract and difficult for students to understand (Garzon et al., 2014; Gomez & Duran, 1998). Therefore, students have some misconceptions about electric circuits (Jaakkola & Nurmi, 2008; Kärrqvist, 1985; McDermott & Shaffer, 1992; Osborne, 1983). Research findings reveal three areas of student difficulties in basic electricity: Students are unable to apply formal concepts to electric circuits, use and interpret formal representations of an electric circuit, and are unable to argue qualitatively about the behavior of an electric circuit (McDermott & Shaffer, 1992). Moreover, students think that one cable between a battery and a bulb is enough to give light to a bulb. This is referred to as the sink model by Jaakkola and Nurmi (2008), Kärrqvist (1985) and the "unipolar model" by Osborne (1983). Another misconceptions is that "current is gradually consumed by the circuit components" referred to by Jaakkola and Nurmi (2008, p.278) as the consumption model, and this misconception was referred sequentially as attenuation model by Osborne (1983), model II sequence model by Shipstone (1984), and the current consumption model by Kärrqvist (1985). Students may also think that current does not change throughout the circuit and that brightness of a bulb is not affected by the number of elements in the circuit. This model is called the constant current model by Jaakkola and Nurmi (2008) and the constant current source models by Kärrqvist (1985) and Cohen, Eylon, and Ganiel (1983). Students may assume that the brightness of a bulb is related directly to the number of bulbs. This misconception is referred as a surface model by Jaakkola and Nurmi (2008) and **"**tendency to focus on

number of elements or branches" by McDermott and Shaffer (as cited in Jaakkola & Nurmi, 2008, p.278). This means that students pay attention to the number of bulbs in a circuit rather than their connections. Finally, even if the students apply parallel and series circuits, they may be unable to understand the effects of them on brightness (Jaakkola & Nurmi, 2008; McDermott & Shaffer, 1992). This misconception is referred as the preliminary ohm model by Jaakkola and Nurmi (2008).

In sum, the literature shows that students may hold some misconceptions about electric circuit concepts (Jaakkola & Nurmi, 2008; Kärrqvist, 1985; McDermott & Shaffer, 1992; Osborne, 1983) and that they have inadequate knowledge of the NOS (Lederman, 2007). BRH may be a tool to teach scientific practices, electric circuit concepts, and the NOS. It may help teachers to teach scientific content and how science progresses (Erduran & Dagher, 2014a). The application of scientific practices in the classroom may eliminate students' misconceptions about electric circuit concepts. Examining Turkish science curriculum for scientific practices before preparing activities and lesson plans for the present study.

## 2.7 The Turkish science curriculum context

The Turkish Science Education Program (2006) highlights the importance of raising scientifically literate students. It suggests some instructional strategies to make students active learners. According to this program, instructional activities should be organized in such a way that the students can understand what data means, how they can be explained by theoretical concepts, and what the results of experiments indicate. Teachers should be guide students when they are recording, explaining, and

relating data with high-level thinking (MEB, 2006). The Turkish Science Education Program is closer to the idea that students find out the required knowledge and conducting activities to evaluate the knowledge, produce and obtain information, and offer discussion of the knowledge as scientists do. This idea is referred to as meaningful learning.

Moreover, the Turkish Science Education Program gives scientific process skills, which are aimed at sixth, seventh, and eighth grade students. They are composed of three aspects: "planning and beginning (observation, comparison-classification, making inference, prediction, etc.), application (constructing hypothesis, designing experiments, measurement, recording data, etc.), and analysis and inference (processing data and setting a model, commenting and making inferences, and presentation)" (MEB, 2006, p.64).

The most recent (2013) Turkish Science Education Program states that the learning environments in classrooms and out of school are designed according to learning strategies based on survey and investigation for students to achieve meaningful and long lasting learning. The process of the survey and investigation is not only discovery and experiment but also explanation and argument. This survey and investigation learning is a learning approach in which students are encouraged to explore around them, construct arguments to explain the natural and physical world based on evidence, and become individuals who get excited about and appreciate science. Briefly stated, it is a student centered approach in which students form knowledge through experiences as scientists. Teachers provide students with dialogs in which students can express their ideas, support their ideas with evidence, and develop alternative ideas to confute opposite arguments. There are examples of scientific practices in the 2013 Turkish Science Education Program such as

"….including skills used by scientists during their work as observation, measurement, classification, recording data, constructing hypotheses, using data and constructing models, changing and controlling variables, experimenting" (p. v). Thus, the activities for the present study were prepared in line with the Turkish Science Education Program.

In the Turkish Science Education Program, scientific practices are not mentioned explicitly; however, the aim is to teach students to get scientific knowledge as scientists. For this reason, BRH is very significant because its holistic representation, including the scientific process and skills, provides teachers with pedagogical information about scientific practices.

In sum, the literature shows that the NOS is important for scientific literacy, which is an important goal of science education (e.g. AAAS, 1993; Driver et al. 1996). For this reason, it is important to teach the NOS in science classrooms. There are different views to the NOS: the "consensus view" of the NOS (e.g. Abd-El-Khalick, 2012; Lederman et al., 2002), the "whole science" (Allchin, 2011), the "features of science" (Matthews, 2012), the "family resemblance approach (FRA)" (e.g. Dagher & Erduran, 2016; Erduran, 2016; 2014; Erduran & Dagher, 2014a; Erduran, Kaya, & Dagher, 2016; Irzik & Nola, 2014), and the "RFN" (Kaya & Erduran, 2016a). This study emphasizes the RFN and scientific practices which is a category of the RFN. Students and teachers have inadequate knowledge of the NOS (Lederman, 1992). Although BRH (Erduran & Dagher, 2014a) is a pedagogic tool for teaching scientific practices, it may be used to enhance knowledge of the NOS. Conceptual understanding is another important goal of science education (NRC, 1996) and both conceptual knowledge and scientific practices should be covered in science instruction (NRC, 2007b). Moreover, students may hold some

misconceptions about electric circuits (Jaakkola & Nurmi, 2008; Kärrqvist, 1985). Therefore, in the present study, the effect of SPBI (vs TDSI) on students' understanding of electric circuit concepts and their perceptions of scientific practices was investigated.

# CHAPTER 3

# RESEARCH QUESTIONS AND HYPOTHESES

## 3.1 The main research questions and sub-questions

The following research questions guided this research. There are four sub-questions for research question 1 and two sub-questions for research question 2.

### 3.1.1 Research question 1

What is the effect of SPBI on seventh-grade students' perceptions of scientific practices and categories of scientific practices (features, holistic, relationship) compared to TDSI?

### 3.1.2 Research question 2

What is the effect of SPBI on seventh-grade students' conceptual understandings about electric circuit concepts?

### 3.1.3 The sub-questions

There are five sub- questions.

1) Is there a significant difference between post-test mean scores of students taught with SPBI and students taught with TDSI with respect to their perceptions of scientific practices?
2) Is there a significant difference between post-test mean scores of students taught with SPBI and students taught with TDSI with respect to their understanding of features of scientific practices?

3) Is there a significant difference between post-test mean scores of students taught with SPBI and students taught with TDSI with respect to their understanding of relationships between scientific practices?
4) Is there a significant difference between post-test mean scores of students taught with SPBI and students taught with TDSI with respect to their understanding of holistic feature of scientific practices?
5) Is there a significant difference between post-test mean scores of students taught with SPBI and students taught with TDSI with respect to their understanding of electric circuit concepts?

## 3.2 The hypotheses

There are five hypotheses tested in this research.

$H_0$1: There will be no significant difference between post-test mean scores of students taught with SPBI and students taught with TDSI with respect to their perceptions of scientific practices.

$H_0$2: There will be no significant difference between post-test mean scores of students taught with SPBI and students taught with TDSI with respect to their understanding of the features of scientific practices.

$H_0$3: There will be no significant difference between post-test mean scores of students taught with SPBI and students taught with TDSI with respect to their understanding of relationships of scientific practices.

$H_0$4: There will be no significant difference between post-test mean scores of students taught with SPBI and students taught with TDSI with respect to their understanding of the holistic feature of scientific practices.

$H_0$5: There will be no significant difference between post-test mean scores of students taught with SPBI and students taught with TDSI with respect to their understanding of electric circuit concepts.

# CHAPTER 4

# METHODOLOGY

This chapter includes the design of the study, population and sample, variables, instruments, implementation and data analysis.

## 4.1 Research design

This study was conducted based on a quasi-experimental design in which "units are not assigned conditions randomly" (Shadish, Cook, & Campbell, 2002, p.12). The research design of the study is given in Table 2.

Table 2. Research Design of the Study

| Group | Pre-test | Treatment | Post-test |
|---|---|---|---|
| EG | ECCT<br>PSPQ | SPBI | ECCT<br>PSPQ |
| CG | ECCT<br>PSPQ | TDSI | ECCT<br>PSPQ |

The followings are the meanings of the abbreviations in Table 2:

EG: Experimental Group

CG: Control Group

ECCT: Electric Circuit Concept Test

PSPQ: Perceptions of Scientific Practices Questionnaire

SPBI: Scientific Practice-Based Instruction

TDSI: Traditionally Designed Science Instruction

## 4.2 Population and sample

The target population of the study was all seventh-grade elementary school students in Istanbul, which is the biggest city of Turkey. The accessible population of the study was all seventh-grade elementary school students in Küçükçekmece (an urban location in Istanbul where the socio-economic status is relatively low). The convenience sampling method was used for selecting the sample of the study. Two of the seventh-grade classes were chosen as sample in a public elementary school where the researcher works as science teacher. The sample of the study was composed of 56 seventh-grade students (31 males and 25 females) from two cohorts in the spring semester of the 2015-2016 academic year. These cohorts were randomly assigned to an experimental (N = 28) or a control (N = 28) group. There were 14 female and 14 male students in the experimental group; there were 11 female and 17 male students in the control group. The ages of the students ranged from 12 to 13 years in both groups. School was located in a low socio-economic area, so the socio-economic level of the students in this study was low.

## 4.3 Variables

### 4.3.1 Dependent variables

Dependent variables were the perceptions scientific practices and conceptual understanding of electric circuit concepts including understanding light bulb connections in electric circuit. All dependent variables were continuous variables.

### 4.3.2 Independent variables

Independent variables in this study were instruction type in terms of SPBI and TDSI. SPBI was coded as 1 and TDBI was coded as 2.

## 4.4 Instruments

The sources of quantitative data were pre- and post-concept tests about a light bulb connection in an electrical energy unit, and pre- and post-questionnaires about perceptions of scientific practices.

Within a quasi-experimental research design, data was collected via an electric circuit concept test (ECCT) and a Perceptions of Scientific Practices Questionnaire (PSPQ).

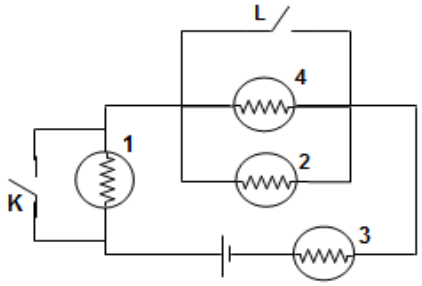
### 4.4.1 Electric Circuit Concept Test

The electric circuit concept test (ECCT) was developed by the researcher in line with the science curriculum of the Ministry of National Education (MEB, 2013). This test written in Turkish consists of 25 multiple choice questions related to a seventh-grade curriculum unit about electricity with the aim of exploring students' understanding of electric circuit concepts. This test was administered to both the control and the experimental group before and after the treatment. For the ECCT, correct answers were coded as "1", and wrong answers were coded as "0". Then, total scores of the students in both groups were computed. Since there are 25 items in ECCT, the maximum score which students could get from this test was 25. Higher scores in ECCT could be interpreted as students' having a better understanding of electric circuit concepts.

The test was examined by some science education experts and elementary science teachers to ensure content validity of the test. Based on their suggestions, some improvements were made on distracters and items. Before the treatment, ECCT was administered to 115 seventh-grade students from a private elementary school in Ankara and a public elementary school in Antalya as a pilot test during the spring semester of 2015-2016. The reliability of this test was calculated based on data collected from the pilot study as .72. After completing the validity and reliability studies of this test through the use of pilot tests, it was administered to the students in both groups before the intervention as a pre-test in order to assess their understanding of electric circuit concepts and after the treatment as a post-test in order to determine the effect of SPBI on students' understanding of electric circuit concepts.

Here some examples from the ECCT:

Question 1: Which bulbs will light in the electric circuit in the below?



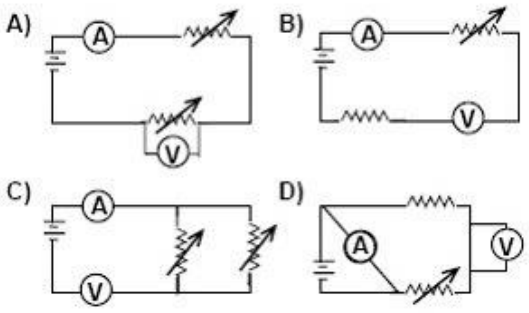

A) 1, 2, 3, 4

B) 1, 3

C) 4

D) 2, 3

Question 2: Which circuit elements are wired correctly in the electric circuit below?



### 4.4.2 Perceptions of Scientific Practices Questionnaire

The Perceptions of Scientific Practices Questionnaire (PSPQ) was developed by Erduran, Saribas, Mugaloglu, Kaya, Dagher, and Ceyhan (2015) to understand what Turkish students know and understand about scientific practices. The test consists of 34 items on a 5-point Likert-type scale. The options for each item are “fully agree”, “agree”, “undecided”, “disagree”, “fully disagree”. The PSPQ includes items on such elements as 1) scientific practices investigate real world, 2) scientific practices include activities such as asking questions, experimenting and observation, 3) scientific practices includes predictions, 4) scientific practices includes collecting data. These given elements are about some components of BRH and they mean that scientific practices are used to explore real world by collecting data through experimenting, observation, and asking questions. The questionnaire has three dimensions: features, relationships between scientific practices, and the holistic feature of scientific practices. The first six items are about the features of scientific practices; items 7 to 21 one are about relationships between scientific practices; items 22 to 34 are about the holistic feature of scientific practices. Before the treatment, the PSPQ was administered to 149 seventh-grade students from a public elementary school in Istanbul as a pilot test during the spring semester of 2015-2016. The reliability of this test was found as .73, based on data collected from the pilot study. The reliability of this test in terms of each dimension was calculated. For the features dimension, it was found as .76, for the relationships dimension it was found as .72, and for the holistic dimension it was found as .68, based on data collected from the pilot study. During the pilot study, students had difficulties understanding some words in the PSPQ. Thus, some words were changed or their meaning was given in parentheses to make the questionnaire understandable.

This test was administered to the students in both the experimental and the control group before the treatment as a pre-test to assess their perceptions of scientific practices and after the treatment as a post-test in order to determine the effect of SPBI on students' perceptions of scientific practices.

In the PSPQ, there were both positive and negative items. In this study, firstly, the data of negative items were recoded from "1" to "5", "2" to "4", "4" to "2", and "5" to "1". Then a total score for each student in both groups was calculated. The maximum score that students could get from this scale was 175 because this scale included 34 items and for every item the highest point would be 5. Higher scores on the PSPQ mean greater understanding and more perceptions about scientific practices. The maximum score that students could get from the feature dimension was 30 for six items. For the relationships between scientific practices dimension, the maximum score that students could get was 75 for fifteen items. The maximum score that students could get from holistic feature of scientific practices dimension was 65 for thirteen items.

Analysis was done for total score and scores from three dimensions for pre- and post-PSPQ in both the experimental and the control group.

## 4.5 Implementation

The study was conducted over a four-week period in the spring semester of the 2015–2016 academic year. The two seventh-grade classes of the teacher participated in this study. One of the classes was randomly assigned as the experimental group and the other one was assigned as the control group.

The researcher was the teacher who implemented the instruction in the classes. The same teacher instructed the students in both classes. The researcher tried

to avoid acting in a biased way and made an extra effort in the experimental group. Thus, the researcher tried to be objective in both groups. There were four sessions of science instruction in a week in both groups; each session was 40 minutes. Thus, both groups received four 40-minute sessions of instruction per week. Before the study, the teacher prepared lesson plans on electric circuit concepts, considering students' possible misconceptions about electric circuit concepts. The lesson plans are given for week 1 and week 2 in both groups (see Appendix A, B, C, and D). Instructional objectives about electric circuit concepts were considered in preparing detailed lesson plans for both groups. The lesson plans were examined by four science education experts. These lesson plans were revised based on the experts' feedback and suggestions.

At the beginning of the treatment, the ECCT administered as pre-tests in both groups in order to assess students' understanding of electric circuit concepts and the PSPQ administered to assess students' perceptions of scientific practices.

During the treatment, the electric circuit concept topics were covered as part of the regular classroom instruction in the elementary science course in both the experimental and the control group. The topics covered in the classes were electric circuit concepts related to parallel and series connection of light bulbs, the current-voltage relationship, and connecting voltmeter and ammeter in an electric circuit, and relationship between current and voltage in a circuit. The same science textbook was used in both groups**.** The teacher started the lesson in both groups by asking some questions related to the topic to activate students' prior knowledge and to assess their misconceptions about electric circuit concepts.

In the experimental group, the topic of electric circuits was taught through SPBI, whereas in the control group, the same topic was taught through TDSI. In the

experimental group, the participants were required to participate in activities based on BRH about electric circuit content. In the control group, the teacher taught electric circuits using the lecturing method based on the textbook.

In the experimental group, SPBI was conducted by using BRH while teaching types of light bulb connections. BRH is a visual representation of scientific practices by Erduran and Dagher (2014a). It shows that there is a dynamic relationship between scientific practices. There are six components of scientific practices on BRH: data, real world, prediction, explanation, activities, and model. The order is not significant. In other words, there is no rule to begin with any of them. There is social certification and reasoning in the middle of BRH. Each component of scientific practices was explained by the teacher during the activities. Four activities developed by the researcher were applied (see Appendix E, F, G, and H). Before starting activities, teacher divided classroom into 5 groups and worksheets were given to each student (see Appendix I, J, K, and L). Students were taught the BRH and they followed the six scientific practices in each activity. The teacher presented the BRH prepared for each activity. The first activity was “Lighting the Camping Tent” and it was about the construction of simple electric circuits with a different number of batteries, and understanding what scientific practices are, and teaching the relationship between scientific practices. The second activity was “Bulbs Always Lighting in a Luminaire” and it was about the construction of series and parallel electric circuits and understanding scientific practices. The third activity was “Travel of Energy in Wire” and it was about measuring current via an ammeter and the voltage of a battery via a voltmeter, exploring the relationship between current and voltage, and scientific practices. The fourth activity was “Blowing a Fuse” and it was

about understanding of the short circuit electricity and scientific practices, and the relationship between scientific practices.

What BRH means for electric circuit concepts may be seen in the activities. In the first activity, “Lighting the Camping Tent”, the aim was to teach energy supplies in electric circuits and the fact that electric current is a type of energy transfer, that scientific practices are holistic, and that there is a relationship between the components of scientific practices. In this activity, students were given a scenario where they go to a camp; however, they forget to take a bulb to light the inside of the camping tent. According to the scenario, they had only batteries, a bulb and the wire of their bicycle’s bulb. This was the real-world aspect of scientific practices. The teacher guided the process by giving them materials, worksheet 1 (see Appendix I) and asked them to try to construct the circuit, first with one battery and then with two batteries. The teacher asked them what happens to the bulb. Students predicted what would happen in a range of simple electric circuits as changes were made to the number of batteries. This part was the prediction aspect of scientific practices. Students constructed two electric circuits in sequence: one with a single bulb, wire and one battery and one with a single bulb, wire and two batteries. They wrote down the brightness of the bulb in both circuits. Here, students completed the activity part and the data part of scientific practices by experimenting and observing, and they wrote down the brightness of the bulb in both circuits while collecting data. They drew both of their electric circuit constructions. Students constructed a model based on their collected data. This was the modeling component of scientific practices. Finally, they explained how batteries affected the electric circuits and the light bulb. This was the explanation part of scientific practices. Every group explained their findings with justifications and then they presented their drawn circuits and discussed

their findings with their classmates. By doing so, the discursive feature of scientific practices took place. At the end of the activity, students completed each component of BRH. After every component of the BRH, the teacher showed explicitly the scientific practices on the smartboard that had been developed for the activity on "Lighting the Camping Tent" (see Fig. 3). During the activities, students completed the worksheet based on their collected data.

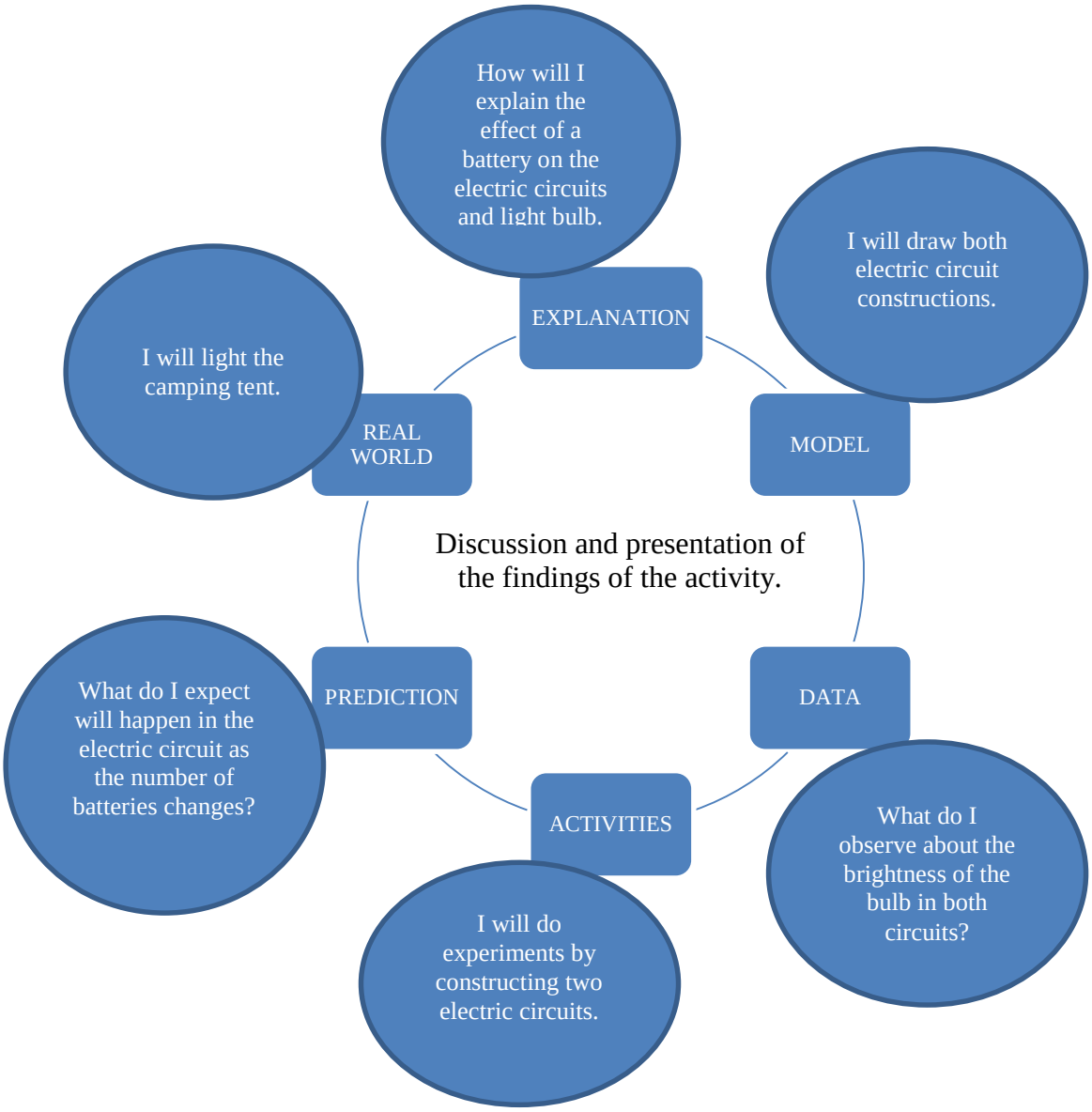



Fig. 3 BRH for activity 1: Lighting the camping tent

In the experimental and control groups, students did experiments by constructing electric circuits in each activity to observe what changes occur when variables change in each activity. In both groups, the teacher guided the students as they were constructing electric circuits. In the experimental group, students drew their constructed electric circuits and explained their findings based on evidence to make concrete the knowledge by representing the findings based on the developed BHR in each activity. After the each activity, students discussed their findings in a whole class discussion to provide students with the opportunity to develop reasoning based on evidence through argumentation. The discussions were conducted in the framework of the developed BRH for each activity. Students discussed what they did in each aspect of scientific practices. They were able to explain the aspects by mentioning the process that they handled and they were able to realize that the process they participated in was the same as the process used by scientists. In the experimental group, the activities were more time consuming than for the control group because the activities included both scientific practices and electric circuit content. For this reason, the time for whole class discussion was about 10 minutes; this is not enough for classroom discussion and reflection. Thus, it was difficult to get an idea of students' understanding of scientific practices and the categories of scientific practices.

In the control group, the TDSI was administered and scientific practices were not mentioned. None of the activities about BRH were applied. In this instruction, the teacher used lecturing, discussion and demonstration to teach the electric circuit concepts. The activities in the science textbook were done. The teacher began the lesson by introducing the topic and gave examples from daily life. While students constructed the circuits in all four activities based on BRH in the experimental group,

students in the control group constructed the circuits in the activities of textbook. The students in the control group did experiments, constructing the electric circuits in those activities. After each activity, a whole classroom discussion was conducted in the control group to discuss what they found during the experiments and to talk about their findings. The time duration in the control group was about 10 minutes. The teacher solved some examples about the topic and then students were asked to solve some exercises from the textbook or supplementary books. At the end of the lesson, the teacher reviewed the topic and asked students whether there was any point that was not clear for them.

Some reflections of both the researcher and the teacher of the study can be mentioned here. Students divided into groups in the experimental and the control group. In both groups, the experiment part of the activities was a bit difficult to follow because the teacher had to guide every group and observe the processes of the experiments. The content of the experiments was the same in both groups. Students in both groups generally had difficulty doing Activity 3, which was about the travel of the energy in a wire, and they were using both an ammeter and a voltmeter in each electric circuit. They were asked to draw the graph of the current and the voltage based on their measurements to show that the rate of the voltage to the current was stable, and that it gave resistance to the conductor. It was difficult for them to understand resistance and they were asking about resistance because it was an abstract concept. The students in the experimental group had easily understood the features of scientific practices and the relationship between scientific practices. They were able to talk about components of BHR such as data, real world, prediction, etc. However, they had difficulty understanding the holistic feature of scientific practices and that scientific practices depend on both scientific knowledge and social context.

It was difficult being a teacher and researcher at the same time in terms of guiding activities in both groups and time management in experimental group. The students in the experimental group stopped paying attention due to some motivational problems. Thus, managing classroom discussions was time-consuming in the experimental group. However, activities based on BHR were easy to do and it was easy to teach students scientific practices when the BHR was opened in the PowerPoint show after each activity.

There are some differences between SPBI and TDSI. SPBI includes scientific practices handled with the scientific topic. Students actively engage in scientific practices in the BRH. SPBI includes cognitive, epistemic and social-institutional aspects of science because it was designed based on the RFN. However, school science addresses the cognitive and epistemic aspects of science (Erduran & Dagher, 2014a). Students in the TDSI performed the activities in the science textbook, without any mention of scientific practices. All in all, it may be said that the difference between SPBI and TDSI is the active engagement of students in both scientific content and scientific practices, and students making sense of what they have done through discursive processes. Students get evidence-based knowledge through processes based on collecting data, making observations, and explanations.

At the end of the instruction, both groups were given the Electric Circuit Concept Test (ECCT) and the Perceptions of Scientific Practices Questionnaire (PSPQ) as posttests to measure the effect of the implementation on their understanding of electric circuits, and to assess their perceptions of scientific practices.

## 4.6 Data analysis

The data analysis procedure consisted of two parts: the first part was descriptive analysis (mean, median and mode) and the second part was inferential analysis (t-test) for quantitative data collected from electric circuit concept test and Perceptions of Scientific Practices Questionnaire. Standard deviation, kurtosis, skewness, minimum and maximum values were calculated and histograms were constructed in descriptive analysis part by using the Statistical Program for Social Science (SPSS). At the beginning, independent samples t-test analysis was performed in order to check whether there was a significant difference between the experimental and the control group in terms of understanding of electric circuit and perceptions of scientific practices. Then analysis of independent samples t-test statistical method was conducted in order to determine the effect of SPBI on seventh-grade students' understanding of electric circuit and perceptions of scientific practices when compared to TDSI.

# CHAPTER 5

# RESULTS AND CONCLUSIONS

This chapter includes the results of descriptive statistics analysis; the results of inferential statistics analysis; and the conclusions figured out at the end of the analysis of all data.

## 5.1 Descriptive statistics analyses

Descriptive statistics related to students' electric circuit concept pre- and post-test scores, and perceptions of scientific practices pre- and post-test scores in the experimental and control groups were determined. Descriptive statistics results such as minimum (min.), maximum (max.), mean, standard deviation (SD), skewness and kurtosis are presented in Table 3.

In Table 3, the experimental group students' pre-electric circuit concept test (pre-ECCT) scores ranged from 6 to 16 with a mean value of 11.04 while the control group students' pre-ECCT scores ranged from 6 to 18 with a mean value of 10.71. The experimental group students' post-electric circuit concept test (post-ECCT) scores ranged from 6 to 22 with a mean value of 15.82. However, the control group students' post-ECCT scores ranged from 9 to 24 with a mean value of 14.89. Thus, it was seen that with respect to ECCT, the mean value increase (15.82-11.04 = 4.78) in the experimental group was higher than the mean value increase (14.89-10.71 = 4.18) in the control group. The descriptive statistics related to students' concept of electric circuits, their pre- and post-test scores, their perceptions of scientific practices, and the pre- and post-test scores in the experimental and control groups were determined.

Descriptive statistics results such as minimum (min.), maximum (max.), mean, standard deviation (SD), skewness and kurtosis are presented in Table 3.

In Table 3, the experimental group's pre-Electric Circuit Concept Test (pre-ECCT) scores ranged from 6 to 16 with a mean value of 11.04, while the control group's pre-ECCT scores ranged from 6 to 18 with a mean value of 10.71. The experimental group students' post-Electric Circuit Concept Test (post-ECCT) scores ranged from 6 to 22 with a mean value of 15.82. However, the control group students' post-ECCT scores ranged from 9 to 24 with a mean value of 14.89. Thus, it was seen that, with respect to ECCT, the mean value increase (15.82-11.04 = 4.78) in the experimental group was higher than the mean value increase (14.89-10.71 = 4.18) in the control group.

The experimental group students' pre-Perceptions of Scientific Practices Questionnaire (pre-PSPQ) scores ranged from 75 to 142 with a mean value of 113.71, while the pre-PSPQ scores of control group students ranged from 71 to 135 with a mean value of 118.39 (see Table 3). The mean value of the experimental group students' post-Perceptions of Scientific Practices Questionnaire (post-PSPQ) was 121.04. Their scores were ranged from 90 to 150. However, the mean value of the control group students' post-Perceptions of Scientific Practices Questionnaire (post-PSPQ) was 119.68. Their scores were ranged from 95 to 136. As in the ECCT results, the mean value increase in terms of PSPQ (121.04-113.71 = 7.33) in the experimental group was higher than the mean value increase (119.68-118.39 = 1.29) in the control group.

Table 3. Descriptive Statistics Analysis Related to Electric Circuit Concept Test (ECCT) and Perceptions of Scientific Practices Questionnaire (PSPQ)

Descriptive Statistics

| Group | Test | N | Min | Max | Mean | SD | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|
| EG | Pre-ECCT | 28 | 6 | 16 | 11.04 | 2.74 | .088 | -1.132 |
| | Post-ECCT | 28 | 6 | 22 | 15.82 | 3.65 | -.966 | 1.005 |
| | Pre-PSPQ | 28 | 75 | 142 | 113.71 | 15.951 | -.701 | .780 |
| | Post-PSPQ | 28 | 90 | 150 | 121.04 | 14.328 | -.297 | .554 |
| CG | Pre-ECCT | 28 | 6 | 18 | 10.71 | 3.31 | .746 | .187 |
| | Post-ECCT | 28 | 9 | 24 | 14.89 | 3.61 | .240 | .106 |
| | Pre-PSPQ | 28 | 71 | 135 | 118.39 | 12.032 | -2.198 | 8.351 |
| | Post-PSPQ | 28 | 95 | 136 | 119.68 | 12.138 | -.563 | -.794 |

There are also three categories in the PSPQ, based on the characteristics of scientific practices asked in the questionnaire. Those categories are features of scientific practices (for items 1-6), relationships between scientific practices (for items 7-21), and holistic feature of scientific practices (for items 22-34).

The descriptive statistics about the categories of PSPQ is given in Table 4. The first category is features of scientific practices for items 1 to 6. It is shown as PSPQ 1 in Table 4. Statistical analysis in the SPSS shows that the experimental group (M = 23.18, SD = 4.381) scored better than the control group (M = 22.64, SD = 3.803) for understanding the features of scientific practices in the post-PSPQ. Moreover, understanding of the features of scientific practices in the experimental was more developed compared to the pre-PSPQ and post-PSPQ scores, given that there was no difference the mean scores of the control group.

The second category in the PSPQ is related to the relationships between scientific practices for the items 7 to 21. It is showed as PSPQ 2 in Table 4. The results shows that students in the experimental group (M = 51.36, SD = 9.370)

scored lower than the students in the control group (M = 53.86, SD = 6.270) in pre-PSPQ. However, after the treatment students in the experimental group (M = 55.32, SD = 7.303) scored better that the students in the control group (M = 53.79, SD = 6.718) in the post-PSPQ.

The final category in the PSPQ is the holistic feature of scientific practices for items 22 to 34. It is shown as PSPQ 3 in Table 4. Analysis results show that the students in the control group (M = 43.25, SD = 3.617) scored higher than the students in the experimental group (M = 42.54, SD = 5.323) for the holistic feature of scientific practices in the post-PSPQ.

Table 4. Descriptive Statistics Analysis Related to Categories of Perceptions of Scientific Practices Questionnaire (PSPQ)

| | | Descriptive Statistics | | | |
|---|---|---|---|---|---|
| Group | Test | N | Mean | SD | Std. Error Mean |
| EG | Pre-PSPQ 1 | 28 | 20.97 | 4.924 | .931 |
| | Post-PSPQ 1 | 28 | 23.18 | 4.381 | .828 |
| | Pre-PSPQ 2 | 28 | 51.36 | 9.370 | 1.771 |
| | Post-PSPQ 2 | 28 | 55.32 | 7.303 | 1.380 |
| | Pre-PSPQ 3 | 28 | 51.57 | 4.122 | .779 |
| | Post-PSPQ 3 | 28 | 42.54 | 5.323 | 1.006 |
| CG | Pre-PSPQ 1 | 28 | 22.64 | 3.783 | .715 |
| | Post-PSPQ 1 | 28 | 22.64 | 3.803 | .719 |
| | Pre-PSPQ 2 | 28 | 53.86 | 6.270 | 1.185 |
| | Post-PSPQ 2 | 28 | 53.79 | 6.718 | 1.270 |
| | Pre-PSPQ 3 | 28 | 41.89 | 4.433 | .838 |
| | Post-PSPQ 3 | 28 | 43.25 | 3.617 | .684 |

In addition to the minimum, maximum and mean values, skewness, and kurtosis values were presented in the Table 3. The value of skewness and kurtosis

near “0” indicates a normal distribution of test scores for the post-PSPQ in both groups and post-ECCT in control group. For the normality of the post-test scores, the Kolmogorov-Smirnov test (K-S) and Shapiro-Wilk (S-W) test was used. The values are shown in Table 5. However, the Shapiro-Wilk Test is more appropriate for small sample sizes. Any value above .05 indicates normality in the Shapiro-Wilk (S-W) test. The analyses show that the scores of the experimental and the control group are normally distributed for post-PSPQ. Also, the scores of the control group for post-ECCT are normally distributed. However, the scores of the experimental group are not normally distributed for the post-ECCT.

Table 5. Normality Test for Post-PSPQ and Post-ECCT

| | | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|---|
| Group | Test | Statistic | df | Sig. | Statistic | df | Sig |
| EG | Post-ECCT | .197 | 28 | .007 | .926 | 28 | .048 |
| | Post-PSPQ | .121 | 28 | .200 | .958 | 28 | .316 |
| CG | Post-ECCT | .091 | 28 | .200 | .966 | 28 | .470 |
| | Post-PSPQ | .124 | 28 | .200 | .932 | 28 | .069 |

## 5.2 Inferential statistics analyses

In this section, the analyses of five null hypotheses of this research are presented. Those hypotheses were tested by using an independent samples t-test at a significance level of .05. The Statistical Program for Social Science (SPSS) was used to carry out analyses.

Before inferential statistics analyses were done, an independent samples t-test was conducted to see whether there was a significant difference between the experimental and the control group regarding students’ understanding of electric

circuits measured by pre-ECCT and their perceptions of scientific practices measured by the pre-PSPQ.

The results of the independent samples t-test show that there was no significant difference between the scores of the students in the experimental group and those in the control group in terms of students' understandings about electric circuit concepts ($t(56) = .396$, $p = .694$, $p>.05$), and their perceptions of scientific practices ($t(56) = -1.239$, $p = .221$, $p>.05$).

### 5.2.1 Null hypothesis 1

This hypothesis states that there will be no significant difference between post-test mean scores of the students taught with SPBI and the students taught with TDSI with respect to their perceptions of scientific practices. This was tested by using an independent sample t-test.

The assumptions of the independent samples t-test were tested before the t-test was conducted. The assumptions of the independent samples t-test are:

i. Dependent variable should be measured on a continuous scale,
ii. Two independent groups should be in independent variable,
iii. There should be independence of observations within each sample,
iv. Dependent variable should be normally distributed in both the samples from the populations,
v. The variances of the populations should be equal (LaerdStatistics, 2016).

The first assumption was satisfied by calculating the scores of PSPQ. The second assumption was satisfied by two independent groups and each group was randomly assigned as either experimental or control. For the third assumption, each

group took the tests under standard conditions and it was assumed that during the test administration, there was no interaction within or between the groups.

The fourth assumption of the t-test was satisfied by the normal distribution of PSPQ scores of experimental and control group are normally distributed, based on the skewness and kurtosis values of post- PSPQ scores (Table 3) and the Kolmogorov-Smirnov test (K-S) and Shapiro-Wilk (S-W) (Table 5). For the final assumption of the independent samples t-test, Levene's Test was conducted by using the SPSS to check homogeneity of variances. The variances of the post- PSPQ scores of the students in both groups were equal, based on the result of Levene's Test of Equality shown in Table 6 ($F(1, 54) = .076$, $p>.05$).

The independent samples t-test was conducted after testing all five assumptions and the result of this analysis is given in Table 6.

Table 6. Independent Samples Test Summary of Post-PSPQ

| | Levene's Test for Equality of Variances | | t-test Equality of Means | | | | |
|---|---|---|---|---|---|---|---|
| | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference |
| Equal variances assumed | .076 | .784 | .382 | 54 | .704 | 1.357 | 3.549 |
| Equal variances not assumed | | | .382 | 52.580 | .704 | 1.357 | 3.549 |

The results indicate that there was no significant difference between the post-test mean scores of the students taught with SPBI and the students taught with TDSI with respect to their perceptions of scientific practices; $t$ (56) = .382, $p>.05$. These results indicate that even though there was no significant difference between post-test mean scores of the students taught with SPBI and the students taught with TDSI with respect to their perceptions of scientific practices, students in the experimental group had higher mean scores (M = 121.04, SD = 14.33) in PSPQ than the scores of the

students in the control group (M = 119.68, SD = 12.14). Table 3 shows the scores for post-PSPQ. During the implementation the students in the experimental group were taught scientific practices and they could talk about what scientific practices were. However, students in the control group were not told about scientific practices.

### 5.2.2 Null hypothesis 2

This hypothesis stating that there is no significant difference between post-test mean scores of the students taught with SPBI and the students taught with TDSI with respect to their understanding of features of scientific practices was tested by using an independent samples t-test.

The results in Table 7 show that there was no significant difference in the understanding of the features of scientific practices between the experimental group and the control group; $t$ (56) = .489, p>.05. Moreover, the results indicated that the students in the experimental group had higher mean scores (M = 23.18, SD = 4.381) than the students of the control group (M = 22.64, SD = 3.803) in terms of understanding the features of scientific practices. During the intervention, students in the control group were able to explain the features of scientific practices such as prediction and generating explanations.

Table 7. Independent Samples Test Summary of Post-PSPQ for Features of Scientific Practices Category

| | Levene's Test for Equality of Variances | | t-test Equality of Means | | | | |
|---|---|---|---|---|---|---|---|
| | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference |
| Equal variances assumed | .055 | .815 | .489 | 54 | .627 | .536 | 1.096 |
| Equal variances not assumed | | | .489 | 52.954 | .627 | .536 | 1.096 |

### 5.2.3 Null hypothesis 3

The hypothesis stating that there is no significant difference between post-test mean scores of the students taught with SPBI and the students taught with TDSI with respect to their understanding of relationships of scientific practices was tested by using an independent samples t-test. Analysis of the results (Table 8) shows that there is no significant difference in the understanding of relationships between scientific practices of the students in the experimental and the control group; $t$ (56) = -.587, p>.05. Students in the experimental group had higher mean scores (M = 55.32, SD = 7.303) than the students in the control group (M = 53.79, SD = 6.718) even though there is no significant difference between the understanding of relationships between scientific practices. During the intervention, the students in the experimental group were able to talk about relationships between scientific practices such as scientific practices includes data collection and activities, and data is used to verify scientific explanations etc.

Table 8. Independent Samples Test Summary of Post-PSPQ for Relationships between Scientific Practices

| | Levene's Test for Equality of Variances | | t-test Equality of Means | | | | |
|---|---|---|---|---|---|---|---|
| | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference |
| Equal variances assumed | .000 | .997 | .819 | 54 | .416 | 1.536 | 1.875 |
| Equal variances not assumed | | | .819 | 53.628 | .416 | 1.536 | 1.875 |

### 5.2.4 Null hypothesis 4

The hypothesis stating that there is no significant difference between post-test mean scores of the students taught with SPBI and the students taught with TDSI with respect to their understanding of holistic feature of scientific practices was tested by

using an independent samples t-test. Analysis results (Table 9) show that there was no significant difference in the understanding of holistic feature of scientific practices between the experimental group and the control group; $t$ (56) = .819, p>.05. The analysis indicated that the mean scores of the students in the experimental group (M = 42.54, SD = 5.323) were lower than the scores of the students in the control group (M = 43.25, SD = 3.617). This may be the result of following the same order in the activities during the intervention in the experimental group. Students in the experimental group had difficulty explaining the holistic feature of scientific practices and completing the items measuring this category in the PSPQ.

Table 9. Independent Samples Test Summary of Post-PSPQ for Holistic Feature of Scientific Practices Category

| | Levene's Test for Equality of Variances | | t-test Equality of Means | | | | |
|---|---|---|---|---|---|---|---|
| | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference |
| Equal variances assumed | 4.500 | .038 | -.587 | 54 | .559 | -.714 | 1.216 |
| Equal variances not assumed | | | -.587 | 47.553 | .560 | -.714 | 1.216 |

Analysis of categories of PSPQ shows there was no significant difference between the understanding of any three categories of the experimental group and the control group. Mean scores shows that students in the experimental group had better understanding for the features of scientific practices and the relationships between scientific practices. However, students in the control group had better understanding for the holistic feature of scientific practices when compared to the students in the experimental group.

### 5.2.5 Null hypothesis 5

The hypothesis stating that there is no significant difference between mean post-test scores of the students taught with SPBI and those of the students taught with TDSI with respect to their understanding of electric circuit concepts was tested by using an independent samples t-test.

The assumptions of the independent samples t-test were tested before the independent samples t-test was conducted. The assumptions of independent samples t-test are:

i. Dependent variable should be measured on a continuous scale,
ii. Two independent groups should be in independent variable,
iii. There should be independence of observations within each sample,
iv. Dependent variable should be normally distributed in both the samples from the populations,
v. The variances of the populations should be equal (LaerdStatistics, 2016).

The first assumption was satisfied by calculating the scores of the ECCT. The second assumption was satisfied by assigning each group randomly as either the experimental or the control group. For the third assumption, all the tests were administered to both groups under standard conditions and it was assumed that during the test administration, there was no interaction within or between the groups.

The fourth assumption of the independent samples of the t-test was satisfied by the normal distribution about ECCT scores of the experimental and control groups, based on the skewness and kurtosis values of post- ECCT scores (Table 3) and the Kolmogorov-Smirnov test (K-S) and the Shapiro-Wilk (S-W) (Table 5). For the last assumption about independent samples of t-test, Levene's Test was

conducted by using the SPSS to check homogeneity of variances. The variances of the post- ECCT scores of the students in both groups were equal, based on the result of Levene's Test of Equality in Table 10 ($F(1,54) = .042$, $p>.05$).

After checking all five assumptions, independent samples t-test was conducted. The results in Table 10 show that there was no significant difference between post-test mean scores of the students taught with SPBI and the students taught with TDSI with respect to their understanding of electric circuit concepts; $t(56) = .956$, $p>.05$.

Table 10. Independent Samples Test Summary of Post-ECCT

| | Levene's Test for Equality of Variances | | t-test Equality of Means | | | | |
|---|---|---|---|---|---|---|---|
| | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference |
| Equal variances assumed | .042 | .839 | .956 | 54 | .343 | .92857 | .97100 |
| Equal variances not assumed | | | .956 | 53.994 | .343 | .92857 | .97100 |

These results indicate that even there was no significant difference between post-test mean scores of the students taught with SPBI and the students taught with TDSI with respect to their understandings of electric circuit concepts, students taught with SPBI had higher mean scores ($M = 15.82$, $SD = 3.65$) than the scores of the students taught with TDSI ($M = 14.89$, $SD = 3.61$). Table 3 shows scores for post- ECCT.

For both the experimental and the control groups, the proportions of correct responses to the questions in the post-ECCT are given in Figure 4. According to Figure 4, for questions 2, 9, 16, 18 and 21 there was a significant difference between the experimental and control group in the proportion of correct responses on the post-ECCT. Moreover, students in the experimental group scored better than the students in the control group for questions 1, 5, 11, 15, 17, 20, 23, and 24.

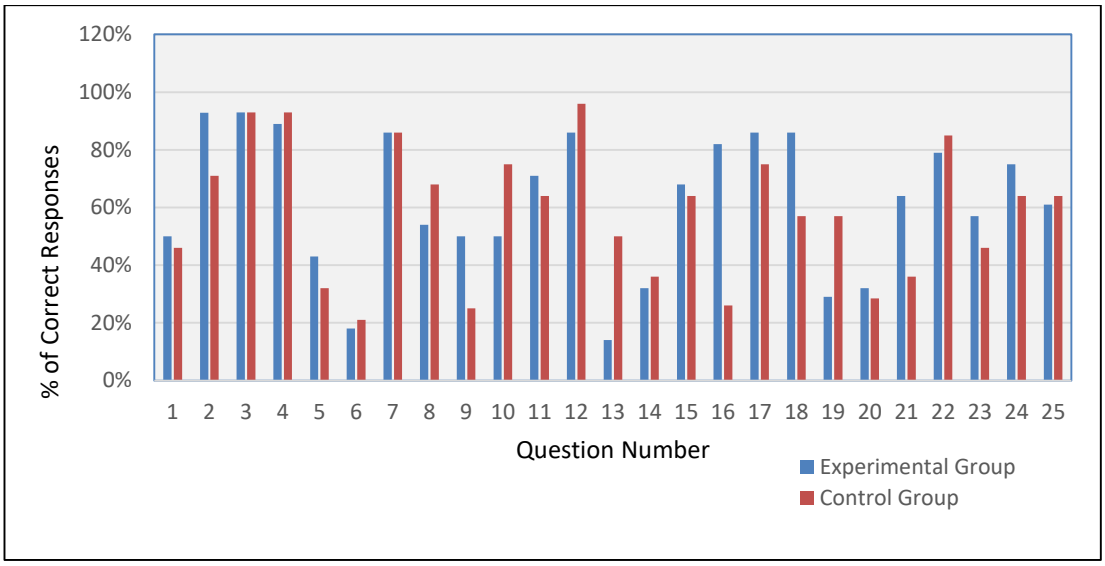



Fig. 4 Comparison of post-ECCT scores of the experimental and control groups

Question 2 asked students to identify the device with which one measures the rate of current flow through an insulator. In the pre-ECCT, 42.9% of students in the experimental group selected B or D. In the control group, 57.1% students selected D (voltmeter). Table 11 presents the percentage of students' responses in both the experimental and control groups, distracters, and the right option for question 2 in the post-ECCT. After the treatment, 92.9% of students in the experimental group chose the right answer to this question. However, only 71.4% of students in the control group answered this question correctly.

Table 11. Percentage of Students' Responses to Question 2

| Question 2: Which one measures the rate of current flow through an insulator? | Percentage of Students" Responses (%) | |
|---|---|---|
| | Experimental Group | Control Group |
| Alternative A Electroscope | 0 | 0 |
| Alternative B* Ammeter | 92.9 | 71.4 |
| Alternative C Rheostat | 3.6 | 0 |
| Alternative D Voltmeter | 3.6 | 28.6 |

*Correct Alternative

In question 9, a graph of voltage-current values of an electric circuit component was given. Students were asked to find the resistance value of that component. Before the treatment, the percentage of students in the control group who got the right answer was 10.7%, and the percentage of students in the experimental group was 32.1%. This question was about the direct relationship between the voltage and current and the stable rate of voltage to the current, and it gives resistance of the conductor. After the treatment, 25% of the students in the control group and 50% of the students in the experimental group selected the correct alternative. However, the percentage of students having misconceptions in the control group was 75% and 50% in the experimental group. Those students in both groups were unable to qualitatively argue about the behavior of an electric circuit (McDermott & Shaffer, 1992).

In the question 16, students were given an image of an electric circuit composed of two series connected bulbs (bulb K and bulb L), 1 ammeter, 1 battery

and 1 wire connected to two sides of bulb K. The test item states that bulb K does not light and asks the reason for this situation. Before the treatment, 39.3% of the students in the control group and 60.7% of the students in the experimental group chose the correct answer, that is, there is short circuit in bulb K. After the treatment, the increase in the percentage of the students' choosing the correct answer was higher in the experimental group than in the control group. Table 12 shows the percentages for distracters and the correct alternative for question 16 for both groups. In the experimental group, 82.1% of the students selected the correct answer versus 53.6% of the students in the control group. However, 10.7% of the students in the control group had misconception that current does not change throughout the circuit and the brightness of a bulb is not affected by the number of elements in the circuit. This model, called the "constant current model" by Jaakkola and Nurmi (2008), is referred to as the constant current source model by Kärrqvist (1985) and Cohen, Eylon, and Ganiel (1983). In the experimental group, 7.1% of the students and 14.3% of the students in the control group had the misconception that "current is gradually consumed by the circuit components," referred to as the consumption model by Jaakkola and Nurmi (2008, p.278), the 'current consumption model' by Kärrqvist (1985), the 'model II sequence model' by Shipstone (1984) and the 'attenuation model by Osborne (1983).

Table 12. Percentage of Students' Responses to Question 16

| Question 16: Bulb K does not light in the given electric circuit. What is the reason for this? | Percentage of Students" Responses (%) | |
|---|---|---|
| | Experimental Group | Control Group |
| Alternative A<br>Bulb L used all the current in the circuit. | 7.1 | 14.3 |
| Alternative B*<br>There is short-circuit in bulb K. | 82.1 | 53.6 |
| Alternative C<br>Too much current came to the bulb K. | 10.7 | 21.4 |
| Alternative D<br>The same current passes trough bulb K and L. | 0 | 10.7 |

*Correct Alternative

In the question 18, students were asked that which option is the correct way to increase the brightness of a bulb. Before the treatment, most students in both the experimental group (67.9%) and the control group (64.3%) selected the correct alternative, that is, increase the number of batteries. After the treatment, while the number of percentage of students selected the correct alternative in the experimental group (85.7%) increased, the percentage of the students that selected the correct alternative in the control group (57.1%) decreased. Table 13 shows the percentages for distracters and the correct alternative for question 18 for both groups.

Table 13. Percentage of Students' Responses to Question 18

| Question 18: Which one is correct to increase the brightness of a bulb? | Percentage of Students" Responses (%) | |
|---|---|---|
| | Experimental Group | Control Group |
| Alternative A<br>Using a wire having bigger resistance. | 0 | 10.7 |
| Alternative B<br>Connecting an ammeter to the circuit. | 14.3 | 17.9 |
| Alternative C*<br>Increasing number of batteries. | 85.7 | 57.1 |
| Alternative D<br>Adding a series connected bulb. | 0 | 14.3 |

*Correct Alternative

In question 21, students were given an electric circuit composed of one bulb, one battery and wire. They were asked what should be added to increase the brightness of the bulb. This question resembled question 18 and this question included electric circuit and basic components of an electric circuit representations. In the alternatives, representations of electric circuit components were given as bulb, resistance, battery and switch. Before the treatment, 35.7% of the students in the control group and 25% of the students in the experimental group selected resistance as the answer. Those students in both groups were unable to apply formal concepts to electric circuits, use and interpret formal representations of an electric circuit, qualitatively argue about the behavior of an electric circuit (McDermott & Shaffer, 1992). After the treatment, 35.7% of the students in the control group and 64.3% of

the students in the experimental group selected the correct answer, battery. However, other students in both groups still had a misconception about interpreting an electric circuit representation. Table 14 gives the percentages, distracters and the correct alternative for question 21.

Table 14. Percentage of Students' Responses to Question 21

| Question 21: What should be added to increase the brightness of the bulb? | Percentage of Students‟ Responses (%) | |
|---|---|---|
| | Experimental Group | Control Group |
| Alternative A<br>Bulb | 7.1 | 14.3 |
| Alternative B<br>Resistance | 21.4 | 17.9 |
| Alternative C*<br>Battery | 64.3 | 35.7 |
| Alternative D<br>Switch | 7.1 | 32.1 |

*Correct Alternative

In sum, students in the experimental group generally scored higher than students in the control group, even if there was not a significant difference between the understanding levels of students taught with SPBI and that of the students taught with TDSI in terms of scientific practices and electric circuit concepts.

## 5.3 Summary of the results

According to the analysis results, the following results can be reached as:

1. It was found that the students in SPBI got higher mean scores in electric circuit concepts than the students in TDSI. However, this difference between the experimental and control groups was not significant.
2. It was found that SPBI caused higher mean scores in the understanding of scientific practices and gaining perception about scientific practices. However, the difference between the experimental and control groups was not significant.
3. The students taught with SPBI got higher mean scores in understanding the features of scientific practices than the students taught with TDSI. However, the difference between the experimental and control groups was not significant.
4. The students taught with SPBI got higher mean scores in understanding relationships between scientific practices than the students taught with TDSI. However, the difference between the experimental and control groups was not significant.
5. The students taught with SPBI did not get higher mean scores in understanding the holistic feature of scientific practices than the students taught with TDSI.

# CHAPTER 6

# DISCUSSION, IMPLICATIONS, AND RECOMMENDATIONS

This chapter presents a summary of the study, a discussion of the results and implications for the teaching and learning of scientific practices and electric circuit concepts, and recommendations for further studies.

## 6.1 Summary of the study

The purpose of this study was to investigate the effect of SPBI on seventh-grade students' perceptions of scientific practices and conceptual understandings about electric circuit concepts when compared to TDSI. Before the implementation ECCT and PSPQ were administered to both groups as pre-tests to assess their understanding of electric circuit concepts and perceptions about scientific practices respectively. Fifty-six seventh-grade students from two classes of the teacher participated in this study. One of the classes was assigned as experimental group and the other one as control group. The experimental group was instructed with SPBI, whereas the control group was instructed with TDSI.

There are some differences between the SPBI and the TDSI. In SPBI, the students engaged in activities related to electric circuit concepts based on BRH. After each activity, BHR was discussed with the students, and BHR models were shown on the board. In TDSI, the activities about electric circuit concepts in the textbook were followed.

After the treatment, the ECCT and the PSPQ were administered as post-tests to the students in both groups to investigate the effect of the SPBI on students' understanding of electric circuit concepts, their perceptions of scientific practices,

and three categories of scientific practices. The data were analyzed using an independent samples t-test to compare the groups with respect to the post-tests ECCT and PSPQ. The results were given in chapter 5. In the section 6.2, the results with respect to students' perceptions of scientific practices and conceptual understanding about electric circuit concepts are discussed, and implications for the teaching and learning of scientific practices and electric circuit concepts are presented.

## 6.2 Discussion and implications of the results

The analysis of the results indicated that the students in the experimental group had higher scores in terms of their perceptions of scientific practices, the features of scientific practices, and the relationship between scientific practices than the students in the control group. In the experimental group, activities based on BRH were designed and each scientific practice was mentioned. However, in the control group, the students were instructed using TDSI without mentioning scientific practices. Generally, studies in the literature indicate that in traditional science instruction, the teacher restricts instruction by using textbooks (Butta, 1998) and that school science addresses cognitive and epistemic aspects of science (Erduran & Dagher, 2014a). The social institutional system of science may be dismissed in the TDSI. However, the SPBI provides students with cognitive, epistemic and social-institutional aspects of science. Erduran and Dagher (2014a) argue that handling the cognitive, epistemic and social-institutional aspects of science helps students understand the formation of scientific knowledge. They also criticize the fact that TDBI mentions a discrete set of features without mentioning the relationship of those features to each other. Moreover, they point out that TDBI may result in the idea that there is a special method that scientists use to reach scientific knowledge. Considering this difference,

the SPBI may provide students with an understanding of science processes and a realization that what they do in the classroom is similar to what scientists do. When the SPBI and the TDSI were compared, it may be said that the SPBI, based on the RFN, offers models of the NOS that are pedagogically, cognitively, and epistemically more suitable for science education (Erduran & Dagher, 2014a; Kaya & Erduran, 2016a). Thus, the SPBI includes all these features and it provides a meta-level understanding of science (Erduran & Dagher, 2014a). For these reasons, explicitly teaching scientific practices based on BHR may result in higher scores on the PSPQ. In this study, only quantitative data analysis was used. If qualitative methods such as interviews had been used, maybe there would have been a statistically significant difference between the mean scores of the students in the experimental group and those in the control group on the ECCT and the PSPQ.

Although the SPBI resulted in a better understanding of scientific practices, the features of scientific practices, relationships between scientific practices, and statistical analysis showed that the students in the control group had higher scores in terms of understanding of holistic feature of scientific practices. This may be result of the activities, because all four activities began with real world practice and generally the same order was followed during the activities. Even the teacher emphasized that the order is not significant between those practices, following the same order during activities may result in students having difficulty understanding the holistic feature of scientific practices. This may result from the items used to measure the holistic aspect of scientific practices in the PSPQ. During the administration of the PSPQ, students in the experimental group had difficulty understanding the items measuring the holistic feature of scientific practices. Some items that they had problems understanding were “scientific practices should include

feedback of other scientists and review scientific work" and "all the processes of scientific practices are open to critical discussion". To overcome this problem the teacher tried to explain those items. Students thought that the critical discussion was something bad and it showed bad sides of something. Students might have misunderstood those items in the instrument.

In addition, the results indicated that the SPBI resulted in higher scores in terms of understanding electric circuit concepts than TDSI. In the SPBI, the activities were developed based on the BRH while in the TDSI, the activities were based on the science textbook. As it was mentioned before, the school science curriculum addresses the cognitive and epistemic aspects of science (Erduran & Dagher, 2014a). In the experimental group, the activities were based on the BHR, which includes scientific practices. Thus, the SPBI incorporates evidence-based processes and the coordination of evidence and models through discursive processes. In addition, the school science curriculum addresses theories, laws, and models as content knowledge, but this is not enough to develop students' understanding about the relationship between different forms of scientific knowledge (Erduran & Dagher, 2014a). Discussing the differences in the data the students use as evidence to reveal what they find contributes to the scientific studies to be more cognitive and to the development of the social dialectic process (Olson & Loucks-Horsley, 2000). Doing these activities helps students to construct new knowledge and eliminate misconceptions about a scientific concept (Olson & Loucks-Horsley, 2000). Thus, the social-institutional aspects of science may have an effect on developing conceptual understanding. Moreover, traditional instruction is teacher-centered and includes rote memorization, so it does not lead to higher-order thinking, and students taught with traditional instruction are not able to transfer learned concepts from one

situation to another (Butta, 1998; Collision, 1993). There would have been a statistically significant difference between the scores of the students in the experimental group and in the control group if another concept test on electric circuits had been administered, even with the high reliability of the ECCT. Besides, the ECCT includes only multiple choice questions and only quantitative data analysis was used. For this reason, if qualitative data analysis had been used in the study, it would have yielded different results. On the other hand, the SPBI provided the students in the experimental group a better understanding of electric circuit concepts. The reasons for this may be students' doing activities based on the BRH, formulating evidence-based explanations, and constructing models to make abstract concepts more understandable.

There is much research in the literature examining the effect of teaching strategies on students' learning of scientific concepts (e.g. Celikten, Ipekcioglu, Ertepinar, & Geban, 2012; Cobern et al., 2010; Frampton, 2009). Some of the studies were about the use of techniques that differ from the traditional instruction with the aim of eliminating students' misconceptions about electric circuit concepts (Shipstone & Cheng, 2001). Electric circuit concepts are difficult to understand and are abstract (Korganci, Miron, Dafinei, & Antohe, 2015; Taber, Trafford, & Quail, 2006). Students generally have difficulty learning about this topic. Before preparing the ECCT, misconceptions described in the literature were considered. When the worksheets and the concept test were examined, misconceptions that had been mentioned in the literature were found (Korganci et al., 2015; Shepardson & Moje, 1994). These misconceptions were about the current in parallel and series connected circuits. For example, some students thought that total resistance decreases and the brightness of bulb increases when new bulb is connected to the circuit in parallel.

Most of the students thought that if the bulb was far away from the battery, its brightness would be less than those which were close to the battery. They also thought that resistance, current, voltage and energy were the same thing. In the short circuit concept, before the activity, many students thought that the reason for the short circuit was excessive resistance. Some of them thought that series connected circuits result in a short circuit because if one of the bulbs burns out, the others would also burn out, causing a short circuit. After the activity, this misconception was changed to another misconception in one of the students. He thought that the current passes faster to the bulb which is not short circuited, so this bulb gives light. Another misconception is that the current is stored in battery. Studying the possible misconceptions found in this study would contribute to the related literature.

Even though the students in the experimental group generally scored higher on the ECCT than the students in the control group, they still had difficulties such as being unable to apply formal concepts to electric circuits, using and interpreting formal representations of an electric circuit, qualitatively arguing about the behavior of an electric circuit (McDermott & Shaffer, 1992). After the treatment, the percentage of the students in the control group who selected the correct alternative for questions 4, 6, 8, 10, 12, 13, 14, 19, 21, and 25 was higher than the percentage in the experimental group. Questions 6, 10, 14 were about series and parallel connection of bulbs; questions 4, 21, and 25 were about electric current and electric energy; questions 8, 12 and 13 were about relationship between voltage and current; question 19 was about connection of ammeters and voltmeters. For question 19, it seemed that students were not able interpret the representation of a connection of a voltmeter in an electric circuit. Students were also unable to interpret representations of the electric circuit components in question 4. Moreover, in question 22, it seemed

that students thought that one cable between a battery and bulb was enough to light a bulb if the switch was on. Students might have assumed that the brightness of the bulb was related directly to the number of bulbs in question 6. Jaakkola and Nurmi (2008) call this misconception a surface model and it is described by McDermott and Shaffer as a "tendency to focus on number of elements or branches" (as cited in Jaakkola and Nurmi, 2008, p.278). For questions 8, 12 and 13, students might have thought that current does not change throughout the circuit and that the brightness of a bulb is not affected by the number of elements in the circuit. This misconception is called a constant current model by Jaakkola and Nurmi (2008), a constant current source model by Kärrqvist (1985) and Cohen, Eylon, and Ganiel (1983). Finally, in questions 6, 10, 14 and 25, students might not have understood the effects on brightness of the parallel and series circuits. Jaakkola and Nurmi (2008) calls this misconception the preliminary ohm model. The fact that the students in the experimental group got the answers wrong might be the result of not having enough time to focus on those concepts or students' end-of-the-year lack of motivation.

Moreover, the teacher realized that students were not paying attention to the scientific practices part of the activities because they would not be graded. Although they were reluctant to do the activity part of the sessions, they were complaining about taking pre- and post-tests, and pre- and post-questionnaires in a short time. This may have caused students to tire of the sessions. These might be the reasons for the ineffectiveness of the SPBI on students' understanding of the electric circuit concepts and scientific practices.

Most of the students in the experimental group seemed to have no intrinsic motivation; they did not care about how they performed on the tests. They complained about the test administration process. They seemed to have extrinsic

motivation (Ryan & Deci, 2000): they asked whether they would be graded, and said that solving tests was not necessary if they were not going to be graded. Motivational constructs such as intrinsic value lead to better conceptual learning (Benware & Deci, 1984; Graham & Golan, 1991; Grolnick & Ryan, 1987; Ryan, Connel, & Deci, 1985). If the students in the experimental group were intrinsically motivated, students would behave to satisfy themselves with their performance (Deci, 1975). The students in the experimental group may have been unable to apply the acquired knowledge in school in a meaningful manner (Caramazza, McCloskey & Green 1981; Halloun & Hestenes 1985). According to Edelson (1998), tools, techniques, attitudes and social interactions are the main requirements to be able to apply science practice in learning settings. Thus, the students' attitudes may have had a negative effect on the results of this study. Those challenges may be another reason for the statistically insignificant results of this study.

All in all, the main contribution of this study is the investigation the effect of the SPBI on students' perceptions of scientific practices and electric circuit concepts. Thus, this study examines the link between scientific practices and conceptual understanding. The SPBI resulted in higher scores in terms of the understanding of electric circuit concepts, scientific practices, the features of scientific practices, and the relationships between scientific practices than the TDSI. It can be said that using scientific practices is important in teaching scientific concepts because scientific concepts maps in all of part of scientific practices. There is a limitation: the elementary school students have limited understanding of scientific practices (Sandoval, Sodian, Koerber, & Wong, 2014). However, this study provides evidence that elementary school students can engage in scientific practices. Students in the experimental group had no knowledge about scientific practices at the beginning of

the treatment. This study adapted the BRH and used it with elementary school students. The students in the experimental group were able to engage with BRH during the study. Thus, the SPBI may have potential to help science education researchers and science teachers. For example, activities based on BRH might be beneficial to science teachers because the activities in the present study are the examples of using scientific practices in the electric concepts. The results would have been different if the treatment had been conducted with another group of seventh-grade students. There may have been a problem with the experimental group that resulted from motivation or attitude issues.

## 6.3 Recommendations

Based on the findings of this study, the following recommendations in terms of learning and teaching of scientific concepts, curriculum applications, and further studies are discussed below.

Teachers can design the instruction to include scientific practices. It may be beneficial to teach scientific practices. They should point out that what students actually do during the science courses is the similar to the activities that scientists do. In addition to the teaching of scientific practices, the SPBI should be used for promoting an understanding of different scientific concepts. Moreover, teachers should have knowledge about scientific practices. For this reason, teacher education programs should be arranged to teach pre-service science teachers about scientific practices and train them through the use of pre-service seminars related to this issue.

Curriculum developers should consider scientific practices in designing or revising science curricula. The BRH-based activities in this study should be incorporated in science textbooks.

The study can be conducted at another elementary schools and the sample size can be larger so that the results can be generalized to a larger population. Qualitative or mixed method data analysis can be used to reach information-rich data in other studies.

The effectiveness of the SPBI can be examined with students at different grade levels and at a different time of the school year, to prevent students' losing motivation and attention. In addition, the effectiveness of the SPBI can be examined in terms of students' achievement and understanding of other science concepts.

Further studies can also be conducted to investigate the affective domain, to include attitude, motivation, and anxiety factors. Students' attitudes and perceptions should give an idea of the best way to design science instruction and activities so that they enhance students' understanding of scientific practices (Ford, 2008). To investigate the self-efficacy of applying the SPBI, further research can be conducted with pre-service science teachers.

APPENDIX A

LESSON PLAN WEEK 1- (EXPERIMENTAL GROUP)

| | |
|---|---|
| Grade Level | 7th Grade |
| Name of the Unit | Unit 6: Electrical Energy |
| Topic | Series and Parallel Connections of Bulbs |
| Duration | 80 Minutes |

Materials

- bulbs (1.5V)
- wires
- batteries (1.5V)

Objectives

At the end of the lesson, students will be able to

- know the source of the electric energy that supplies energy to the electric circuits and that the electric current is a type of energy transfer.
- construct a simple electric circuit.
- explain scientific practices.
- express the relationship between scientific practices.

Teaching method(s)

Scientific practice-based instruction

- The topic is introduced by a questioning technique.

- The teacher uses direct instruction to give information about the electrical energy which is supplied by the battery.
- Activity 1 is conducted with the guidance of the teacher.
- Scientific practices are shown during Activity 1.

Connections with other subjects

In the science and technology curriculum, this exercise connects to the 5th grade unit about simple electrical circuits. Furthermore, this exercise is the basis for the electric circuit concepts that will be introduced in the following years of school.

Activities (description of procedures)

Starting (connect prior knowledge and introduce the topic)

The teacher begins the lesson with a question to understand the students' background knowledge about simple electric circuits.

Teacher: What can you say about simple electric circuits? What are the circuit elements?

The students will most probably answer these questions using their ideas which they learned in 5th grade. After some students answer, the teacher will summarize the electric elements by drawing on the board.

Teacher: A simple electric circuit is composed of a battery, a bulb, wires, and a switch. What is the source of energy in the circuit?

The students will probably answer this question by saying battery. The teacher asks how it supplies energy to the battery.

Teacher: In a simple electric circuit, the battery applies force on the negative (-) charges. The negative (-) charges are forced to move from the negative (-) pole of the battery to the positive (+) pole. Therefore, the battery supplies energy to the charges in the circuit, and the negative (-) electrical charges transfer their energy from the positive (+) pole of the battery to the negative (-) pole. In this way, the electric current is formed. The direction of the current is from the negative (-) pole of the battery to the positive (+) pole as a result of the direction of the negative (-) charges' movement. As the number of batteries increases, the electric current will increase and so will the brightness of the bulb.

Middle (procedures and strategies)

Teacher: In this lesson, you will learn about the sources of electric energy that supplies energy to electric circuits and that electric current is a type of energy transfer.

She divides the class into four groups. Then, she distributes materials to each group and a worksheet to each student.

Students are told that they are in a camp and they have forgotten to take their lamp to light inside the camping tent. They have only batteries with them, a bulb and the wire of their bicycle (real world). They are asked how they can make light inside their camping tent. The teacher divides the class into six groups composed of five students and gives them batteries, bulbs and wire, as if they had removed the wire and bulb from their bicycle. The teacher directs the activity based on the Benzene Ring Heuristic and she shows this heuristic on the smartboard. After each component of the heuristic, she tells the students to do these activities. The teacher guides the

process by giving them materials and asking them to try to construct the circuit, first with one battery and then with two batteries. The teacher asks them to report what happens to the bulb. Students predict what will happen in a range of simple electric circuits as changes are made to the number of batteries (prediction). Students construct two electric circuits, one with one bulb, wire and one battery and one with one bulb, wire and two batteries in sequence (activities: experimenting and observation) and they write down the brightness of the bulb in both circuits (data). They draw both electric circuit constructions (model).

During the activity every group will be given a worksheet to fill according to their findings.

End (summarize, review, and set the stage for the next lesson)

Finally, they explain how the battery affects the electric circuits and the light bulb (explanation). Every group explains their findings with justifications, they present their circuits and discuss their findings with their classmates (argumentation as discourse).

Then, the teacher summarizes the lesson.

Teacher: As we have learned, the battery supplies energy to the electric circuit, and as the number of batteries increases, the brightness of the bulb also increases.

Evaluation

The teacher takes worksheet 1 (see Appendix I) from the students in order to assess their learning.

APPENDIX B

LESSON PLAN WEEK 1- (CONTROL GROUP)

| | |
|---|---|
| Grade Level | 7th Grade |
| Name of the Unit | Unit 6: Electrical Energy |
| Topic | Energy in Simple Electrical Circuit |
| Duration | 80 Minutes |

Materials

- bulbs (1.5V)
- wires
- batteries (1.5V)

Objectives

At the end of the lesson, students will be able to

- know the sources of electric energy that supplies energy to the electric circuits and that the electric current is a type of energy transfer.
- construct a simple electric circuit.

Teaching method(s)

Traditionally designed science instruction

- The topic is introduced by questioning technique.

- The teacher uses direct instruction to give information about the electrical energy which is supplied by the battery.

Connections with other subjects

In the science and technology curriculum, this exercise connects to the unit which includes simple electrical circuits in 5th grade. Furthermore, this exercise is the basis of the electric circuit concepts that will be introduced in the following years of school.

Activities (description of procedures)

Starting (connect prior knowledge and introduce the topic)

The teacher begins the lesson with a question to understand students' background knowledge about simple electric circuits.

Teacher: What can you say about simple electric circuits? What are the circuit elements?

The students will most probably answer these questions from what they learned in 5th grade. After some students answer, the teacher will summarize the electric elements by drawing on the board.

Teacher: A simple electric circuit is composed of battery, bulb, wires, and switch. What is the source of energy in the circuit?

The students will probably answer this question by saying "battery". The teacher asks how it supplies energy to the cicuit.

Teacher: In a simple electric circuit, the battery applies force on negative (-) charges. The negative (-) charges are forced to move from the negative (-) pole of the battery to the positive (+) pole. Therefore, the battery supplies energy to the charges in the circuit. Negative (-) electrical charges transfer their energy from the positive (+) pole of the battery to the negative (-) pole. In this way, the electric current is formed. The

direction of the current is from the negative (-) pole of the battery to the positive (+) pole as a result of the direction of the negative (-) charge's movement. As the number of batteries increases, the electric current will increase and so will the brightness of the bulb.

Middle (procedures and strategies)

Teacher: In this lesson, you will learn the sources of electric energy that supply energy to the electric circuits and that electric current is a type of energy transfer. She divides the class into four groups. Then, she distributes materials to each group and worksheets to each student. Students construct electric circuits with one battery, one bulb and wire, and then with two batteries, one bulb and wires. They observe the brightness of the bulbs in the two circuits.

End (summarize, review, and set stage for next lesson)

Finally, the students explain how the battery affects the electric circuits and the light bulb. Every group discusses their findings with their classmates.

Then, the teacher summarizes the lesson.

Teacher: As we have learned, the battery supplies energy to the electric circuit and, as the number of batteries increases, the brightness of the bulb also increases.

Evaluation

The teacher evaluates the students' learning according to their classroom discussions.

APPENDIX C

LESSON PLAN WEEK 2 (EXPERIMENTAL GROUP)

| | |
|---|---|
| Grade Level | 7th Grade |
| Name of the Unit | Unit 6: Electrical Energy |
| Topic | Series and Parallel Connections of Bulbs |
| Duration | 4 Lecture Hours |

Materials

- bulbs (3 x 1.5V)
- wires
- battery (1.5V)
- 3 lamp sockets

Objectives

At the end of the lesson, students will be able to

- discover series and parallel electric circuits.
- draw an electric circuit schema composed of series and parallel connected bulbs.
- predict the brightness of bulbs in simple series and parallel circuits.
- explain scientific practices.
- express the relationship between scientific practices.

Teaching method(s)

Scientific practice-based instruction

- The topic is introduced by eliciting what students already know.
- The teacher uses direct instruction to give information about the series and parallel connections in electric circuits.
- Activity 2 is conducted by the guidelines of teacher.
- Scientific Practices are shown during Activity 2.

Connections with other subjects

In the science and technology curriculum, this exercise connects to the unit in the 5$^{th}$ grade that includes simple electrical circuits. This exercises is the basis for the electric circuit concepts that will be introduced in the following years of school.

Activities (description of procedures)

Starting (connect with prior knowledge and introduce the topic)

The teacher begins the lesson by showing students a video (NCStatePhysics, 2010). In the video, parallel connected bulbs are shown. As the number of bulbs increases or decreases, their brightness does not change. Students are asked why the bulbs of a luminaire are not affected if one of the bulbs goes out, as the bulbs in the video (real world). The teacher asks the students to predict the reason for this (prediction). By doing so the students handle the prediction component of BRH.

Teacher: Why were the bulbs of a luminaire not affected when one of the bulbs went off, as was the case with the bulbs in the video?

After some students' answer, the teacher will say that the luminaires are connected in parallel.

Teacher: The components of an electrical circuit can be connected in different ways: as a series and parallel.

In a series connection, all components are connected end-to-end, forming a single path for electrons to flow. The negative (-) side of one component is connected to the positive (+) side of the other component. The same current passes from the series of connected components. Thus, series-connected identical bulbs all light the same, and if one bulb goes out, the other bulbs do not give light. If we add extra bulbs in the series, the brightness of the first bulb decreases.

In a parallel connection, components are connected between the same set of electrically common points. The negative (-) side of one component is connected to the negative (-) side of the other component. Parallel-connected identical bulbs give the same amount of light, and if one of the bulbs goes out, the other bulbs continue to give light. Unlike the series connection, if we add extra bulbs to the series, the brightness of the first bulb does not change.

The teacher draws some examples of electric circuits, connected as series and parallel.

Middle (your procedures and strategies)

Teacher: In this lesson, you will construct electric circuits in parallel and in a series. She divides the class into four groups. Then she distributes materials to each group and a worksheet to each student.

Then the teacher gives the materials (battery, wire, bulbs) to construct the series and parallel circuits, and a worksheet to complete according to their findings. The

students first construct a series circuit with one battery, one bulb and wire. Then they add a second and third bulb to the circuit and take notes about the change of the brightness of the bulbs (data). Then they construct a parallel circuit by adding a second and third bulb to the circuit in parallel (activities: experimenting, observation). They construct the circuits in line with the direction of the teacher.

On the worksheet, the students are asked to draw their circuits (model) and write the cause of the different levels of brightness of the bulbs a in series and bulbs in parallel circuits (explanation).

End (summarize, review, and set the stage for the next lesson)

Every group explains their findings with justifications; they present their circuits drawings and discuss their findings with their classmates (argumentation as discourse).

Then, the teacher summarizes the lesson.

Teacher: As we have learned, there are two types of connections in electric circuits: series and parallel. The same current passes through the bulbs in a series connection, and if one bulb goes out, the other bulb does not gives light. However, in parallel circuits, the bulbs are not affected even if one bulb goes out.

Evaluation

The teacher collects worksheet 2 (see Appendix J) from the students in order to assess their learning.

APPENDIX D

LESSON PLAN WEEK 2 (CONTROL GROUP**)**

| | |
|---|---|
| Grade Level | 7th Grade |
| Name of the Unit | Unit 6: Electrical Energy |
| Topic | Series and Parallel Connections of Bulbs |
| Duration | 4 Lecture Hours |

Materials

- bulbs (3 x 1.5V)
- wires
- battery (1.5V)
- 3 lamp sockets

Objectives

At the end of the lesson, students will be able to

- recognize series and parallel electric circuits.
- draw an electric circuit schema composed of series and parallel connected bulbs.
- predict the brightness of bulbs in a simple series and parallel circuits.

Teaching method(s)

Traditionally designed science instruction

- The topic is introduced by eliciting what students already know.
- The teacher use direct instruction to give information about the series and parallel connections in electric circuits based on the activities in the science textbook.

Connections with other subjects

In the science and technology curriculum, this exercise connects to the unit in $5^{th}$ grade which includes simple electrical circuits. Furthermore, this exercises is the base for the electric circuit concepts that will be introduced in the following years of school.

Activities (description of procedures)

Starting (connect prior knowledge and introduce the topic)

Teacher starts lesson by the question in the textbook.

Teacher: Think that you have one more bulbs. How can you ensure that the bulbs give the brightest light possible? Are there any different ways to connect bulbs in an electric circuit?

After waiting for students' answers, the teacher explains the connections in an electric circuit.

Teacher: The components of an electrical circuit can be connected in different ways, such as series and parallel.

In series connection, all components are connected end-to-end, forming a single path for electrons to flow. The negative (-) side of one component is connected to the positive (+) side of the other component. The same current passes from the series-connected components. Thus, the series-connected identical bulbs lights as same as each other and if one bulb goes out, the other bulbs do not give light. If we add extra bulbs in a series, the brightness of the first bulb decreases.

In a parallel connection, the components are connected between the same set of electrically common points. The negative (-) side of one component is connected to the negative (-) side of the other component. Parallel-connected identical bulbs give the same light, and if one of the bulbs goes out, the other bulbs continue to give light. Unlike a series connection, if we add extra bulbs in a series, the brightness of the first bulb does not change.

The teacher draws some examples of electric circuits connected as series and parallel.

Middle (procedures and strategies)

Teacher: In this lesson, you will construct electric circuits in parallel and in a series. She divides the class into four groups. Then, she distributes materials to each group. Then the teacher distributes the materials (battery, wire, bulbs) for students to construct series and parallel circuits, and a worksheet to fill according to their findings. The students first construct the series circuit with one battery, one bulb and wire. Then they add a second and third bulb to the circuit and take notes about the change of the brightness of the bulbs. Then they construct a parallel circuit by adding a second and third bulb to circuit as parallel. They construct the circuits with the direction of the teacher.

End (summarize, review, and set the stage for the next lesson)

Each group explains their findings and discusses their findings with their classmates. Then, the teacher summarizes the lesson.

Teacher: As we have learned, there are two types of connections in electric circuits: series and parallel connections. The same current passes through the bulbs in a series connection, and if one bulb goes out, the other bulb does not gives light. However, the bulbs are not affected even if one bulb goes out in parallel circuits.

Evaluation

The teacher evaluates the students' learning according to their classroom discussions.

# APPENDIX E

## ACTIVITY 1

Title of the activity: Lighting the camping tent

Aim of the activity:

The aim of the activity is to engage students in a practical activity involving the construction of simple electric circuits with a different number of batteries, to ensure that students understand what scientific practices are, and to teach the relationship between scientific practices.

Learning objectives:

By the end of this activity, the students will be able to:

- know the sources of electric energy that supply energy to electric circuits and that electric current is a type of energy transfer (MEB, 2013).
- explain scientific practices.
- express the relationship between scientific practices.

1) Scientific content

In a simple electric circuit, a battery applies force on negative (-) charges. Negative (-) charges are forced to move from the negative (-) pole of the battery to the positive (+) pole. In this way, the battery supplies energy to the charges in the circuit and the negative (-) electrical charges transfer their energy from the positive (+) pole of the battery to the negative (-) pole. In this way, electric current is formed. The direction of the current is from the negative (-) pole of the battery to the positive (+) pole as a

result of the direction of the negative (-) charge's movement. As the number of batteries increases, the electric current will increase and so will the brightness of the bulb.

2) Activity

Students are told that they are in a camp and that they have forgotten to take their lamp to light the inside of the camping tent. They have batteries with them, a bulb and the wire of their bicycles (real world). They are asked how they can make light inside their camping tent. The teacher divides the class into six groups composed of five students each and gives them batteries, bulbs and wire, as if they had removed the wire and the bulb from their bicycles. The teacher directs the activity based on BRH (see Fig. 5) and she opens this heuristic in the smartboard. After each component of the heuristic, she tells the students to perform these activities. The teacher guides the process by giving them materials and asking them to try to construct the circuit, first with one battery and then with two batteries. The teacher asks them what will happen to the bulb. The students predict what will happen in a range of simple electric circuits as changes are made to the number of batteries (prediction). Students construct two electric circuits, first with one bulb, wire and one battery and then with one bulb, wire and two batteries (activities: experimenting and observation) and they write down the brightness of the bulb in both circuits (data). They draw their electric circuit constructions (model). Finally, they explain how the battery affects the electric circuits and the light bulb (explanation). Every group explains their findings with justifications, and they present their drawn circuits and discuss their findings with their classmates (argumentation as discourse).

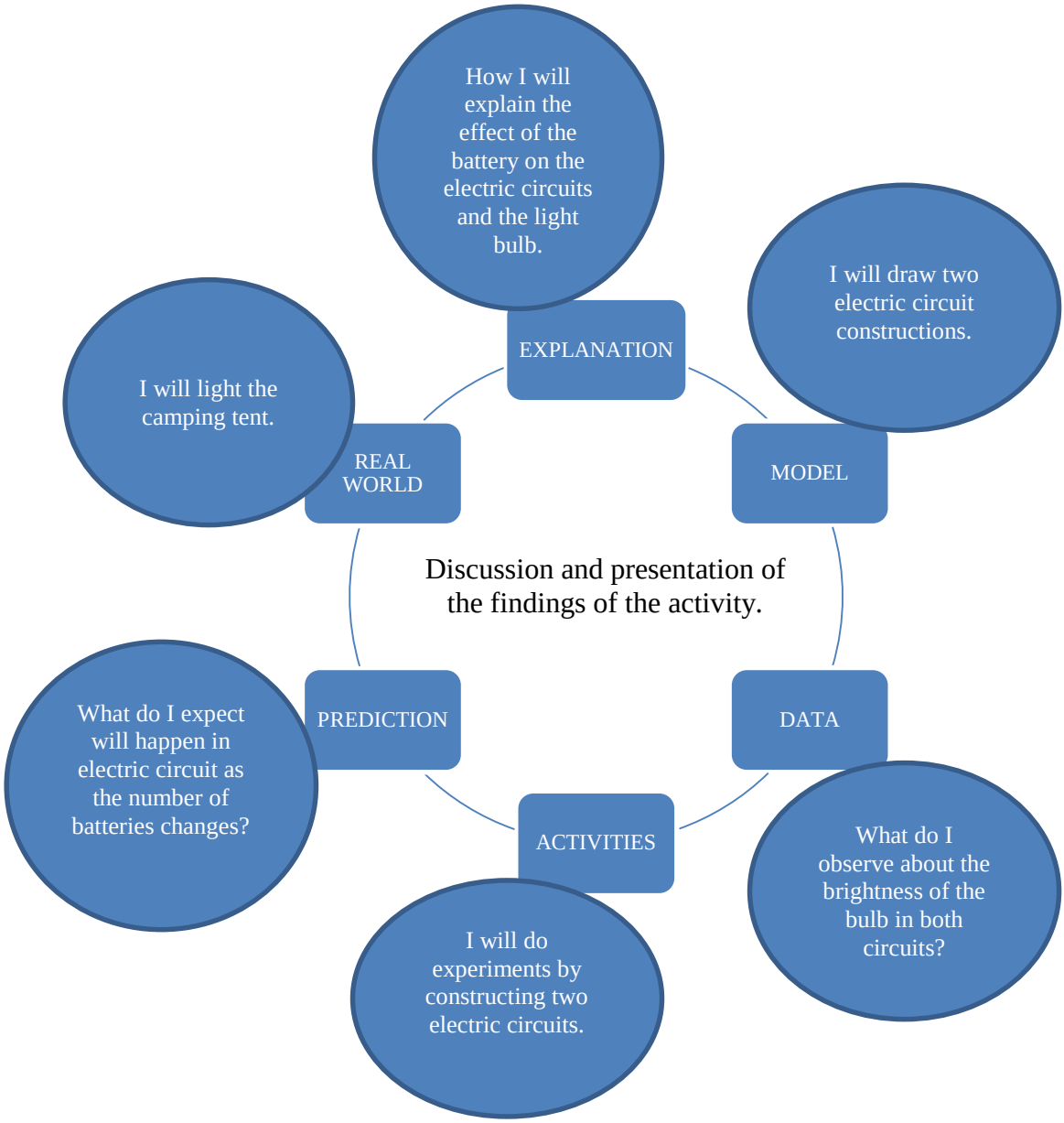



Fig. 5 BRH in activity 1: Lighting the camping tent

APPENDIX F

ACTIVITY 2

Title of the activity: Bulbs always lighting in a luminaire

Aim of the activity:

The aim of the activity is to engage students in a practical activity involving the construction of series and parallel electric circuits and scientific practices such as collecting data, experimenting, and explanation.

Learning objectives:

By the end of this activity, the students will be able to:

- discover series and parallel electric circuits.
- draw an electric circuit schema composed of series and parallel connected bulbs.
- predict the brightness of bulbs in simple series and parallel circuits.
- explain scientific practices.
- express the relationship between scientific practices.

1) Scientific content

In a simple electric circuit, the bulbs are connected in a series where the same current passes through the bulbs ($I=I_1=I_2=I_3$). The total voltage is the sum of the voltage of each resistance ($V= V_1+V_2+V_3$). The total resistance increases as the bulbs are connected in a series in an electric circuit ($R_{total}= R_1+R_2+R_3$). As the total resistance increases, the current will decrease, as will the brightness of the bulbs. However, in

parallel circuits, the current is divided between the arms of the circuit ($I_{total}= I_1+I_2+I_3$) and the voltage is the same between all bulbs ($V=V_1=V_2=V_3$). As the resistance changes with the increase or decrease in the number of bulbs, the total current changes. However, as the number of bulbs increases or decreases, the brightness of the bulbs does not change because the voltage is the same between parallel bulbs.

2) Activity

In this activity, teacher directs the activity based on BRH (see Fig.6). At the beginning, students watch a video (NCStatePhysics, 2010). In the video, parallel connected bulbs are shown and as the number of bulbs increases or decreases, their brightness does not change. Students are asked why the bulbs of a luminaire are not affected if one of the bulbs goes out, as in the video (real world). Teacher asks them to predict the reason of this question (prediction). Then she gives them materials (battery, wire, bulbs) to construct series and parallel circuits, and a worksheet to complete, according to their findings. The students first construct a series circuit with one battery, one bulb and wire. Then they add a second and third bulb to the circuit and take notes about the change of the brightness of the bulbs (data). Then they construct a parallel circuit by adding a second and third bulb to the circuit as parallel (activities: experimenting, observation). They construct the circuits with the direction of the teacher. In the worksheet, the students are asked to draw their circuits (model), write the cause of the difference in the brightness of the bulbs in the series and parallel circuits (explanation). Moreover, at the end of the activity, each group shares their findings with their classmates (representation, discourse).

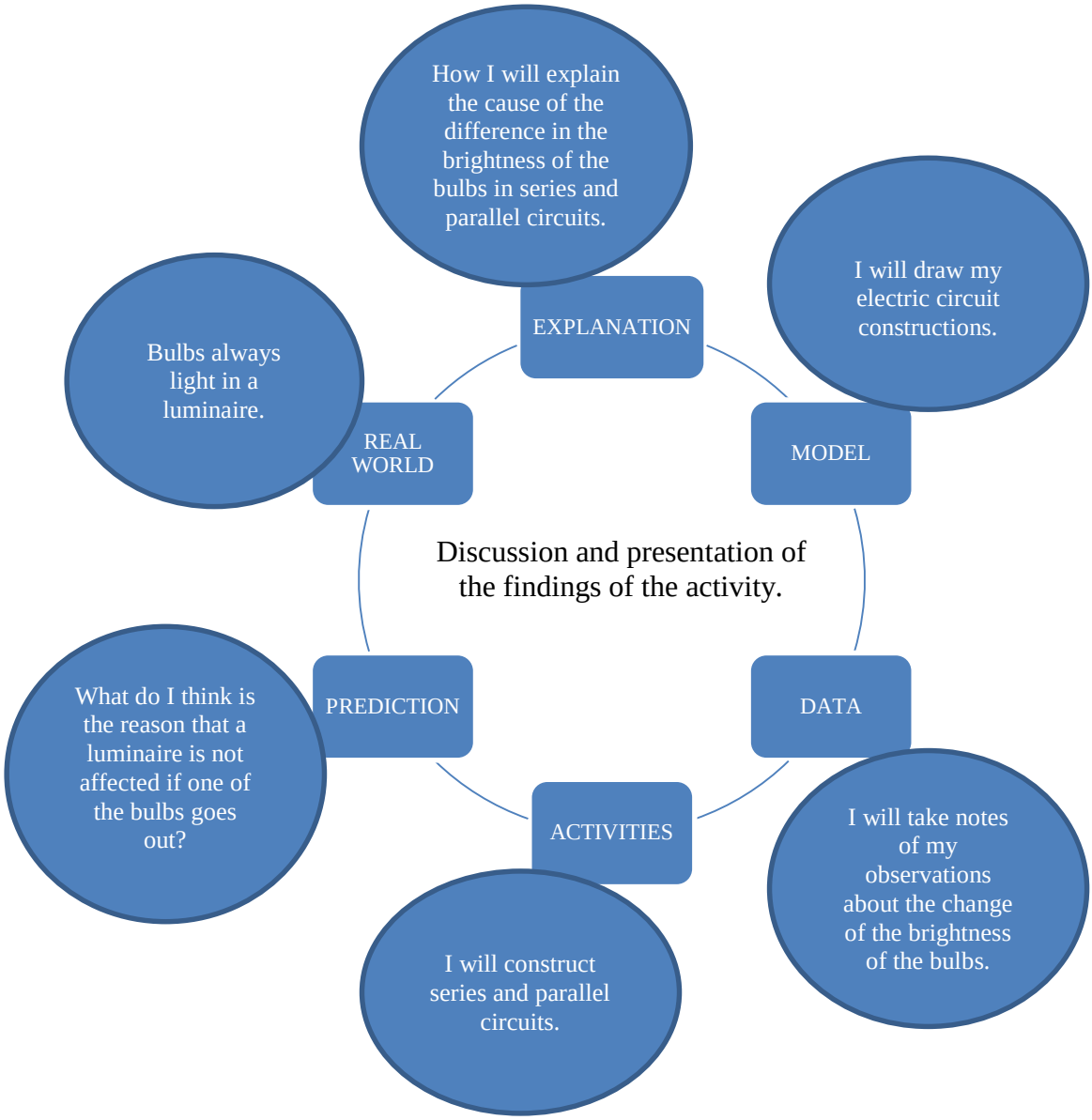



Fig. 6 BRH in activity 2: Bulbs always lighting in a luminaire

APPENDIX G

ACTIVITY 3

Title of the activity: Travel of energy in wire

Aim of the activity:

The aim of the activity is to engage students in a practical activity involving measuring current using an ammeter and voltage of battery using a voltmeter, exploring the relationship between current and voltage, and understanding scientific practices and gaining perceptions of scientific practices.

Learning objectives:

By the end of this activity, the students will be able to:

- name the read the value on the ammeter as strength of current by connecting the ammeter in a series in an electric circuit and state the unit of current.
- measure the voltage between the end points of a circuit and state the unit of voltage.
- discover the relationship between the voltage and the current of the end points of one circuit element by experimenting.
- relate the cause of brightness difference of bulbs between series and parallel circuits to electrical resistance.
- explain scientific practices.
- express the relationship between scientific practices.

1) Scientific content

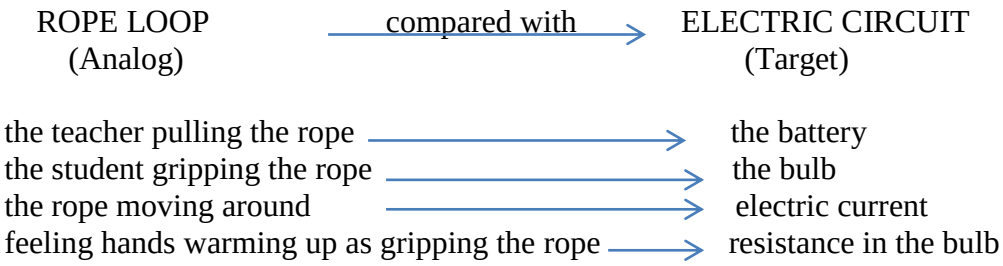
In a simple electric circuit, a battery supplies energy to the circuit. This energy is referred to as current and it is measured by an ammeter by connecting the ammeter in a series in an electric circuit. The unit of the current is ampere and the symbol for ampere is A. An ammeter measures the number of charges flowing past each point per second. The energy of the charges differs as a result of electric current and this energy causes voltage. Voltage is measured by a voltmeter by connecting it in a parallel in a circuit. Its unit is volt and the symbol for volt is V. The voltage value is a measure of the amount of energy transferred for each unit of charge that passes. There is a direct relationship between the voltage and current, and the rate of voltage to the current is stable, and this rate shows resistance of the conductor.

2) Activity

An activity named as rope loop analogy (the National Strategies, 2008) can be used to teach a scientific model for the electric circuit.

At the beginning, the teacher brings a rope and ties it. Then teacher pulls it through with one hand and passes it out with the other. A student grips tightly the rope with his/her fingers. As the teacher moves the rope faster, the student feels his/her hands' warming up. Here, the teacher asks students the reason for this warming up. Then, teacher gives an analogy between rope loop movement and electric circuit.

The rope loop is analog and electric circuit is the target of this analogy.




The teacher explains the similarity between her pulling the rope and the battery in the circuit as the source of energy. When a student grips the rope, it can be considered like a bulb in a circuit. The electric current (flow of negative (-) charges) may be likened to the rope moving around. Then, the teacher asks students how the student's hands warming up can be explained in the electric circuit. After the students answer, the teacher explains the cause of the warming up as the result of the force of friction against the movement of the rope. Similarly, in an electric circuit, the bulb provides a resistance to the flow of the electric current. Therefore, the student's hand in the rope loop and the bulb in the electric circuit show resistance to transferred energy. However, the analogy breaks down where the movement of the rope loop and charges differ. We can measure the movement of the rope loop by calculating the distance of movement of the rope loop for a second. Then, the teacher asks how the movement of charges can be measured. Here, the teacher waits for the students to give answers that the number of charges can be measured by an ammeter and the amount of energy transferred for each unit of charge that passes can be measured by a voltmeter (the National Strategies, 2008).

Then, the classroom is divided into five groups and each group is given

- a variable DC power supply or batteries
- bulbs

- 10V voltmeters
- wires
- ammeters

Each group is given worksheet 3. While doing the activity, the teacher opens the BRH (see Fig. 7) on the smartboard. After each component of the scientific practices, the teacher explains in detail the conducted practices. The students try to construct circuits using the given materials (real world) and measure the voltage and current value (activities). The teacher asks students to predict the measurements they will get with the ammeter and the voltmeter (prediction). They write down their measurement values on the worksheet (data). They explain what happens as the battery number increases in a circuit and the relationship between current and voltage (explanation). They draw the graph of the current and the voltage based on their measurements (model).

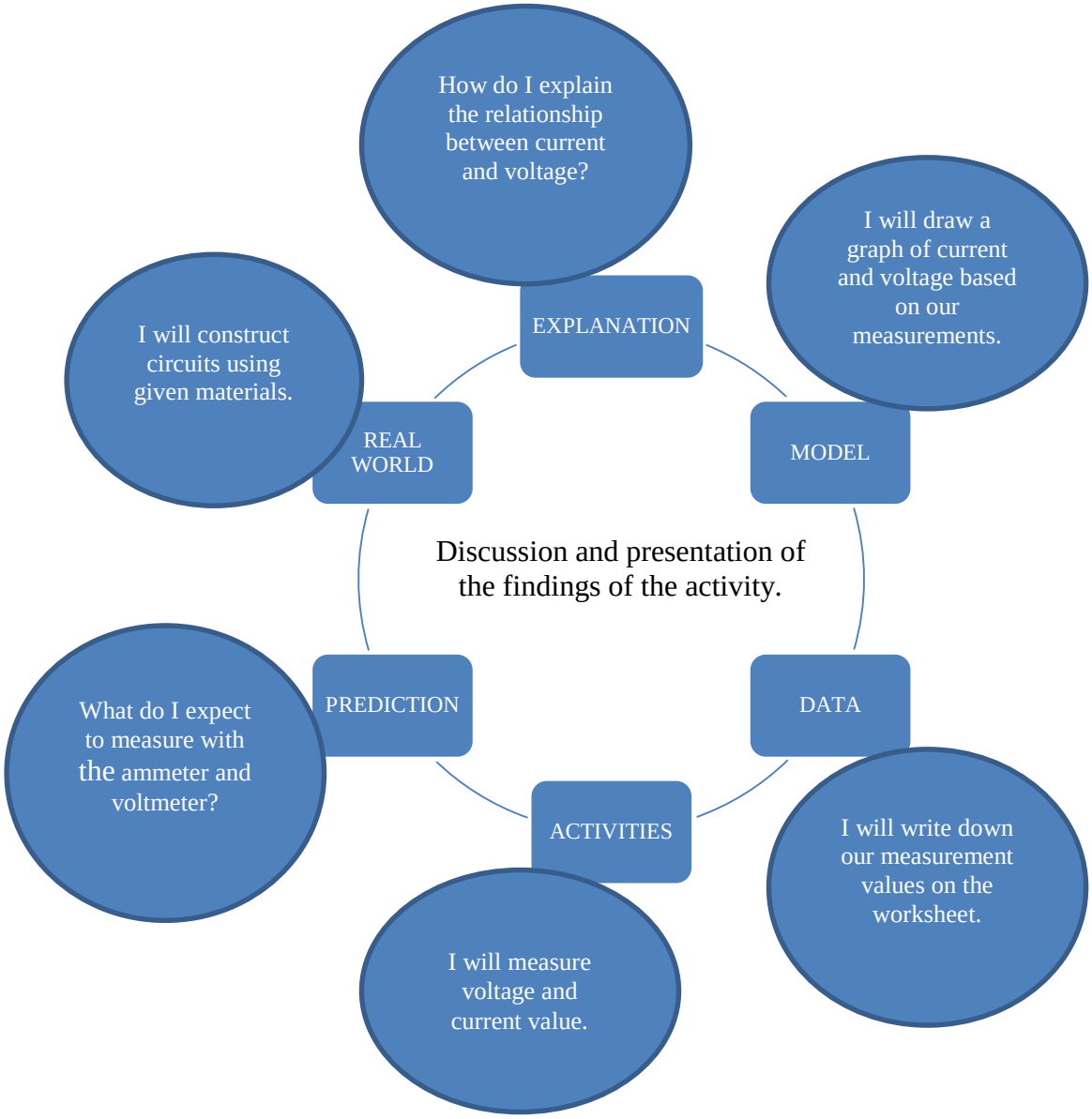



Fig. 7 BRH in activity 3: Travel of energy in wire

APPENDIX H

ACTIVITY 4

Title of the activity: Blowing a fuse

Aim of the activity:

The aim of the activity is to engage students in a practical activity involving understanding of short circuit electricity and what scientific practices are, and to teach the relationship between scientific practices.

Learning objectives:

By the end of this activity, the students will be able to:

- know the sources of electric energy that supplies energy to the electric circuits and that electric current is a type of energy transfer.
- explain that the flow of current is on the wire with low resistance instead of the wire with high resistance.
- explain scientific practices.
- express the relationship between scientific practices.

1) Scientific content

In a simple electric circuit, if two sides of a wire are connected to a bulb, then the current passes from the wire instead of the bulb. Thus, the bulb gives no light. If there is a short circuit in an electric circuit, then the total resistance decreases but current increases in the circuit. A short circuit in electrical gadgets may be dangerous

because the increased current overheats the wire and it may result in a fire. For this reason, the fuse box in a house blows when there is short circuit.

2) Activity

Students are told that the fuse box in houses sometimes blows (real world). They are asked what they think about this issue and what the reason is (prediction). The teacher divides classroom into six groups composed of five students each and gives them batteries, bulbs and wire. The teacher directs the activity based on BRH (see Fig. 8) and she opens this heuristic on the smartboard. After each component of the heuristic, she tells the students do these activities. The teacher guides the process by giving them materials and asking them to try to construct the circuit, first with one battery and two bulbs. Then they are asked to construct a second circuit using one battery and two bulbs, and an extra wire is added to the two sides of one of the bulbs. The teacher asks what happens to the bulbs. The students predict what will happen in a range of simple electric circuits (prediction). Students construct two electric circuits, one with two bulbs, wire and one battery and one with two bulbs, an extra wire connected to one of the bulbs and one battery in a sequence (activities: experimenting and observation) and they write down the brightness of the bulb in both circuits (data). They draw both electric circuit constructions (model). Finally, they explain how added wire affects the electric circuits and the light bulb (explanation). Every group explains their findings with justifications, they present their drawn circuits, and discuss their findings with their classmates (argumentation as discourse).

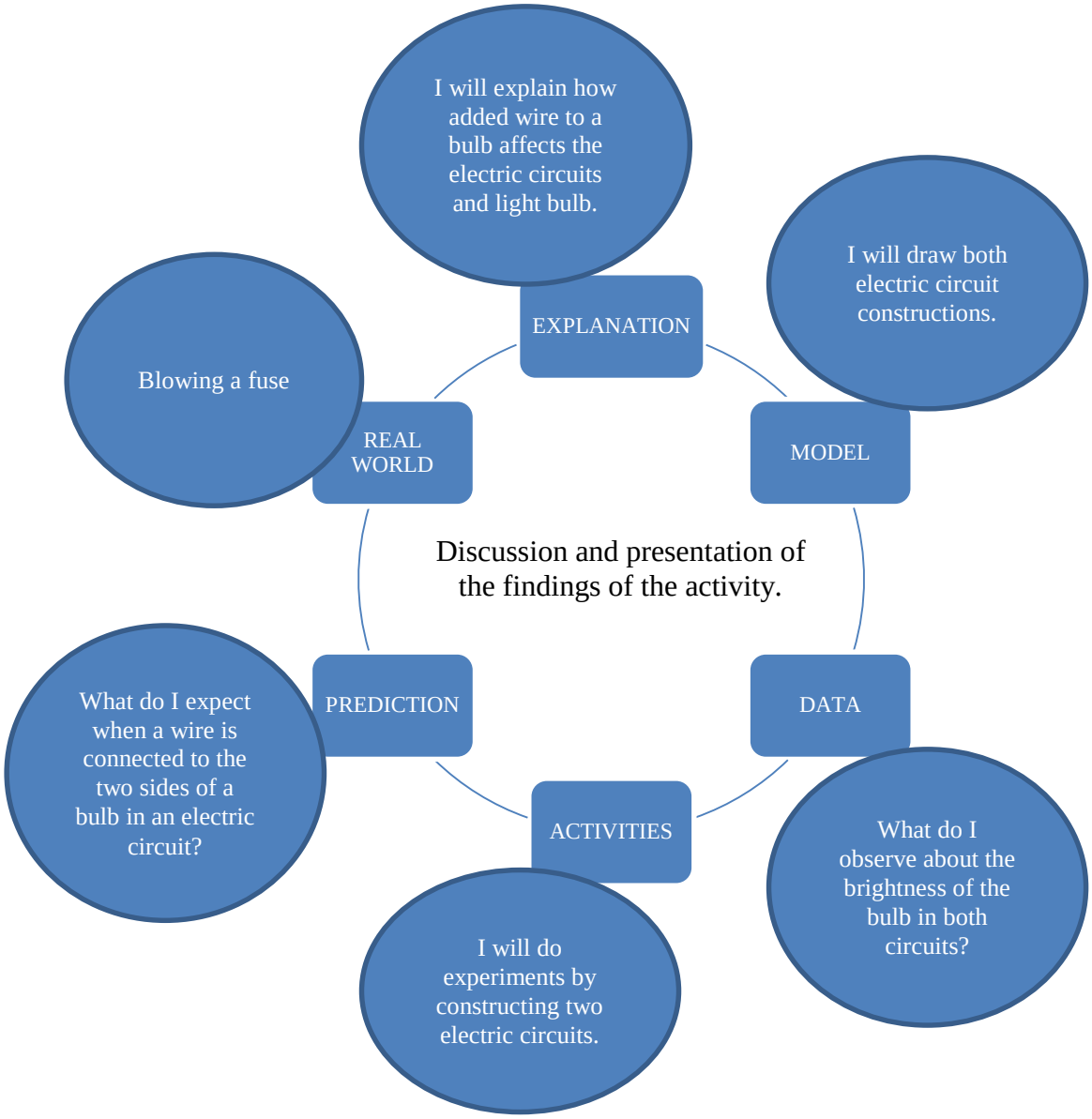



Fig. 8 BRH in activity 4: Blowing a fuse

APPENDIX I

WORKSHEET 1

LIGHTING THE CAMPING TENT

Imagine that you are at a camping area with your friends. You pitch your camping tent; however, you forget to take your lamp to light inside the camping tent. You have only batteries, a bulb and the wire from your bicycle's lamp. How can you make light inside your tent?

Based on the problem given above, answer the questions below.

1) What will happen in a simple electric circuit as the number of batteries decreases or increases?

2) Draw your electric circuits with

a) one bulb, wire and one battery and

b) one bulb, wire and two batteries.

Circuit a

Circuit b

What happens to the bulb when the second battery is added to circuit a? How can you explain this difference?

APPENDIX J

WORKSHEET 2

BULBS ALWAYS LIGHTING IN A LUMINAIRE

You will watch a video where parallel-connected bulbs are shown. As the number of bulbs increases or decreases, their brightness does not change.

Based on the video, answer the questions below.

1) Predict why a luminaire is not affected if one of the bulbs goes out?

2) Construct the circuits according to the directions below:

   a) circuit with one battery, one bulb and wire.

   b) add a second and third bulb as a series to the circuit in a (above)

   c) add second and third bulb as parallel to the circuit in a (above)

3) Draw the circuits that you constructed in question 2:

Circuit a  Circuit b  Circuit c

4) In a parallel circuit, how does the brightness of the two bulbs differ when the second battery is added to the circuit? Why?

5) In a series circuit, how does the brightness of two bulbs differ when a second battery is added to the circuit? Why?

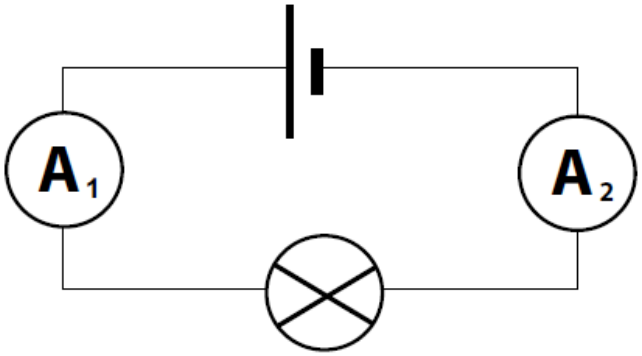
APPENDIX K

WORKSHEET 3

TRAVEL OF ENERGY IN WIRE

1) Answer the questions below based on the rope loop analogy.

a) Construct the circuit as shown below and write your answers. (Use just one ammeter.)




(Explaining How Electric Circuits Work, the National Strategies, 2008, p.37)

Measure current 1 =……..ampere

PREDICT current 2 =……..ampere

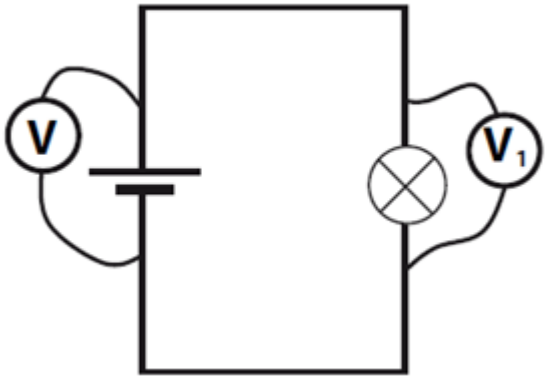
Measure current 2 =……ampere

b) Circle the true word and write your answer.

I know the current is the same / different all around the circuit above because:……

……

2) Construct the circuits as shown below and write your answers.

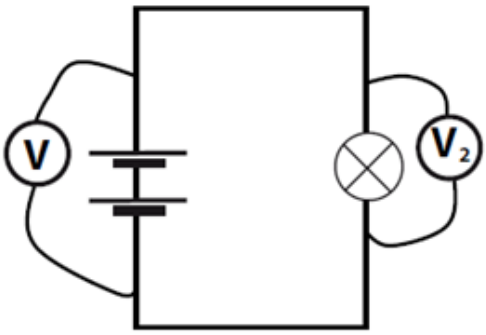



(Voltage Energy Power in Electric Circuits, the National Strategies, 2008, p.44)

Measure voltage (V) across battery =……volt

Predict voltage ($V_1$) across bulb =……volt

Measure voltage ($V_1$) =…….volt



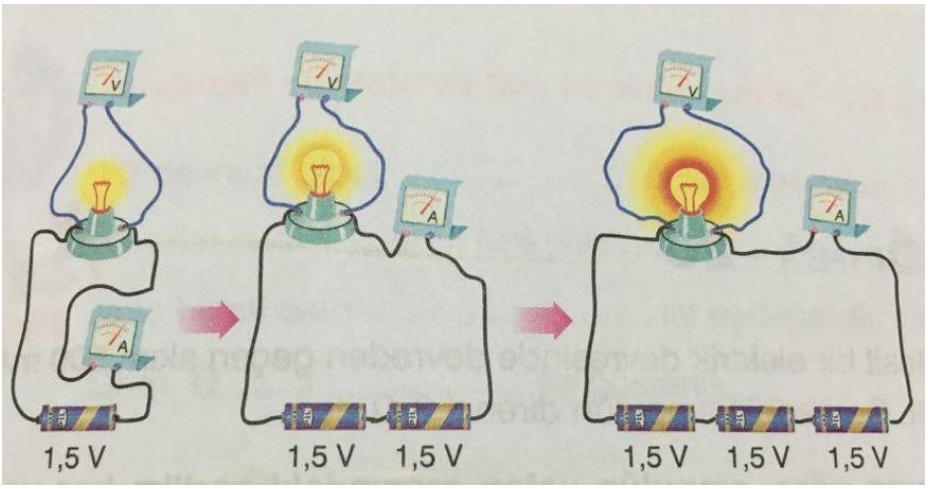

(Voltage Energy Power in Electric Circuits, the National Strategies, 2008, p.44)

Measure voltage (V) across battery =……volt

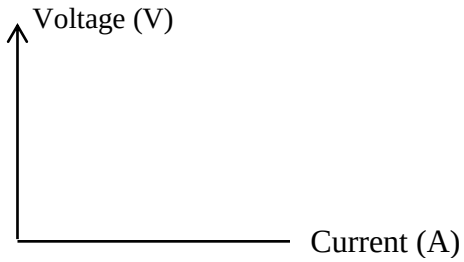
Predict voltage ($V_2$) across bulb =……volt

Measure voltage ($V_2$) =…….volt

3) Construct the circuits below and fill in the table. Based on your findings, draw the voltage-current graph.




| Voltage (V) | Current (A) | Voltage/ Current (V/A) |
|---|---|---|
| | | |
| | | |
| | | |




4) How can you explain the relationship between voltage and current? How does current change as voltage increases or decreases? Why?

APPENDIX L

WORKSHEET 4

BLOWING A FUSE

Sometimes you see that a fuse blows in a house or the wires may burn. Have you ever thought about the cause of this situation?

Based on the problem given above, answer the questions below.

1) What do you think is the cause of the blowing of the fuse?

2) Draw your electric circuits with

a) two bulbs, wire and one battery in series;

b) two bulbs, wire, one battery and one extra wire connected to the two sides of one of the bulbs.

Circuit a Circuit b

3) What happens to the bulb when an extra wire is connected to one of the bulbs in circuit a? How can you explain this difference?

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