AN INVESTIGATION OF UNDERGRADUATE STUDENTS' SCIENTIFIC INQUIRY PROCESSES IN A PHYSICS LABORATORY

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ABSTRACT

AN INVESTIGATION OF UNDERGRADUATE STUDENTS' SCIENTIFIC INQUIRY PROCESSES IN A PHYSICS LABORATORY

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The aim of this study is to investigate undergraduate students' scientific inquiry processes in a physics laboratory designed using problem-based learning. Case study, one of the qualitative research methods, was employed for this aim. Sixteen undergraduate students were participated in this study. Participants conducted inquiry activities for five weeks. The data sources were the observations of participants while they were doing inquiry activities and the laboratory work sheets filled by the participants.

A framework suggested by Klahr and Dunbar (1988) in Scientific Discovery as Dual Search model was used to gain better understanding of scientific inquiry process. In this framework, inquiry process consist of three phases; hypothesis formation, designing and conducting experiments, and evidence evaluation. The variations on the participants' scientific inquiry processes were analyzed and categorized for each phase of inquiry.

Participants' hypothesis formation processes were categorized based on the nature of sources used by the participants and how these sources were used. The emerging categories were labeled as "concept-based hypothesis formation", "equation-based hypothesis formation", and "context-based hypothesis formation". Participants' designing and conducting experiment processes were categorized into two types: "Systematic manipulations" and "unsystematic manipulations". "Haphazard manipulation of variables" and "using two manipulated variable simultaneously" were the two different types of observed unsystematic manipulations. Lastly, participants' evidence evaluation processes were categorized based on the driving sources: "Data-driven evidence evaluation" and "prior knowledge-driven evidence evaluation". Detailed descriptions of these categories were presented with examples.

Keywords: Physics Education, Scientific Inquiry Skills, Undergraduate Students

ÖZ

FİZİK LABORATUVARINDA ÜNİVERSİTE ÖĞRENCİLERİNİN BİLİMSEL ARAŞTIRMA SÜREÇLERİNİN İNCELENMESİ

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Bu çalışmanın amacı probleme dayalı öğrenmeye göre tasarlanmış fizik laboratuvarında üniversite öğrencilerinin bilimsel araştırma süreçlerinin incelenmesidir. Bu amaç için nitel araştırma yöntemlerinden biri olan durum çalışması kullanılmıştır. Bu çalışmaya on altı üniversite öğrencisi katılmıştır. Katılımcılar beş haftalık süre içerisinde araştırma etkinliklerinde yer almışlardır. Katılımcılar araştırma etkinliklerini yaparken gerçekleştirilen gözlemler ve katılımcıların doldurduğu laboratuvar çalışma kâğıtları veri kaynağı olarak kullanılmıştır.

Bilimsel araştırma sürecini daha iyi anlayabilmek için Klahr ve Dunbar'ın (1988) "Çifte Arayış Olarak Bilimsel Keşif" modelinde önerilen çerçeve kullanılmıştır. Bu çerçevede, araştırma süreci üç aşamadan oluşmaktadır; hipotez kurma, deney düzeneği tasarlama ve deneyi gerçekleştirme, ve bulgu değerlendirme. Katılımcıların bilimsel araştırma süreçlerindeki çeşitlilikler her bir aşama için analiz edilmiş ve sınıflandırılmıştır.

Katılımcıların hipotez kurma süreçleri, kullandıkları kaynakların doğasına ve bu kaynakların nasıl kullanıldığına göre sınıflandırılmıştır. Ortaya çıkan kategoriler "kavrama dayalı hipotez kurma", "formüle dayalı hipotez kurma" ve "duruma dayalı hipotez kurma" olarak isimlendirilmişlerdir. Katılımcıların deney düzeneği tasarlama ve deneyi gerçekleştirme süreçleri iki türe ayrılmıştır: "Sistemli eyletimler ve "sistemli olmayan eyletimler". "Değişkenlerin düzensiz eyletimi" ve "aynı anda iki eyletilen değişken kullanma" gözlemlenen iki farklı sistemli olmayan eyletim çeşididir. Son olarak, katılımcıların kanıt değerlendirme süreçleri, süreci yönlendiren kaynaklara göre sınıflandırılmıştır: "Verilerin yönlendirdiği kanıt değerlendirme" ve "ön bilgilerin yönlendirdiği kanıt değerlendirme". Bu sınıflandırmaların detaylı açıklamaları örnekleriyle sunulmuştur.

Anahtar Kelimeler: Fizik Eğitimi, Bilimsel Araştırma Becerileri, Fizik Öğretmenliği Adayları

To my family

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LIST OF ABBREVIATIONS

CpB: Concept-Based Hypothesis Formation

CxB: Context-Based Hypothesis Formation

DDEE: Data-driven evidence evaluation

EqB: Equation-Based Hypothesis Formation

G: Group

NRC: National Research Council

NSES: National Science Education Standards

PKDEE: Prior knowledge-driven evidence evaluation

SM: Systematic Manipulation

SSME: Secondary Science and Mathematics Education

SUV: Sport Utility Vehicle

Not Obs.: Not Observable

HMV: Haphazard Manipulation of Variables

UTMVS: Using Two Manipulated Variables Simultaneously

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Students' interest to science has decreased throughout the world in the last two-decades. For example, number of students who take science courses in high schools and enter graduate schools to become scientists has decreased in United States (National Science Foundation, 1996). The situation is not different in Turkey. The percentage of enrollment to science division of high schools has decreased in recent years. Departments of Physics, Chemistry, and Biology in different universities in Turkey have been closed one by one due to lack of students. To stimulate students' interest to science learning, policy makers around the world have been taking several precautions. Changing instructional methods of science teaching seems to be a promising approach to increase students' interest as well as achievement in science.

One of the instructional methods used as an alternate to traditional instruction is inquiry. In the National Science Education Standards (National Research Council (NRC) 2000) of United States, inquiry is defined as "the activities of students in which they develop knowledge and understanding of scientific ideas as well as an understanding of how scientists study the natural world" (p. 23). Inquiry encompasses ways of knowledge come to exist, investigations to reach an understanding, and justifications grounded to evidence. Inquiry also has social and discursive characteristics. Inquiry is mostly based on constructivism. The constructivist perspective of learning science emphasizes the importance of individuals' interpretations in the process of the construction of knowledge. "Constructivism implies that students require opportunities to experience what they are to learn in a direct way and time to think and make sense of what they are learning" (Tobin, 1990, p. 405). Students need to be able to arrive at an understanding of why they do, what they do, and to construct feasible explanations for their experiences, instead of completing a set of prescribed steps presented by another individual.

The interest to inquiry has been increased among the curricula of different countries in the last two decades. For example, the main theme of National Science Education Standards of United States is inquiry. It highly encourages teachers to use scientific inquiry in their instruction to advance students' understanding of scientific concepts and procedures (NRC, 2000). Similar encouragements have also been made in countries such as United Kingdom (Department for Education, n.d.) and Australia (Goodrum & Rennie, 2007) along with international organizations like European Commission (2007). Parallel to these efforts, National Physics Curriculum of Turkey (Talim ve Terbiye Kurulu Başkanlığı, 2007) recommended physics teachers to use instructional methods that make students physically and mentally active in classrooms. Some characteristics of new physics curriculum are prominently associated with inquiry. This association is explicit in the arguments that knowledge must be acquired by the students, students' interests must be attracted, emphasis on hands-on and minds-on activities, effective use of school laboratory, and teaching students to think.

Teachers are one of the primary components of the educational systems. Reforms in education cannot be accomplished without having them gain the necessary knowledge and skills. Therefore, teachers need to get prepared for applications of inquiry-based instructions in classrooms. How can we provide opportunities to pre-service teachers for inquiry-based instruction? McDermott, Shaffer and Constantinou (2000) made a strong assertion on this issue; "in physics, neither course … provides the kind of preparation required for teaching physics or physical science by inquiry. Science methods courses cannot help teachers develop the depth of understanding needed for this type of teaching" (p. 411). They suggested that physics should be learned as inquiry in laboratories for gaining necessary understanding and skills of inquiry.

Laboratory activities have long had a distinctive and central role in the science education for promoting inquiry skills. Lunetta (1998) defines laboratory activities as “experiences in school settings in which students interact with materials to observe and understand the natural world” (p. 249). Science educators have suggested that many benefits can be attained from engaging students in science laboratory activities. Laboratory experiences have been supposed to promote central science education goals including: understanding of scientific concepts, the development of scientific practical skills and problem-solving abilities, and interest and motivation (Roth, 1994).

Scholarly efforts have identified serious inconsistencies between goals for science education and learning outcomes visible in school laboratories. “Several researchers have reported that students regularly performed school science experiments with very different purposes in mind than those perceived by their teachers” (Lunetta, 1998, p. 250). Laboratories often are used to verify knowledge given in lectures by asking students to follow a recipe, instead of engaging students in problem finding and problem solving (Brown, Abell, Demir, & Schmidt, 2006). As a result of this, students are apt to perceive the purpose of laboratory tasks as either following the pre-defined steps or getting the right answer. In the laboratory, students can accomplish manipulating equipment and measuring the pre-defined variables, but they can still fail to reach a conceptual understanding (Hofstein & Lunetta, 1982). Students often fail to understand the relationship between the purpose of the investigation and the design of the experiment which they had conducted. They do not connect the experiment with their prior knowledge, and they seldom note the discrepancies between their own conceptions and the conceptions of their peers (Eylon & Linn, 1988). Another problem responsible for the deficiencies of laboratory experiences is epistemological in nature. Tobin (1990) asserted that current science teaching is embedded on an inappropriate epistemology. Laboratories are usually perceived as exercises with a primary focus on the confirmation of established laws and principles, or on the discovery of objectively knowable facts. In traditional laboratories, students gather data without comprehending the meaning of their actions. The cognitive demand of laboratory tasks is reduced to a minimal level.

In science, processes of acquiring scientific knowledge are as important as scientific knowledge. Scientific inquiry is the primary method of acquiring and accumulating scientific knowledge. Scientific inquiry stem from how scientists' work and help students understand how scientists think, work, and investigate their own questions. There are many terms used in the literature to name the processes of conducting scientific inquiry such as scientific reasoning, inquiry skills, and science process skills. Regardless of the terms used for it, there is a consensus about the major processes of scientific inquiry (Etheredge & Rudnidsky, 2003). For example, Martin (2000) classified the processes of scientific inquiry into "basic" and "integrated" process skills. Basic inquiry/process skills include observing, classifying, communicating, measuring, predicting, and inferring. On the other hand, integrated inquiry process skills include identifying and controlling variables, formulating and testing hypotheses, interpreting data, defining operationally, experimenting, and constructing models.

However, presenting inquiry processes in a fragmented structure may cause some problems. This fragmented structure creates an unrealistic model of authentic practice (Hammer, 1995). Inquiry skills are intertwined and it is hard to separate them. For example, it is hard to make distinction between identifying and controlling variables and experimenting, since these two processes are highly merged on each other in the conduction of a scientific inquiry. To avoid the fragmented structure and deal with the inquiry processes in a holistic manner, Klahr and Dunbar's (1988) scientific inquiry model was used in this study.

Klahr and Dunbar (1988) proposed Scientific Discovery as Dual Search (SDDS) model to provide a general framework for the processes of scientific discovery. They described the framework in terms of three phases, each of which refers to some particular processes used during a scientific inquiry. These phases are categorized as Searching Hypothesis Space, Test Hypothesis, and Evidence Evaluation. Searching Hypothesis Space includes the process of generating a new hypothesis with the accumulated knowledge of a domain. Test Hypothesis includes designing and conducting experiments that would yield interpretable outcomes. Evidence Evaluation process assesses the fit between theory and evidence and guides further research.

Research on the processes of scientific inquiry is mostly on the developmental level which particularly focuses on the development of inquiry skills from early ages onwards (Zimmerman, 2000, 2007). These studies revealed that primary school students can accomplish investigations with the help of guidance. Inquiry skills are developed gradually when students find chance to investigate scientific problem in the classroom. The inquiry skills can reach to a high level when investigations performed in meaningful context (Roth & Roychoudhury, 1993).

In recent years, the studies that investigate university students' inquiry skills have been increased in different academic domains (Apedeo, 2007; Lawson et al., 2000; Park Rogers, 2009). These studies were in fragmented structure and deal with some parts of the inquiry processes. For example, Park Rogers (2009) conducted an investigation to understand how elementary pre-service teachers connecting evidence to explanation. The numbers of studies which investigate the whole inquiry process, from hypothesis formation to reaching a conclusion, are limited.

1.2 Purpose of the Study

The main purpose of this study is to investigate undergraduate students' inquiry processes in a physics laboratory designed using problem-based learning. While investigating this, the inquiry processes are handled within three subcategories parallel to SDDS model of Klahr and Dunbar (1988): Hypothesis Formation, Designing and Conducting Experiments, and Evidence Evaluation.

The following research questions have been investigated to guide the analysis of phenomena:

1. How do undergraduate physics education and physics students form hypothesis in an inquiry task?
2. How do undergraduate physics education and physics students design and conduct experiments in an inquiry task?
3. How do undergraduate physics education and physics students evaluate evidence in an inquiry task?

1.3 Significance of the Study

Contemporary teaching and learning approaches like inquiry issues that practices in schools for teaching science should be changed. Consequently, teachers are being forced to teach science in ways differ from how they learned it (Putnam & Borko, 1997). To accomplish this notion it is required that prospective teachers need to have specific experiences about scientific inquiry as learners. Using inquiry activities in pre-service science teachers programs can serve two main purposes. First, elucidating future teachers about both science processes and products through firsthand experience with inquiry lead them to improve their understanding of science content as well as scientific processes. Second, future teachers who have experience about inquiry can help future scientists develop the interests, skills, and understanding necessary to conduct scientific research. In this study, undergraduate physics education and physics students engaged in authentic inquiry activities as physics learners. Because future physics teachers will be chosen among these students, it would not be unreasonable to identify participants as prospective physics teachers.

The teachers play the key role in a successful inquiry instruction. Students cannot conduct inquiry activities without proper guidance (Kirschner, Sweller, & Clark, 2006). Teachers must design classroom environment that support the development of inquiry skills. If teachers do not know the merits of inquiry and value the products of it, it is not reasonable for us to expect that they would create kinds of opportunities and experiences needed to develop students' inquiry skills. Avraamidou and Zembal-Saul (2005) asserted that before we expect prospective teachers to teach science as inquiry, they must first be given the opportunities to develop inquiry skills. In this study, prospective physics teachers' inquiry processes are observed to investigate their abilities and understanding of scientific inquiry. Their deficiencies and inconsistencies as well as successful applications of inquiry are identified. Understanding prospective physics teachers' inquiry skills is important because it can affect directly their use of inquiry-based teaching methods in classroom.

Shulman and his colleagues (as cited in Abell, 2007) defined pedagogical content knowledge as teachers' knowledge needed to teach a particular topic.

Pedagogical content knowledge consists of three kind of knowledge; subject matter knowledge, pedagogical knowledge, and knowledge of context. Subject matter knowledge divided into two parts, substantive and syntactic. "The substantive structure of a discipline is the organization of concepts, facts, principles, and theories, whereas syntactic structures are the rules of evidence and proof used to generate and justify knowledge claims in the discipline" (p. 1107). There is a direct relationship between this syntactic knowledge and scientific inquiry. We need to identify the syntactic knowledge and integrate it to the teacher education programs. From this aspect, this study would be useful for teacher education programs about which characteristics of scientific inquiry should be emphasized.

Science educators increasingly perceive the school science laboratory as a unique learning environment in which students can work cooperatively in small groups to investigate scientific phenomena and relationships (Hofstein & Lunetta, 1982, 2004). The laboratory offers unique opportunities for students and their teacher to engage in collaborative inquiry and to function as a classroom community of scientists (Gunstone & Champagne, 1990). Such experiences offer students opportunities to consider how to solve problems and develop their understanding of content knowledge as well as scientific inquiry. Better understanding of students' inquiry skills is important since all activities in the laboratory directly related to these skills. Therefore, the results of this study will provide instructors and researchers with some insights regarding what are the main components of prospective physics teachers' inquiry skills in physics laboratory and what are the variations among them. Although educators concern about the quality of instruction, there are little knowledge on the working force of laboratory instruction (Hofstein & Lunetta, 1982, 2004). The available information on the use of laboratory does not reflect on processes in an inquiry laboratory settings. Most of the research were conducted with the product orientation and usually had not described the details of inquiry processes performed by students (Eylon & Linn, 1988). Therefore, this study is an attempt to fill the gap in the literature through an exploratory and in-depth examination of inquiry practice.

CHAPTER 2

LITERATURE REVIEW

This chapter is presented in five sections. Constructivism which is constituted the theoretical background of the inquiry instruction is presented in the first section. Several definitions of inquiry are presented in the second section. Third section discusses how an inquiry instruction should be in science education. Several applications of inquiry instruction are provided in the fourth section. Lastly, literature about inquiry skills is presented in the fifth section.

2.1 Constructivism

Constructivism is defined as "the view that emphasizes the active role of the learner in building understanding and making sense of information" by Woolfolk (2001, p. 329). Ebenezer and Connor (1998) defined constructivism as constructing personal knowledge from experience. They also argued that a constructivist himself responsible for constructing knowledge, which means that the learners themselves responsible for their own learning. Constructivism is based on the research of Piaget, Vygotsky, the Gestalt psychologists, Bartlett, and Bruner as well as the educational philosophy of John Dewey (Woolfolk, 2001). For example, Piaget (1964) described the term of "*operation*" to describe the development of knowledge.

> To know an object is to act on it. To know is to modify, to transform the object, and to understand the process of this transformation, and as a consequence to understand the way the object is constructed. An operation is thus the essence of knowledge; it is an interiorized action which modifies the object of knowledge…In other words, it is a set of actions modifying the object, and enabling the knower to get at the structure of the transformation. (Piaget, 1964, p. 176-177)

Doolittle (1999) stated that there are four main epistemological tenets of constructivism according to work of von Glasersfeld (1984) and recent writings. These tenets are:

1. Knowledge is not passively accumulated, but rather, is the result of active cognizing by the individual;
2. Cognition is an adaptive process that functions to make an individual's behavior more viable given a particular environment;
3. Cognition organizes and makes sense of one's experience, and is not a process to render an accurate representation of reality; and
4. Knowing has roots in both biological/neurological construction, and social, cultural, and language based interactions. (Doolittle, 1999, p. 1)

The characteristics and differences of types of constructivism are rooted from how they stress these tenets or admit these tenets. The common point in all types of constructivism is that they emphasize the first two tenets. In other words, knowing is an active process and experience is most important source of this process, are the main corner stones for constructivism.

2.1.1 Weak Constructivism

Weak constructivism only emphasizes the first two tenets of constructivism. Knowledge acquisition is an active, not passively received, adaptive, and recursive process. "The data it (brain) processes is self-constructed, all the way down to the basic level of electrochemical nerve impulses" (Ernest, 1996, p. 339). Therefore, the new understanding is a product of previously constructed knowledge. The experience is shaped in learners mind according to his prior knowledge. Piaget (1964) describes these processes with the terms of *assimilation* and *accommodation*. Assimilation is "the integration of any sort of reality into a structure" (p. 185) and accommodation is changing the cognitive structure to make sense of the environment. Knowledge is either assimilated into cognitive structure or the structures are changed to accommodate new and different information. Knowledge is extended through assimilation and new knowledge develops through accommodation (Ebenezer & Connor, 1998).

The ontology or world model of weak constructivism is scientific realism/Newtonian absolute space (Ernest, 1996). That mean, there is an ultimate reality and we can experience and get that reality. Main difference, on the epistemological level, of weak constructivism from both radical and social constructivism is on the third tenet of constructivism. While weak constructivism keeps the view of the existence of an ultimate reality and it is knowable by the individuals, the other types of constructivism reject it (Ernest). According to weak constructivism, there is absolute, objective knowledge and the things that we construct are part of that reality. Hence, learning is the product of the accurate internalization and construction of reality. "…from the cognitive (weak) constructivism position,…learning is the process of building accurate internal models or representations that mirror or reflect external structures that exist in the real world" (Doolittle, 1999, p. 2).

2.1.2 Radical Constructivism

Radical constructivism is mostly based on epistemological work of Ernst von Glasersfeld (Ernest, 1996). Radical constructivism emphasizes the first three tenets of constructivism. That is, knowledge is the result of a constructive activity and cognition organizes and makes sense of one's experience, not the reality. Von Glasersfeld (1993) stated that;

> What we perceive, feel, and think is essentially the result our ways and means of carrying out these activities. The results can never be said to be alike, let alone "congruent" with an ontological reality; all we may conclude is that this "real world" allow us to perceive and think certain things. If a prediction turns out to be right, a constructivist can only say that the knowledge from which the prediction was derived proved viable under the particular circumstance of the case. (p. 26)

The ontology or world model of radical constructivism is neutral, it does not deny the outside world or reality, but it emphasizes the belief that "the only world we can know is the world of our experience" (von Glasersfeld, 1993, p. 24). The epistemology is whole-heartedly fallibilist, skeptical and anti-objectivist (Ernest, 1996). Von Glasersfeld replaced the word "truth" with "viability" in constructivism. "If we want to talk in terms of "truth" and mean by this that what we say and what we think should be a replica of the world as it is, we have to believe that we can visualize or imagine what that "real" world is like" (von Glasersfeld, 1993, p. 25).

Society or social interactions is seen as a conceptual construct by von Glerserfeld. He acknowledged that social interaction has a powerful effect on the construction of knowledge. However, he refuses to devise a model for the entire elementary constructs. He claims that "society" must be analyzed as a conceptual construct before its role in the further construction of concepts can be explained and properly assessed. However, Doolittle (1999) mentioned that more radical constructivist researcher began to recognize social interactions as a source of knowledge. Whatever the radical constructivists think about social interaction, all of them accept that individual worlds become adapted to one another.

2.1.3 Social Constructivism

Social constructivism emphasizes all the tenets of constructivism. It upholds the social nature of knowledge, and the belief that knowledge is the result of social interaction and language usage. "Social constructivism regards individual subjects and the realm of the social as indissolubly interconnected" (Ernest, 1996, p. 343). In addition, this social interaction always occurs within a socio-cultural context, resulting in knowledge that is bound to a specific time and place (Doolittle, 1999). In the social constructivism, mind is seen as a part of broader context, the social construction of meaning. Persons in conversation, comprising persons in meaningful linguistic and interaction, and dialogue are underpinning elements of social construction (Ernest, 1996).

The ontology of social constructivism is "there is world out there supporting the appearance we have shared access to, but we have no certain knowledge of it. It is based on a fallibilist epistemology that regards "conventional knowledge" as that which we "lived" and socially accepted" (Ernest, 1996, p.343). Constructed knowledge is always exposed to modification and interaction by community to reach the ontological reality, but we can never see that reality.

Doolittle (1999) argues that social constructivism generally sees the mental construction of knowledge less important than the social construction and highlights the construction of meaning within a social activity. This is rooted from that mental construction is seen as relatively trivial by social constructivists.

Consequently, he claimed that social construction is more concerned with meaning than structure.

2.2 Definition of Inquiry

As the arguments provided in the previous sections reveals, constructivism is not a teaching theory; it is a theory about how an individual learns. It defines individuals learning as embedded in active engagement with the environment and constantly constructing and reconstructing knowledge through interaction (Llewellyn, 2005). According to Brooks and Brooks (1999), the tenets of constructivist classrooms closely aligned with the practice of inquiry. For example, according to Brooks and Brooks, in constructivist classrooms, pursuit of student questions is highly valued and curricular activities rely heavily on data and manipulative materials as primary sources during the instruction. These are also the core tenets of practice of inquiry. Anderson (2007) asserted that “what is called inquiry learning in the literature is very similar to what others call constructivist learning” (p. 809). The practices of inquiry also reveal that classroom practices reflect not only one aspect of constructivism. Dominant use of group works in inquiry activities reveals that the arguments of social constructivism as well as radical constructivism shape the practices of inquiry in classroom settings.

Although there is an agreement that the epistemological root of inquiry is constructivism, there is not a shared definition of inquiry in the literature. The word inquiry is used ubiquitously in the literature, but it means different things to different researchers. For example, some researchers use inquiry as a style of teaching, the others use it as a method for conducting research (Flick, 1995). In this study, inquiry is seen as the fully integration of these two ideas and admitted as a style of teaching rooted from the scientists’ researches. Because there is a great variability in definitions of inquiry commonly used by academics and teachers, it is necessary to present different definitions of the term which shaped and represented the perspective of this study.

Wheeler (2000) defined science and scientific inquiry as the following:

> Science is the process of talking to the material world. Scientists understand their world by figuring out how to pose questions to the phenomena at hand. In the same

> way, we want our students to understand their world by learning how to ask the right questions – to the phenomena, not the teacher. (p. 16)

He also emphasized on three characteristics of scientific inquiry; it engages students, students' interaction with the material world, and the content dimensions of it which includes both scientific content and ways and nature of inquiring scientific content.

Hofstein and Lunetta (2004) described inquiry based on the work of scientist.

> Inquiry refers to diverse ways in which scientist study the natural world, propose ideas, and explain and justify assertions based upon evidence derived from scientific work. It also refers to more authentic ways in which learners can investigate the natural world, propose ideas, and explain and justify assertions based up evidence and, in the process, sense the spirit of science. (p. 30)

Since National Science Education Standards (NSES) of United States was published by National Research Council (NRC) in 1996, the discussions about inquiry mostly have shaped by this document (Anderson, 2007). However, NSES did not contain a clear definition of inquiry and usage of it in different educational contexts. Possibly to resolve this deficiency, NRC released an additional publication in 2000 titled Inquiry and National Education Standards: A Guide for Teaching and Learning. This book provided a clear rationale for the use of inquiry in instructional settings and the activities shed light to the teachers on how to use them during their instructions. Nevertheless, there are still differences in interpretations of NSES and inquiry among the researcher.

According to Anderson (2007) there were three different usages of inquiry in the NSES. These are scientific inquiry, inquiry learning¸ and inquiry teaching. These three usages of inquiry are different from each other, although they also have many connections. The usage of scientific inquiry refers to the work of scientists, nature of scientific investigations, and science process skills. NSES defines inquiry learning as an active process of learning which is parallel to the constructivist view of learning. Lastly, there are various forms of inquiry teaching such as partial inquiry and full inquiry. However, NSES did not make careful differentiation among these various forms of teaching.

Lederman and Niess (2000) asserted that the NSES presents inquiry as having three different perspectives; as a teaching approach, as process skills, and as content. Inquiry as a teaching approach means that it consists of instructional methods to enable students understand the subject matter specified in the content standards. From the perspective of process skills, the emphasis is on students' ability to successfully perform investigations. The third perspective of inquiry is knowledge about inquiry which is also discussed in the literature in terms of nature of science. According to writers, the third perspective of NSES is what distinguishes this reform effort from the previous ones.

2.3 Science Teaching as Inquiry

Asay and Orgill (2010) made an operational definition of inquiry, based on the National Standards of United States as the following; "Inquiry put emphasis on learners working under the guidance of experienced teachers to construct understanding of scientific concepts through interactions with scientific questions and data" (p. 58).

The science teaching as inquiry consists of developing the "abilities necessary to do scientific inquiry and understanding the nature of scientific inquiry" (NRC, 1996, p.105). There is a strong relationship among the inquiry process, constructing scientific knowledge, and the nature of scientific inquiry. Scientific inquiry enables learners understand science concepts and the nature of science as well as creates appreciation of how and what we know in science.

Colburn (2000) defined the inquiry-based instruction as "the creation of a classroom where students are engaged in essentially open-ended, student-centered, hands-on activities." (p. 42). In an inquiry-based science class, students encounter with the similar methods and activities that scientists use during the scientific process. For example, creating and asking questions, researching materials and information, making observations, and designing experiments can be done by students, not by teachers in an inquiry class. In order to gain those kinds of abilities, it is obvious that students must be engaged in inquiry practices in an authentic setting. The following points are listed as the essential features of classroom inquiry in the "Inquiry and the National Science Education Standards":

1. Learners are engaged by scientifically oriented questions.
2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3. Learners formulate explanations from evidence to address scientifically oriented questions.
4. Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
5. Learners communicate and justify their proposed explanations. (NRC, 2000, p. 25)

As stated in the NSES, inquiry does not mean to practice one instructional method in the classroom. In order to give students the opportunity to construct a meaningful understanding of subjects, a variety of methods should be used in the classroom environment. Inquiry based instruction defines under three different forms.

Open inquiry: In this method, student's question leads the lesson. Experiments or activities are designed, conducted, and resulted by students (Martin-Hansen, 2002). Colburn (2000) gives science fairs as an example for this type of inquiry. This type of inquiry requires higher thinking skills.

Guided inquiry: In this inquiry method, teacher raises the question and the other parts are developed as in the open inquiry (Colburn, 2000). This approach enables teacher to stick his/her plan during the instruction.

Structured inquiry: Structured inquiry starts with a question raised by teacher. The materials and procedures to be followed for the inquiry are also given to the students. Colburn (2000) and Martin-Hansen (2002) describe this inquiry type as cookbook lesson.

2.4 Inquiry in Science Education

As mentioned before, there are some disagreements on the meaning of inquiry and how to use it in the classroom. The debate continues on the topic that whether it is a teaching approach or it is a teaching method. Some researchers use it as if it is a teaching method and name their instructional method as inquiry. Others admit that it is a teaching approach and use other names for their instructional method which are compatible with tenets of inquiry. For example, Inquiry Synthesis Project (2006), it is argued that inquiry learning, discovery learning, teaching by problem solving, inductive methods, and hands-on exploration are the common terms used to describe inquiry in the literature. They categorized all of these terms under the large umbrella of inquiry in their research synthesis about inquiry. Learning cycle, problem-based learning and project-based learning can also be added to these terms.

McDermott, Shaffer, Rosenquist, and Physics Education Group at University of Washington published two books named Physics by Inquiry Volume 1-2 in 1996. These laboratory-based physics activities were designed to use in physics teachers education program. The aim of the Physics by Inquiry was increasing physics teachers' qualitative understanding of physics topics included in K-12 curriculum. They employ a step-by-step process of constructing a qualitative model by guided inquiry. Students are guided through carefully sequenced activities and questions to make observations that they can use as the basis for their model. As the observations getting more complex, students needed to extend their model with new concepts. During the instruction, specific problems are explicitly addressed and development of coherent conceptual model is emphasized. At the end, students asked to synthesize what they have learned. McDermott, Shaffer, and Constantinou (2000) reported that Physics by Inquiry is effective not only on students' deep understanding of conceptual knowledge but also on the retention of acquired knowledge.

Thacker, Kim, Trefz and Lea (1994) conducted an investigation to compare problem solving performance of physics students in inquiry-based and traditional introductory physics courses at the university level. The comparison was based on two different examination problems about electricity. One problem was qualitative which was typically used in inquiry-based class, and the other problem was quantitative which can be found in a standard introductory physics textbook. The students in inquiry-based physics course was compared to students in three different traditional physics courses; the standard calculus-based physics course for engineering students, another introductory physics course for non-science majors, and an introductory physics course for honors students. The students in the inquiry-based course physics course were all elementary education major (non-science major). The results showed that students in inquiry-based physics course performed significantly better than the engineering and non-science major students as well as the honor students on the qualitative problem. Moreover, they performed better than the engineering and non-science major students on the quantitative problem. The researchers asserted that inquiry-based method of teaching may be superior to traditional methods for non-science majors.

Minner, Levy, and Century (2010) conducted a meta-analysis, Inquiry Synthesis Project, to understand the impact of the inquiry science instruction on K-12 students' science learning. They analyzed 138 research studies, qualitative and quantitative, by using a mixed methodology approach. Their primary focus was students' conceptual science learning. Their results which included analysis of 138 research studies indicated that there was a positive trend favoring inquiry based instruction, particularly in which students' active thinking and drawing conclusions from data were emphasized. They also stressed that "instruction within the investigation cycle (i. e., generating questions, designing experiments, collecting data, drawing conclusions, and communicating findings)… has been associated with improved student content learning , especially learning scientific concepts" (p. 493). Moreover, hands-on experience was in some extent significant predictor of increased conceptual learning.

Newman et al. (2004) reported the results of four years of experience during the study of inquiry in teacher education programs. They presented the dilemmas faced by instructors and students during the elementary science method course. Identified dilemmas were varying definitions of inquiry, the struggle to provide sufficient inquiry-based science learning experiences, perceived time constraints, determining how much course time should be scheduled for science instruction versus pedagogy instruction, instructors' and students' lack of inquiry-based learning experiences, grade versus trust issues, and students' science phobia. Researchers were believed that it would be impossible to provide prospective teachers with multiple embracing experiences with inquiry-based learning. This may cause implications for professional development of teachers, and suggests that longer-term contributions might be needed.

Lotter, Harwood and Bonner (2006) reported the results of the summer component of a year-long professional development program. They studied the effects of the summer workshop on their nine teachers in detail, with audiotape, videotape, written observer transcripts, and written teacher reflections on the workshop. Using a constant comparative qualitative method, the researchers found that teachers are feeling limited by the time needed to prepare for and teach with inquiry. The teachers somehow improved their own abilities to do inquiry, and developed more accurate picture of what scientists do through the summer research experience. Researchers suggested that engaging teachers in identifying key issues in their own professional development may be an effective strategy for using new methods like inquiry in the classroom.

Brown, Abell, Demir, and Schmidt (2006) conducted a phenomenographic research to identify college science instructors' understanding of inquiry-based instruction¸ their views of implementing it in the laboratories. They interviewed with 19 college science professors from different science disciplines such as physics, chemistry, biology, and geology. They presented their findings with four assertions. The participants believed that (1) students form authentic questions and perform independent research in inquiry instruction; (2) students' characteristics like knowledge, ability, and motivation and logistical factors like time, class size, and physical facilities constrain inquiry instruction; (3) inquiry instruction is more appropriate for students who have fundamental knowledge and skills; and (4) inquiry instruction increase students' understanding, motivation, and abilities.

2.5 Inquiry Skills

There are many terms used in the literature to name the processes of scientific inquiry such as scientific reasoning, inquiry skills, and science process skills. Without a particular emphasis on terms used by researchers, a review of literature about processes of scientific inquiry is presented in this section.

Krajcik et al. (1998) conducted a study in which they employed problem based learning as an inquiry method to teach science content to the middle school students. They analyzed how students generated questions, planned and designed investigations, constructed apparatus and carried out procedures, analyzed data, drew conclusions, and presented findings. In term of questions, the researchers observed that students often failed to consider the scientific merits of their questions, failed to use evidence they generated in respond to their questions, and confused the roles of questions and procedures. While the researchers are not certain why this occurred, they believe it may be because students lack of sufficient experience with inquiry. Examining how students planned and designed investigations, researchers observed considerable sophistication on students' performances such as including an awareness of the need to control variables. They reported missing aspects of understanding and skills during students' inquiry processes. Students did not always specify what they were looking for. Researchers also reported that students did not appreciate the need for consistency in conducting measurements, following through the procedure, or maintaining experimental control. Lastly, many students did not develop scientific arguments to support their claim and they stated conclusions without linking them to the evidence they collected.

Roth and Roychoudhury (1993) presented a qualitative research report about high school students' science process skills. Their aim was to investigate the development of integrated process skills in the context of open inquiry activities. Students worked in collaborative groups on experiments of personal relevance in authentic context for fourteen weeks. Their findings indicated that students develop higher-order process skills through nontraditional laboratory experiences that provided the students with freedom to perform open inquiry laboratory activities. Participants learned to identify and define pertinent variables, interpret, transform and analyze data, plan and design an experiment, and formulate hypothesis. Researchers argued that process skills should not be taught separately. Integrated process skills can develop gradually and reach a high level of sophistication when experiments are performed in meaningful context.

Hofstein, Navon, Kipnis, & Mamlok-Naaman (2005) explored the abilities of high-school chemistry students' asking higher-level questions after participating in an inquiry-based laboratory investigation for two years. A group of students who participated in traditional laboratory activities was used as a control group. They investigated the ability of students to ask questions related to their observations and findings in an inquiry-type experiment (a practical test) and the ability of students to ask questions after critically reading a scientific article. Results showed that students improved their ability to ask better and more relevant questions as a result of gaining experience with the inquiry-type experiments. In addition, the students who were involved in the inquiry experiences were more motivated to pose questions regarding scientific phenomena that were presented to them with a scientific article.

Apedoe (2007) presented a case study report about three undergraduate students engaged in inquiry-based activities in a geology course. The inquiry activities in the study can be categorized as guided inquiry, because students provided with an inquiry question and multitude of data. They were expected to develop alternative explanations and interpretations from the data. Participants' inquiry processes were investigated with the following subtitles; how students engaged in scientific questions, gave priority to evidence, formulated explanations, evaluated explanations, and communicated and justified their findings. The findings of the research indicated that while two of the students were quite capable of engaging in all components of analyzed inquiry practices, one of the student showed some deficiencies in formulating explanations from evidence, and communicating and justifying explanations. In this study, students' challenges during the inquiry activities were stated as the perceived lack of guidance from the teaching assistants and insufficient prior knowledge.

Lawson et al. (2000) investigated the various forms of hypothesis-testing skills. They hypothesized that there are two levels of hypothesis-testing skills exist. They assumed that one level involves skills associated with testing hypothesis about observable causal agents; the other level involves skills associated with testing hypothesis about unobservable entities. They administrated a hypothesis testing skills test to 667 participants both at the beginning and at the end of a biology course in which several hypothesis were generated and tested. They also used a transfer problem which includes the test of a hypothesis involving unobservable entities and a knowledge test which measures participants' declarative knowledge about transfer problem. They found that participants become better at testing alternative hypothesis with the help of repeated experiences of hypothesis generation and testing. They also analyzed test scores with stepwise multiple regression analysis and found that hypothesis testing skills, but not declarative knowledge, significantly accounted for performance difference on the transfer problem. They concluded that their study provides some support to the argument that general hypothesis testing skills can be categorized according to whether it involves observable or unobservable variables.

Park Rogers (2009) examined elementary pre-service teachers' evidence evaluation processes with a biology activity. Ten participants worked on the "Life in a Square" activity for six weeks. Their findings indicated that students relied mainly on their sense of sight and not on all senses to make observations. A second finding was that students had difficulties giving priority to the evidence gathered to generate explanations. They could not make connections among the sources of data. Lastly, students needed multiple opportunities in class to explicitly discuss and reflect on their findings.

Schauble, Klopfer, and Raghavan (1991) defined two different goal orientation in experimentation; science model of experimentation and engineering model of experimentation. Whereas in science model of experimentation, the goal is to understand relations among causes and effects, in engineering model of experimentation, the goal is to produce a desired outcome. They connected students' strategic weaknesses in experimentation like unsystematic investigations, fail to control extraneous variables, and distort evidence with engineering model of experimentation. They investigated experimentation of fifth- and sixth grade students while they were working in science context and engineering context. When students worked as scientists, the goal was determining factors which made a difference. When they worked as engineers, the goal was producing a desired effect. In the science context, students worked more systematically to find causal and non-causal relations. In the engineering context, students used highly complex combinations of variables and only focused on factors believed to be causal. Their findings suggested that teachers need to be conscious about perceived goal of the experimentation which students possessed.

2.6 The Frameworks of Current Study

The aim of this study was to investigate undergraduate physics education and physics students' inquiry processes in a physics laboratory. To accomplish this aim, an instructional method in which participants can conduct open inquiry activities was chosen. The chosen instructional method was problem-based learning, because it is a convenient instructional method which can provide students opportunities of experiencing whole scientific inquiry process. On the other hand, there needed to be a framework to process and present data clearly in this study. To avoid the fragmented structure and deal with the inquiry processes in a holistic manner, Klahr and Dunbar's (1988) Scientific Discovery as Dual Search (SDDS) model was used. In the following sections problem-based learning and Scientific Discovery as Dual Search (SDDS) model were explained in detail.

2.6.1 Problem-based Learning

Problem-based learning was originally developed in medical education and has been used in a variety of settings from middle school to professional education and domains such as science education and engineering. Problem-based learning is an inquiry-based instructional method in which experiential learning organized around the investigation, explanation, and resolution of meaningful problems (Barrows, 2000). In problem-based learning, students learn by inquiring about specific problems and reflecting on their experiences. Problem-based learning is useful for students because it places learning on real-world problems and makes students responsible for their own learning. It puts emphasis on developing strategies and constructing knowledge (Cognition and Technology Group at Vanderbilt, 1997).

In problem-based learning, students work in small collaborative groups and learn what they need to know in order to solve a problem. The teacher acts as a facilitator to guide students' learning through instruction. During the instruction, students are presented with an ill-defined problem scenario at the beginning. They formulate and analyze the problem by identifying the specific characteristics of the scenario. Since the scenarios make the problem meaningful, students can generate hypotheses about possible solutions. An important aspect of this process is identifying own knowledge deficiencies related to the problem situation. These knowledge deficiencies become the source of investigation topics. Students conduct self-directed investigations to eliminate knowledge deficiencies. Teacher helps students learn the cognitive skills needed for problem solving and collaboration throughout the instruction (Hmelo-Silver, 2004).

Barrows and Kelson (1995) defined five important goals of problem-based learning. First of the goals is the construction of extensive and flexible knowledge which is coherently organized around the deep principles in a domain. This goal may exceed the boundaries of a domain and it involves integration of knowledge across multiple domains. Second goal is the development of effective problem solving skills. It also includes metacognitive and reasoning skills. Third goal is the development of self-directed, lifelong learning skills which enables autonomous learning. Fourth goal is to help individuals become a good collaborator which means that knowing how to behave as a part of team. This embraces seeing differences, negotiating about the actions, creating a common ground, and coming to an agreement (Barron, 2000). The last goal of the problem-based learning is to help students become intrinsically motivated. Intrinsic motivation occurs when learners work on a task motivated by their own interests, challenges, or sense of satisfaction (Ferrari and Mahalingham, 1998).

2.6.2 Scientific Discovery as Dual Search (SDDS)

Klahr and Dunbar (1988) presented (also presented at the Klahr (2000)) the Scientific Discovery as Dual Search (SDDS) as a general model of scientific reasoning to show how search in two problem space shapes scientific discovery. The fundamental assumption of SDDS is that scientific reasoning requires search in two related problem spaces: the hypothesis space and experiment space. Hypothesis space includes all hypotheses which can be generated during the discovery process. Experiment space includes all possible experiments that could be conducted during the discovery process. SDDS consist of a set of three basic components that guide search within and between these two problem spaces. These are Search Hypothesis Space, Test Hypothesis and Evaluate Evidence.

The researchers used the Marvin Minsky's (1975) "frame" notation to describe the mental representation of hypotheses. In the most general sense, frame is a compact structure or structures representing a stereotyped situation. When one encounters a new situation or makes a substantial change in the view of the present situation (problem situation), s\he selects a “frame” from the memory. A frame can be accepted as a network of relations. The general characteristics of a frame are fixed. The specific characteristics of a frame have many "slots" that must be filled by specific instances or data. A frame has a set of elements with slots whose values can vary according to context, and fixed relations among these elements. According to SDDS, initial hypotheses are constructed by a series of operations that result in the instantiation of a frame with default values. Subsequent hypothesis within that frame are generated by changes in values of particular slots and new frames are generated either by a search of memory or by generalizing from experimental results.

Search Hypothesis Space has two components: Generate frame and assign slot values. If there is not an active frame, then it is generated. Because a new frame has unfilled slots, it is necessary to assign specific values to those slots. If there is an active frame, it may require changes in slot values. Generate frame has two components corresponding to the two ways that a frame may be generated: Evoke frame and induce frame. Evoke frame is a search of memory for information that could be used to construct a frame. In this process, prior knowledge has influence on hypothesis formation process. Induce frame generates a new frame by induction from a series of observations. The distinction between evoke frame and induce frame is resulted from the differences between the situations in which subjects are able to remember prior knowledge and use it as the basis of the frame, or the situations in which subjects observe some instances and use it as the basis of the frame. Assign slot values is the raw prediction of relationships within the frame.

Test Hypothesis has four main phases: Search e-space, predict, run, and match. Experiments are designed in search e-space phase. The important feature of this phase is to focus on some aspect of the situation which is under investigation. It is highly based on hypothesis. In predict phase, prediction of specific experiment results are formed based on the hypothesis and experiment design. In the run phase, the experiment is conducted. In match phase, the discrepancies between the prediction and the actual outcomes are described. When Test Hypothesis process is finished, it presents a representation of evidence for or against the hypothesis. This representation is used as input in the Evidence Evaluation process.

Evaluate Evidence determines whether or not the all evidence obtained with the experiments are sufficient to support or falsify the hypothesis. In this process assessment of consistency between theory and evidence takes place and it guides further research. It has two main components: Review outcomes and decide a conclusion. Review outcomes include evaluation of not only experiment results but also experiment design and experimentation process. The conclusion should be based on whole discovery process.

CHAPTER 3

METHOD

3.1 Research Design

The main purpose of this study was to explore undergraduate students' inquiry processes in a physics laboratory designed using problem-based learning. Case study, one of the qualitative research methods, was employed for this purpose. Case study was one of the best research methodologies for this study because "case study is an empirical inquiry that investigates contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (Yin, 2003, p. 13). In this study, "SSME404 Laboratory Experiments in Physics Teaching" course was seen as a part of prospective physics teachers' education life and a real situation in which they are experiencing inquiry teaching. In addition, prospective physics teachers, laboratory environment, and inquiry activities were dealt with as a whole.

Yin (2003) also asserted that case study is well suited in the situations where the aim of the study is to explore, discover and interpretation instead of hypothesis testing. In other words, case study is more appropriate for "how" and "why" questions. In line with this statement, this study especially focused on "how" question and tried to understand how prospective physics teachers' conducted inquiry activities.

Stake (1995) defines three types of case study according to the purpose of using it. These are intrinsic case study, instrumental case study, and collective case study. In an intrinsic case study, the focus is about the case itself, not a specific issue, concept, or process because the case present valuable information. For example, evaluating a specific program having a particular importance or studying a specific student having particular problems can be considered as intrinsic case studies. Most of the time participants of intrinsic case studies are extreme cases. On the other hand, instrumental case studies are conducted for understanding a general issue by studying a case. Different from intrinsic case studies, the focus of instrumental case studies is not participants but a specific issue. The role of participants in instrumental studies is to make the issue observable. For example, the focus of an instrumental case study can be an instructional strategy by studying to understand the issues related to its implementation in a classroom context. In general, typical cases are chosen for instrumental case studies. Collective case study aims to illustrate an issue for multiple cases. This provides an in-depth analysis of an issue, a concept, or a process and includes comparisons among the cases.

This research study can be best suited to the instrumental case study. This study examined the lived experiences of prospective physics teachers in a problem-based laboratory to understand their inquiry processes. In other words, the issue under the investigation is the participants' inquiry processes without a particular emphasis on the comparison of participants. Participants' inquiry activities in a physics laboratory were taken as a case and their performance in this context was analyzed. This case consists of several elements such as participants, teaching assistants, the course, and activities which will be detailed in the following sections.

3.2 Participants of the Study

This study conducted in Middle East Technical University, Faculty of Education, Department of Secondary Science and Mathematics Department. Participants of the study were all students of "SSME404 Laboratory Experiments in Physics Teaching" course offered during the fall semester of the 2008-2009 academic year. 18 students enrolled to SSME404 course in that semester and all of them recruited on a voluntary basis. The following sections gave brief descriptions of the teaching assistants and students. Age, gender, and academic background of participants were presented.

3.2.1 Teaching Assistants

There were two teaching assistants participated in this study. They both have several years of experiences in laboratory experiments and teaching in laboratory courses. At the time of this study was conducted, both teaching assistants were doctoral students and working as research assistants in the Faculty of Education. Their duty in this laboratory course was to organize activities and guide students while they were conducting experiments.

First teaching assistant was also the researcher of this study. He was male and 30 years old. He got his master degree from The Ohio State University in Integrated Science, Mathematics, and Technology Education. He continued his doctoral study in Physics Education at Middle East Technical University. He has been working at the Middle East Technical University since 2006 as a research assistant. Before this study, he had been a teaching assistant in laboratory courses for 4 semesters. He also worked in the content development of SSME403 and SSME404 laboratory courses at the Department of Secondary Science and Mathematics Education.

Second teaching assistant was a male and 30 years old. He got his master degree from the Middle East Technical University in Physics Education. He continued his doctoral study in Physics Education at Middle East Technical University. He worked at a high school as a physics teacher for one year. He has been working at the Middle East Technical University since 2007. Before this study, he was a teaching assistant in laboratory courses for one semester.

3.2.2 Students

The participants of this study included 16 college students from two different departments of Middle East Technical University. The names of participants kept hidden by using fake names for them. In this and following chapters these fake names will be used to keep their confidentiality.

Baha was a 23 years old, male senior student at the Department of Physics. He took most of the physics courses offered by the Department of Physics. He also took general chemistry laboratory, mechanic laboratory, electromagnetic laboratory, optic and waves laboratory, and modern physics laboratory courses.

Yakup was a 22 years old, male senior student at the Department of Physics. He took most of the physics courses offered by the Department of Physics. He also took general chemistry laboratory, mechanic laboratory, electromagnetic laboratory, and optic and waves laboratory courses.

Haluk was a 21 years old, male junior student at the Department of Secondary Science and Mathematics Education with a specialization in Physics Teaching. He took approximately half of the physics courses offered by the Department of Physics. He also took general chemistry laboratory, mechanic laboratory, electromagnetic laboratory, electronic laboratory, and optic and waves laboratory courses.

Sadri was a 20 years old, male junior student at the Department of Secondary Science and Mathematics Education with a specialization in Physics Teaching. He took approximately half of the physics courses offered by the Department of Physics. He also took general chemistry laboratory, mechanic laboratory, and electromagnetic laboratory courses.

Bedia was a 22 years old, female senior student at the Department of Physics. She took most of the physics courses offered by the Department of Physics. She also took general chemistry laboratory, mechanic laboratory, electromagnetic laboratory, electronic laboratory, optic and waves laboratory, and modern physics laboratory courses.

Canan was a 22 years old, female senior student at the Department of Physics. She took most of the physics courses offered by the Department of Physics. She also took general chemistry laboratory, mechanic laboratory, electromagnetic laboratory, electronic laboratory, analog electronics laboratory, digital electronics laboratory, optic and waves laboratory, and modern physics laboratory courses.

Yavuz was a 23 years old, male senior student at the Department of Physics. He took most of the physics courses offered by the Department of Physics. He also took general chemistry laboratory, mechanic laboratory, electromagnetic laboratory, modern physics laboratory, and optic and waves laboratory courses.

Erdal was a 24 years old, male senior student at the Department of Physics. He took most of the physics courses offered by the Department of Physics. He also took general chemistry laboratory, mechanic laboratory, electromagnetic laboratory, modern physics laboratory, and optic and waves laboratory courses.

Leman was a 21 years old, female junior student at the Department of Physics. She took approximately half of the physics courses offered by the Department of Physics. She also took general chemistry laboratory, mechanic laboratory, electromagnetic laboratory, and optic and waves laboratory courses.

Saliha was a 22 years old, female junior student at the Department of Secondary Science and Mathematics Education with a specialization in Physics Teaching. She took approximately half of the physics courses offered by the Department of Physics. She also took general chemistry laboratory, mechanic laboratory, electromagnetic laboratory, and optic and waves laboratory courses.

Özlem was a 21 years old, female junior student at the Department of Secondary Science and Mathematics Education with a specialization in Physics Teaching. She took approximately half of the physics courses offered by the Department of Physics. She also took general chemistry laboratory, mechanic laboratory, electromagnetic laboratory, electronic laboratory, and optic and waves laboratory courses.

Öznur was a 21 years old, female junior student at the Department of Secondary Science and Mathematics Education with a specialization in Physics Teaching. She took approximately half of the physics courses offered by the Department of Physics. She also took general chemistry laboratory, mechanic laboratory, electromagnetic laboratory, electronic laboratory, and optic and waves laboratory courses.

Demet was a 21 years old, female junior student at the Department of Secondary Science and Mathematics Education with a specialization in Physics Teaching. She took approximately half of the physics courses offered by the Department of Physics. She also took general chemistry laboratory, mechanic laboratory, electromagnetic laboratory, electronic laboratory, and optic and waves laboratory courses.

Banu was a 20 years old, female junior student at the Department of Secondary Science and Mathematics Education with a specialization in Physics Teaching. She took approximately half of the physics courses offered by the Department of Physics. She also took general chemistry laboratory, mechanic laboratory, electromagnetic laboratory, electronic laboratory, and optic and waves laboratory courses.

Engin was a 21 years old, male junior student at the Department of Secondary Science and Mathematics Education with specialization in a Physics Teaching. He only took mechanic and electromagnetic courses. He also took general chemistry laboratory, mechanic laboratory, and electromagnetic laboratory courses.

Nalan was a 20 years old, female junior student at the Department of Secondary Science and Mathematics Education with a specialization in Physics Teaching. She took approximately half of the physics courses offered by the Department of Physics. She also took general chemistry laboratory, mechanic laboratory, and electromagnetic laboratory courses.

3.3 Context

This study conducted in the "SSME404 Laboratory Experiments in Physics Teaching" course. The aim of the course was to equip prospective physics teachers with the ability of designing laboratory experiments or activities in accordance with the national high school physics curriculum. After this course, prospective physics teachers are also expected to interpret daily life applications of scientific principles.

SSME404 course was conducted in three modules; inquiry activities, hands-on activities, and confirmatory experiments. Inquiry activities, which were the main focus of this study, will be described in detail later. During hands-on activities, students conducted simple activities with the equipment they can find easily all around. In confirmatory experiments module, students worked with detailed worksheets which described all the steps of the experiments. The experiments were about different physics topics covered in high school physics curriculum like centripetal force, heat capacity, free fall, etc.

During the activities students worked in groups of pairs. Teaching assistants guided and monitored their performances. Performance-based assessment was one of the grading methods for this course. At the final project of the course, students developed a demonstration material or laboratory activity for teaching of a specific topic from high school curriculum.

This course conducted in the physics laboratory of Faculty of Education. The condition of the physics laboratory was as follows: There was a big bench in the middle of the laboratory. All students conduct their experiments around this bench. There were twelve stools around the bench which were used by students when they felt the need to sit in the laboratory. At the two sides of the room there were cabinets. All cabinets full of experiment equipment and in front of the cabinets there were labels showing the kind of equipment included in the cabinet. Students went to cabinets and chose their equipment from the cabinet to set up their experiments. The range of equipment hold by the laboratory was limited to the equipment needed for middle and high school physics laboratory which is mostly provided by Course Tools Making Center (Ders Aletleri Yapım Merkezi). All these equipment can be found in high school physics laboratories.

The physical condition of the laboratory was convenient for maximum of ten students. Because of that, the course was conducted in two different sessions; Monday session, and Wednesday. Eight of the participants attended to the laboratory on Monday afternoons, and eight of the participants attended to the laboratory on Wednesday afternoons. Each laboratory sessions lasted approximately 3 hours.

3.3.1 Inquiry Activities

There were five activities in the inquiry module of the course. These activities were prepared using problem-based learning by the researcher (Ünal & Özdemir, 2009). The original forms of laboratory worksheet used during the inquiry activities were presented at the Appendix A-E.

Problem-based learning is an inquiry based instructional design in which experiential learning organized around the investigation, explanation, and resolution of meaningful problems (Barrows, 2000). In spite of the many variations of problem-based learning, six core characteristics of problem-based learning are distinguished in the core model described by Barrows (1996). The first characteristic is that learning needs to be student-centered. Second, learning has to occur in small student groups under the guidance of a tutor. The third characteristic refers to the tutor as a facilitator or guide. Fourth, authentic problems are primarily encountered in the learning sequence, before any preparation or study has occurred. Fifth, the problems encountered are used as a tool to achieve the required knowledge and the problem-solving skills necessary to eventually solve the problem. Finally, new information needs to be acquired through self-directed learning.

Inquiry activities in accordance with the characteristics of problem-based learning begin with a problematic scenario which can be encountered in real life. Participants read this scenario from the laboratory worksheet at the beginning of the laboratory session. Laboratory worksheets also include several sections which guides participants' actions to reach a conclusion.

3. 3.1.1 Scenarios of Inquiry Activities

Five problematic scenarios were written for inquiry activities. These scenarios were hypothetic scenarios that can be easily faced in daily life situations. Each scenario was about a different physics topic and required different experimental setup to reach a solution. The characteristics of written scenarios were as the followings:

- Problems about different topics
- Scenarios can be encountered in real life
- Dependent variable was hidden
- More than two possible independent variables
- The availability of lab equipment for possible experiments

First activity was about the topic of simple harmonic motion. The heading of the activity was Competitive Fathers. The scenario was as the following:

In a playground, children are swinging and their fathers are pushing them. The fathers are not pushing their son randomly, but periodically. Every time they push their son, they get one point. In 5 minutes, the father getting more points will be the winner of the competition. The fathers try to develop strategies to win the competition. Can you give some advice to them on this issue as a physicist?

The aim of this scenario was to have participants conduct experiments about simple harmonic motion of a pendulum. The hidden dependent variable of the scenario was period or frequency of a pendulum. Participants were expected to investigate the effect of one variable of pendulum like length, mass, or maximum angular displacement on period of it.

Second activity was about the topic of heat transfer. The heading of the activity was Tea Pleasure. The scenario was as the following:

Like most of the Turkish man, Mr. Peşman loves drinking hot tea. He prepares half a pot of tea every evening and drinks it while watching television. However, he has not got an electric teapot and he must go to the kitchen to refill his slim-waisted glass. He bored up travelling between kitchen and living room and decided to bring teapot near his sofa. Eventually, he realized that second glasses of tea were not hot enough. He is thinking about how he can satisfy his hot tea pleasure without going to the kitchen to refill his glass. Can you give some advice to Mr. Peşman on this issue as a physicist?

The aim of this scenario was to have participants conduct experiments about heat transfer. The hidden dependent variable of the scenario was rate of cooling time. Participants were expected to investigate the effect of one variable like first temperature, mass or surface area of cooling matter, or type or thickness of isolated material on rate of cooling time.

Third activity was about the topic of electromagnetism. The heading of the activity was The Junkyard. The given scenario was as the following:

In a junkyard, Mr. Üstün, the owner of the junkyard, uses big electromagnet cranes to move old cars. The electromagnet crane he uses is able to lift standard-sized cars easily. However, Mr. Üstün has realized that it is not appropriate for holding bigger cars, such as SUVs, which are two times heavier than usual cars. Because Mr. Üstün cannot afford to buy a new electromagnet crane, he tries to make a more powerful electromagnet crane by doing some changes using the materials that are available in his junkyard. Can you give some advice to Mr. Üstün on this issue as a physicist?

The aim of this scenario was to have participants conduct experiments about electromagnets. The hidden dependent variable of the scenario was magnetic strength of an electromagnet. Participants were expected to investigate the effect of one variable like current, potential difference, size of the iron core, or number of turns of wire on magnetic strength of an electromagnet.

Fourth activity was about the topic of inertial mass. The heading of the activity was Journey to the Mars. The scenario was as the following:

Mrs. Arslan is the first woman astronaut of Turkey and the geologist of the TRK1's crew. During the investigation on the surface of the Mars, she found a stone that she had never seen before. She decided to take this stone to the laboratory in the space shuttle to make a detailed examination. The space shuttle is revolving around the Mars. At the beginning of the examination process, she wants to find the density of the stone. However, she does not know how to measure the density of the stone exactly. Can you give some advice to Mrs. Arslan on this issue as a physicist?

The aim of this scenario was to have participants think about the inertial properties of matter. This activity mainly focused on measurement unlike the previous activities. Participants forced to establish an experiment design in which they can measure the mass of a matter without the effect of gravity. There was not a topic restriction in this activity, on the contrary, participants were encouraged to consider different topic such as mechanics, rotational motion, and simple harmonic motion of springs.

Fifth activity was related to relative motion and light. The heading of the activity was Spearfishing. The given scenario was as the following:

Uncle Salih is a former dart player and the owner of a trout farm. Every afternoon, he puts one big trout on a pool, sits on a chair near the pool, and hunts that trout with a fish spear for dinner. After these spearfishing sessions, he realized that his dart accuracy was decreased. Moreover, he also felt that he could not do spearfishing as well as he played dart. He decided to investigate the possible reasons of these problems. Can you give some advice to Uncle Salih on this issue as a physicist?

The aim of this activity was to have participants analyze the scenario and predict a reason which may cause the problem. In this scenario, there were two problems (decreasing dart accuracy after spearfishing sessions and not doing spearfishing as well as he played dart) and the possible dependent variables were not clear. Participants determined their dependent variable according to chosen problem and their possible reason for that problem. They could do a wide variety of experiments about topics of refraction of light and relative motion.

3.3.1.2 Procedure of Inquiry Activities

Participants worked in groups of two during the inquiry activities. Inquiry activities began after the participants read the scenario from their worksheets. Then, participants followed the laboratory worksheets throughout the laboratory session. There were 8 parts in the worksheets to guide participants through the activities.

In the first part, participants needed to identify the physics concepts that can be related to scenario. There was not any restriction for this part. Participants wrote concepts which they thought related to the scenario. Second part required participants identify the problem of the scenario in terms of physical concepts. The aim of this part was to enable participants formulate a researchable problem by activating physics related prior knowledge. What is meant by researchable problem is simply identification of appropriate physical variables in the scenario and formulating a context free physical problem to initiate an inquiry. First and second parts intend to lead participants to an analysis of the real life situation from a physicist's perspective. Moreover, participants' responses in these parts can provide the researcher with information about what degrees students understand the scenario and generate a researchable problem.

In the third part, participants wrote a hypothesis which may provide a solution to the problem. This hypothesis shaped participants subsequent laboratory work. In the fourth part, they designed an experiment to test their hypothesis. They required explaining their experiment, drawing a scheme of their experiment and writing numerical values of their controlled variables on the worksheets. In the fifth part participants wrote variable of their experiment. Variables were divided into subgroups as manipulated, responding, controlled, and uncontrolled variables.

In the sixth part, they reported their experimental results with tables and graphs. Seventh part of the worksheet consisted of their interpretation about the experiment and results. Participants wrote the limitation of their experiment and the degree they believe in their results in this part. At the last part, they wrote a recommendation as a solution to the problem situation. In this part, the participants were expected to turn back to the original scenario and generate a solution by using their context free interpretations about the experimental results revealing the possible relations about some physical concepts.

After all participants finished the experiment and filled the laboratory worksheets there was a post-lab discussion session. In these post-lab discussion sessions, each group described their hypothesis, experimental design, results, and conclusion. The other groups and teaching assistants could ask questions in this session.

3.4 Data Sources

The raw data were included observation of participants while they were doing inquiry activities and the laboratory work sheets filled by the participants. In order to obtain detailed information about participants' inquiry processes, all laboratory sessions about inquiry activities were video recorded and each group's conversations were audio recorded separately. These records began with participants' entrance to the laboratory in each laboratory session and finished at the end of the session.

One video camera placed at the corner of the laboratory and all the participants worked in the camera's field of view. There were totally 10 video records each lasting approximately 3 hours. These video records showed the behavior of the participants, their experiment designs and execution of experiments. Four audio recorders were used in this study. Audio recorders distributed to the groups and placed on positions where each recorder recorded the sound of one group. There were totally 40 audio records each lasting approximately

3 hours. With these audio records the discussions of participants before, during, and after the experiments were captured.

Participants' laboratory worksheets were another data source for this study. Each group filled one laboratory worksheets for each activity. There were totally 40 laboratory worksheets. These laboratory worksheets can be seen as a summary of the participants' inquiry process. They wrote their hypothesis, experiment results, and conclusion with much other information on the laboratory sheets.

3.5 Data Analysis

Data analysis was conducted iteratively in several steps. This means that all data reviewed at least three times to reach the final version of the results. In the first step video records were watched and audio records were listened in a synchronized manner. By this synchronization each group' performance in each activity was obtained along with the conversations. During the first step, the notes were taken about general inquiry performances and striking behaviors. Based on the first analysis, the general analysis schema of inquiry processes was determined. It was decided that general analysis schema was constituted of hypothesis formation, designing and conducting experiments, and evidence evaluation. The suitability of the general schema was also checked with the literature and discussed with the colleagues having research interest and experience about inquiry processes.

In the second step, video records and audio records watched again. In this step, the data was conceptualized and organized around the general analysis schema. Participants' inquiry process related to the general schema was identified and classified under sub-categories. Meanwhile, the meaning of sub-categories was formed with common characteristics of participants' inquiry process in each activity.

In the last step, consistency of classifications was reviewed. All records were gone over again. The characteristics of participants' inquiry process and the meanings of sub-topics were compared and contrasted.

3.6 Trustworthiness of the Study

There are variations in the ways that reliability and validity are constructed in qualitative and quantitative research due to distinctive characteristics of qualitative research design. In qualitative research, Lincoln and Guba (1985) proposed the terms credibility, transferability, dependability and confirmability as qualitative counterpart of internal validity, external validity, reliability, and objectivity, respectively. These are the criteria for the trustworthiness of the study.

3.6.1 Credibility

According to Lincoln and Guba (1985), credibility is a twofold task; "first, to carry out the inquiry in such a way that the probability that the findings will be found to be credible is enhanced and, second, to demonstrate the credibility of the findings by having them approved" (p. 296). They proposed different techniques to provide credibility of a study. These are prolonged engagement, persistent observation, triangulation, peer debriefing, member checking, negative case analysis, and referential adequacy. In order to increase the credibility of this study, first five of these techniques were applied.

3.6.1.1 Prolonged Engagement

According to Lincoln and Guba (1985) prolonged engagement in the research site has two main purposes. One of them is to understand the research site fully to avoid the distortions of data. As mentioned above, researcher is an experienced teaching assistant in the laboratory. This experience provided him information about laboratory environment and lab equipments used in the experiments. Researcher conducted some other experiments with the participants before this study. Therefore, he found opportunity to know participants and their reasoning in the experiments.

The other purpose of prolonged engagement is to provide the researchers an opportunity to build trust. In qualitative inquiry, the researcher needs to increase the participants' level of comfort, to encourage them to talk normally in research (Bogdan & Biklen, 2007). Laboratory periods were designed to provide participants a cozy environment. They decided their own pace, they gave breaks whenever they want, and walking and talking in the laboratory was highly encouraged. Taking suggestions for first day proposed by Bogdan and Biklen (2007), researcher was friendly and remained relatively passive in the first week of this study. Thorough the study researcher participated in laboratory activities, observed the experiences while participants were doing experiments, guided their inquiry process, and provided support when they needed.

3.6.1.2 Persistent Observation

Lincoln and Guba (1985) defined the purpose of persistent observation as focusing the intended aim of study and identifying characteristic of the situation that are most relevant to the aim. As mentioned above, participants` laboratory sessions were video and audio recorded. These records were matched and analyzed by synchronizing them to understand fully the behaviors and ideas of participants. This process repeated two more times for all records until classifications were shaped and all groups` performances in each activity were identified.

3.6.1.3 Triangulation

Triangulation is the most used activity to increase credibility of a qualitative research. Triangulation means that using multiple sources of evidence to increase trustworthiness of study. The important point of triangulation is to support an idea by collecting information from multiple sources. Triangulation of data cannot be obtained when multiple sources are used but each indicates different ideas. (Yin, 2003)

The findings of this study employed different kinds of data sources like laboratory worksheets, video records, and audio records. Every step of analysis conducted in the light of these data sources. By cross-checking the consistency information acquired from different data sources, more accurate information about participants' inquiry skills was obtained.

3.6.1.4 Peer Debriefing

Peer debriefing is "a process of exposing oneself to a disinterested peer in a manner paralleling an analytic session and for the purpose of exploring aspects of the inquiry that might otherwise remain only implicit within the inquirer's mind" (Lincoln & Guba, 1985, p. 308). It is like an external check on the study. In this study, the researcher analyzed all data independently and then told and explained findings to a colleague in detail. They discussed all findings and interpretations of experiences together until they reached a consensus. The researcher also discussed concerns and ideas with other colleagues who have general understanding of the study. Peer debriefing decreased the bias and clarified interpretations related to participants' experiences.

3.6.1.5 Member Checking

Member checking is to discuss findings and interpretation with the participants who were provided the data (Lincoln & Guba, 1985). In this study, two participants included member checking process. They gave feedback to the interpretations of their experiences generated by the researcher. This activity provided researcher the opportunity to correct errors and wrong interpretations.

3.6.2 Transferability

The transferability corresponds to external validity and generalizability of findings. It refers to the degree of usefulness of a study's findings in other similar situations, with similar research questions. The transferability is a problematic issue in qualitative research, because some qualitative researchers reject generalizability as a goal (eg. Denzin, 1983). According to Lincoln and Guba (1985), a qualitative researcher "cannot specify the external validity of a study; s\he can provide only thick description necessary to enable someone interested in making a transfer to reach a conclusion about whether transfer can be contemplated as a possibility" (p. 316).

In this study, the researcher only provided widest possible information of the context, inquiry process, and participants for the transferability construct. It is readers' duty to determine in what degree the finding of this study can be transferred to their own settings.

3.6.3 Dependability and Confirmability

Dependability corresponds to reliability in quantitative research whereas confirmability corresponds to objectivity. Dependability means that providing consistency between the data and interpretation of data. Confirmability means that the findings or conclusions are based on the data rather than researcher's bias. Although the dependability and confirmability criteria are considered as different constructs, Lincoln and Guba (1985) proposed the same activities to ensure these: Detailed explanation of study and inquiry audit.

In this study, inquiry process, data and data analysis were explained in detail to show the consistency of findings and interpretations. In this manner dependability and confirmability of the study were attempted to establish. Moreover, advisor did the work of inquiry auditor and examined whole process and product of this study. By being an inquiry auditor, he attested that the findings and interpretations of this study were internally coherent and supported by data.

CHAPTER 4

DATA ANALYSIS

The aim of this study was to investigate undergraduate physics education and physics students' inquiry processes in a physics laboratory. The research questions which guided collection and analysis of data were used as a framework for the presentation of the results into three major sections. Each section corresponded to a specific inquiry process. At the first section, Hypothesis Formation, participants' hypothesis formation processes were described. The second section, Designing and Conducting Experiments, includes analysis about participants' design and use of experiments during their inquiries. Last section, Evidence Evaluation, focused on participants' evidences and evidence evaluation processes.

The main sources of data used during the analysis were observations on prospective physics teachers' inquiry processes and laboratory worksheets filled by them during their inquiries. Participants attended to the inquiry module of the course and followed required steps for the inquiry tasks. Required steps of inquiry tasks were given in the laboratory worksheets. Figure 4.1 presented to illustrate which steps of inquiry task observed for each inquiry process.

There were 8 required steps in the worksheets to guide participants through the inquiry activities. Laboratory worksheets began with a hypothetic scenario. After reading the scenario, participants were expected to determine the possible physics concepts that can be related to scenario. At the second step, participants identified a researchable problem which emerged from the scenario. At the third step, they determined a hypothesis which may provide a solution to their problem.

Participants' conversations and actions in these three steps analyzed to understand their hypothesis formation process.

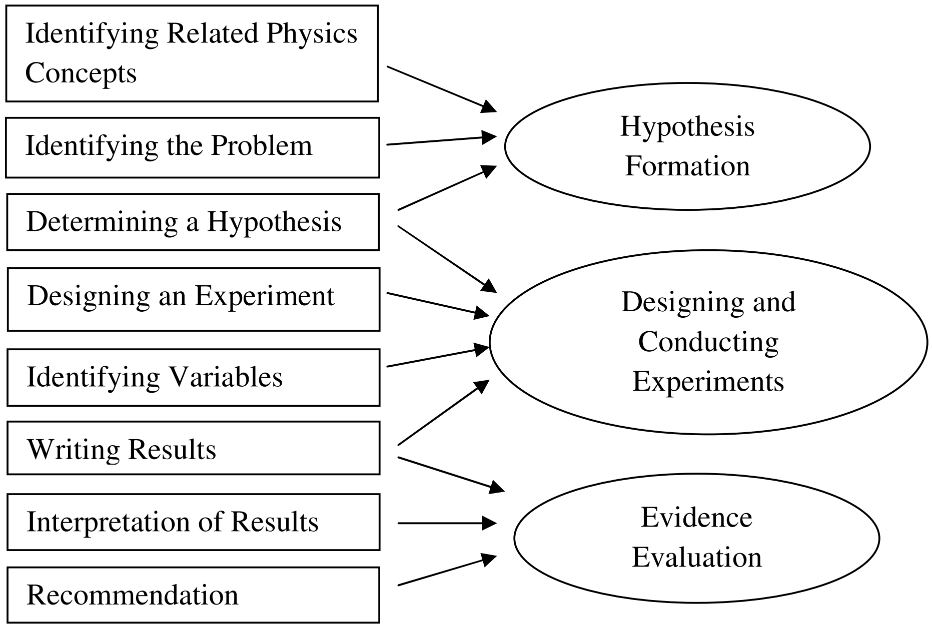


Figure 4.1 Observed steps for each inquiry process

After determining the hypothesis, participants designed an experiment to test their hypothesis. At the fifth step, they identified the variables of their experiment. Then, they conducted experiments with the equipment they found in the laboratory. They recorded their raw data in tables and drew graphs of their data. All of these actions were taken as a whole and analyzed to understand participants' designing and conducting experiments process.

At the seventh step, participants interpreted their experimental results. They stated the limitation of their experiment and in what degree they believed in their results. At the last step, they recommended a solution to the problem of the scenario based on their inquiry. The consistency among experiment results, interpretation, and recommendation was analyzed to understand participants' evidence evaluation process.

4. 1 Hypothesis Formation

Prior knowledge of the participants and the given ill-defined problem situations were the major sources of hypothesis formation. Problem situation activated some particular set of knowledge related to the problem. Participants decided their hypothesis with this activated prior knowledge. During the hypothesis formation process, many different types of prior knowledge like previous experiences, similar situations, physical equations, and physics theories and laws can be used. Because of diversity of these sources and the structure of them, the nature of hypothesis formation is not a straightforward process. This means that not only one source is activated and shaped hypothesis alone. The hypothesis is the product of different kind of sources and relationships among these sources associated with the problem situation. The plausibility and consistency of a generated hypothesis is also checked and evaluated by this organized structure.

During a laboratory session, participants began the activities by reading and trying to understand the scenario provided by the researcher. Then, they determined a researchable problem emerging from the scenario and proposed a hypothesis which led their inquiry process. This section focused on hypothesis formation processes. The data searched to capture hypothesis formation process primarily consisted of laboratory worksheets and conversation between the group members and among the group members and teaching assistants. The discussions occurred during the hypothesis formation process provided productive information. Participants asked questions about the meaning of the problem situation and explained their ideas about the hypothesis to their group friends. In addition to this, teaching assistants asked questions to clarify participants' hypothesis before they conducted experiments. All these pre-lab discussions made known not only the participants' used sources, but also their steps followed during the hypothesis formation process.

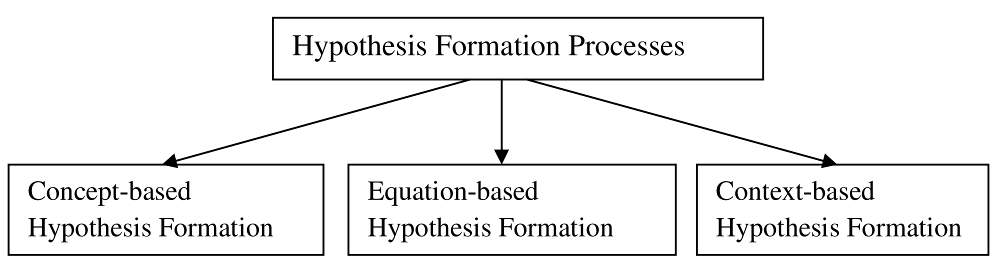


Figure 4.2 Types of hypothesis formation process

In this study, hypothesis formation was classified according to participants' used sources and how these sources used. As mentioned above hypothesis formation is a complex process not a linear one. Participants sometimes used different types of sources and they went over all these sources again and again to reach a hypothesis. The classification of hypothesis formation was based upon the dominantly used sources. Three major types of hypothesis formation process were categorized as concept-based hypothesis formation, equation-based hypothesis formation, and context-based hypothesis formation. These types of hypothesis formation processes were illustrated at the Figure 4.2. In the following sections these hypothesis formation processes were explained in detail.

4.1.1 Concept-based Hypothesis Formation

Concept-based hypothesis formation refers to participants' use of physical concepts to form a hypothesis. During the concept-based hypothesis formation process, participants specified the characteristics of the scenario by identifying physical concepts related to the scenario or converting the terms used in the scenario to the physical concepts. Along with these efforts, the scenario was conceptually linked with a physical framework (a specific physics topic such as magnetic field, simple harmonic motion, etc.). They defined the problem and their hypothesis within this physical framework with physical concepts. As a result, the hypothesis composed of physical concepts and context independent relationships between the concepts.

In this study, discussions of the physical concepts hidden in the scenarios and using them in the hypothesis formation process were taken as an indicator of concept-based hypothesis formation. Identifying contextual properties of the scenario in terms of physical concepts and using both of them interchangeable during the discussions was also signaled the use of concept-based hypothesis formation. Following vignette was provided to exemplify the concept-based hypothesis formation process.

Vignette 1

The following conversations took place at the beginning of the Junkyard activity while the participants in fifth group were working on it. Participants began the activity by reading the scenario on the worksheet silently. After that the following conversation took place.

Leman: What is the problem?

Saliha: The cars are big…

Leman: What is junkyard? Is it the places contain metals?

Saliha: It is a place full of old cars.

Leman: Okay.

Saliha: He uses big electromagnet for carrying cars. It can lift small size cars easily, but it is not appropriate for double size cars. Also, he could not afford to buy a new one. Do you know what an electromagnet is?

Leman: It is kind of magnet but I do not know exactly. As far as I remember it is working with electric. Let's ask it.

As seen in the dialog, they first try to make sense of the scenario. They asked questions to each other to clarify the scenario. While both of the participants could not remember electromagnet, they asked its working principle to another friend. As we see in the following dialogs, the participants related the characteristics of the situation to a physical framework of magnetic field.

Banu: The current generates magnetic field, we are going to bring this magnet feature. It is not a natural magnet…solenoids…

Leman: So eventually it is working with electric, magnet feature…(Turns to the group friend)

Leman: Selenoid…there was something, for example, if the number of turns of wire are increase it will become more magnetic, is not it?

Saliha: How?

Leman: There is a relationship. Directly or indirectly. Besides with current. What else…Is width important?

After they confirmed some of their ideas and learned that they need a solenoid, they began to think about magnetic field of solenoid. They tried to find out ways of increasing magnetic field. In this point, they began to think in a physical framework by identifying related concepts and the possible relationships among the concepts.

Leman: What else can we change to increase electromagnet?

Saliha: We can try the number of turns of wire.

Leman: For example, if it is 100 turns, we will make it 200.

Saliha: Is it affect?

Leman: I think so. Is it is like this (draw a straight line) and only passes current, there is nothing to change. However, it is like this (demonstrate turnings of solenoid by hand) it became a magnet.

Saliha: What? How?

Leman: How much does it have, that much magnetic field generates. Magnetic field generated because of its shape.

Saliha: No, no. Magnetic field also generated with straight line wire. Magnetic field generates with both of them but it is not like a magnet.

Leman: But magnetic field generates.

Saliha: Yes but it is not like the magnet.

Although they asked friends about the working principle of electromagnet, they could not get sufficient information. They began to think about the problem situation in the light of acquired information. However, it was seen that they did not comfortable with new information. It did not fit with participants' prior knowledge exactly. They realized that there were some inconsistencies in their physical framework. Thereupon, they began to dive into more prior knowledge and activated different aspects of the physical framework.

Leman: Let's think something else.

Saliha: What can be the shape of electromagnet, let's think about it. What can be an electromagnet?

Leman: Firstly, we need to find out how its structure is?

Saliha: Yes.. We need to apply potential difference because it is an electromagnet. Current pass through. Is that current generates magnetic field?

Leman: Yes. This (Shows on their drawings) is a solenoid. Is not it?

Saliha: Hı-hı. Current is passing through it.

Leman: Is this pull now? Is it a complete magnet?

Saliha : I do not know.

Leman: Is the direction of magnetic field generated in this way? (Use right hand rules to show the direction of magnetic field)

…

They activated many aspect of the physical framework in these conversations. They used many concepts related to magnetic field of a current-carrying wire and solenoid. They tried different approaches to make it clear in their mind. However, they had not reached a conclusion yet. They were stuck at this point and asked for help from teaching assistants. One of the teaching assistants told that they also needed to put an iron core inside of the solenoid to make an electromagnet. With the help of this information, participants understood the missing point of their physical framework and began to think about increasing the power of electromagnet in new physical framework.

Leman: What can we change in the experiment?

Saliha: We can change size of it. Maybe the battery.

Leman: Yes, size can be. Shape can be. Number of turns, because current pass through.

Saliha: Yes.

Leman: I think all of these enough.

Saliha: We need to choose one of them. We cannot do all of them. Let's look at the equipment in the laboratory and choose one of them.

Leman: Ok. Let's write the hypothesis. What do you prefer? Size or type.

Saliha: Size.

…

After the conversation, they decided to investigate the effect of iron core's size of the electromagnet on the strength of it. Their physics concepts related to the scenario were "*electromagnetism and magnetic field"*. Their question was "*How can we increase the power of electromagnet?*" Their hypothesis was "*Increasing size of the metal of the electromagnet will increase the magnetic field.*"

When looked fifth group's overall process of hypothesis formation in Junkyard activity, it was seen that group members successfully used physical concepts to form a hypothesis. Although they wrote only two physics concepts related to the scenario on the worksheet, they used these two concepts with many other physics concepts related to the magnetic field of current-carrying wire during their discussion. Some of these concepts were current, potential difference, number of turns of wire, and magnetic field. Moreover, they wrote their hypothesis with these concepts.

Although they did not know the structure of electromagnet at the beginning of the activity, they tried to put the situation in a physical framework. When they stuck in some points, they asked for help from their friends or teaching assistants instead of continuing with the present framework. They activated many related knowledge like current, magnetic field, and right hand rule until they reached a satisfactory framework. They continuously searched for new concepts that can be a variable in the problem situation. As a result of all of these efforts, they converted problem situation to the relationships among a set of physical variables and formed a context independent hypothesis.

4.1.2 Equation-based Hypothesis Formation

Equation-based hypothesis formation refers to participants' use of physical equations during the hypothesis formation process. Equations are most used models in physics education and students are highly dependent on these models. During the equation-based hypothesis formation process, participants associated the scenario with a physical framework to find a specific equation compatible with the scenario. The emphasis was not on the concepts emerging from the scenario or the possible relations among them but on the physical equations and finding a solution based upon these equations. They dealt with the task as if it was a deductive reasoning task in which they would find solutions to the problem situation with physical equations. Therefore, equation-based hypothesis formation was no more than trying to find a formula fitting into the scenario and to confirm this formula in the lab. Equation-based hypothesis formation process can be seen as transforming inquiry laboratory into a confirmatory laboratory.

Participants used physical equations to form a hypothesis during equation-based hypothesis formation. Thinking with equations not only shaped participant's hypothesis but also warranted their results. However, the validity of this warranty is restricted to using accurate equations in the appropriate situations.

In this study, discussions of the physical equations and using them in the hypothesis formation process were taken as an indicator of equation-based hypothesis formation. Following vignette was provided to exemplify equation-based hypothesis formation process.

Vignette 2

The following conversations took place at the beginning of the Competitive Fathers activity while the participants in the third group were working on it. Participants began the activity by reading the scenario on the worksheet silently. After that the following conversation took place.

Canan: What is the phenomenon in the scenario?

Bedia: They gain one point with every push. Who does gain more points in five minutes?

Canan: Then, he should push slowly, with the minimum level he wins.

Bedia: I could not see a problem in this scenario? I push, than, it goes and returns, goes and returns eventually…

Canan: I could not understand the scenario either; let's ask it to the assistants. (They called assistant and begin talk with him.)

Bedia: I could not see a problem with this scenario. I push constantly, it goes and returns.

Canan: He (one of the father) pushes with a minimum force. So he wins. Is not he?

Teaching Assistant 1: Well, let's think another way, what do you have in the scenario; a swing. What do we have in physics similar to a swing?

Bedia: Pendulum.

TA1: Yes. We know that the more force you apply to a pendulum, the more it goes. However, do you think that the more force you apply to a pendulum, the more swing time it gets? This can be a problem. You could find different problems about the scenario. Ok?

Canan: Ok. Let's think. (TA left the group.)

Group struggled to find a question about the scenario. They thought that pushing the swing slowly decreases the swinging time. Although they were not sure about this knowledge, they recommended swinging with minimum force decrease swinging time. Instead of putting scenario in a physical framework, they preferred to reach a quick solution. Teaching assistant provided guidance to the group members by stimulating them to think the physical aspects of the scenario. He also gave an example of problem parallel to the group members' idea.

Bedia: We apply a certain force and it needs to move with that force. The important point is what the force is, is not it?

Canan: No. The important point is the speed of the pendulum.

Bedia: Speed is changing when we apply different forces. It also changes time. However, the important point is which one of them changes more. More force increase time unnecessarily.

Canan: Yes. How can we find time?

Bedia: We need to find total time. We may think about projectile motion.

Canan: How can you find time from projectile motion?

It was seem that the advices of teaching assistants did not work. They thought about the effect of applied force on the speed of the swing instead of searching other physical variables that can affect the period. In other words, they tried to find a solution without thinking about the different concepts and relationships among concepts. They felt the need to confirm their idea by finding some specific equations. Nevertheless, they did not find an equation describing the period of pendulum. In the following episode, it was seen that they applied an alternative strategy by using different equations related with different physical frameworks.

Bedia: The hypothesis may be they are the same. Both of the fathers gain equal points. In one long-time, in one long-distance, they balance each other.

Canan: Is whether it (hypothesis) is right or wrong important?

Bedia: I do not know.

…

Bedia: (Turns to the Erdal) There is an equation like $\frac{1}{2}xt^2$ .What is it?

Erdal: $\frac{1}{2}mv^2 = mgh$

Bedia: No, I did not ask it. It is like $\frac{1}{2}xt^2$. The equation with t^2.

Erdal: Is not it $\sqrt{2gh}$?

Bedia: No I did not ask it. There is an equation with t^2.

Erdal: It is $x = Vt$. You make it $v = \frac{x}{t}$. Put ν in place, that's it. (After this conversation, Bedia and Canan continued to work with equations.)

In this section of the discussion, it was clearly seen that participants tried to associate different physical equation with the problem situation to confirm their previous idea. When they thought about the movement of a pendulum, group decided intuitively that applied force does not have any effect on period of pendulum. They wanted to confirm this idea with mathematical equations. Because group members did not know exactly which equations they need to use, they asked for help from other groups. This conversation also showed that this group members' knowledge of equations and appropriate use of equations was very weak.

Bedia: That's it. I found. (She showed her finding with the equations to the group friend.)

Bedia: Times are equal. That means that both of the father gains equal points. (They called teaching assistant.)

Canan: We wrote our hypothesis. We said that father gain equal points.

Bedia: We found this with equations. (She explained the equations they used.)

TA1: Do not talk me with equations.

Bedia: Why? Cannot we calculate with equations?

TA1: I want you that show this to me with an experiment.

Bedia: Ok.

TA1: Design an experiment that can prove your hypothesis.

Bedia: Ok. We can do it with a pendulum.

TA1: Ok.

In spite of their inadequate knowledge of equations, group settled on a decision. Their decision was to investigate the effect of applied force to the pendulum on period. Their physics concepts related to the scenario were "*pendulum and period*". Their question was "*The problem is if one dad pushes his son with big force, son will come fast to the beginning point. On the other hand if* *other dad pushes his son with little force, son will come to the beginning point slowly but the distance son take is lower.*" Their hypothesis was "*If force is changed, the period is not changed.*"

During the hypothesis formation process, participants dive into a deductive process in which they applied different physical equations to confirm their idea. They only focused on two variables and did not think about the other possible variables, because they thought that their only aim in the task was finding a solution to the problem situation, not finding out the relationships between variables with an experiment. They converted inquiry laboratory into a confirmatory laboratory with this process.

As can be seen from the conversations, group's idea about the problem situation changed during the work with equations. At the beginning of the laboratory session, the group thought that force applied to the pendulum, in other words the maximum angular displacement and period of pendulum are inversely related. However, their work with physical equation changed their hypothesis.

4.1.3 Context-based Hypothesis Formation

Context-based hypothesis formation refers to participants' use of contextual elements of scenarios without considering the physical concepts to form a hypothesis. During the context-based hypothesis formation process, participants focused on contextual characteristic of the situation and tried to find a solution to the problem with the help of similar situations. They did not use physical concepts during the pre-lab discussions or they used them improperly. Instead of relating scenario with a physical framework, they only focused similar situations that can provide a solution to the scenario. As a result, the problem and their hypothesis consist of contextual elements of scenario or similar situations. They dealt with the task as if their only aim was finding a solution to the scenario with their existing knowledge.

In this study, discussions of the similar situations and using contextual elements in the hypothesis formation process were taken as indicators of context-based hypothesis formation. Following vignette was provided to exemplify context-based hypothesis formation process.

Vignette 3

The following conversations took place at the beginning of the Tea Pleasure activity while participants in first group were working on it. Participants began the activity by reading the scenario on the worksheet silently. After that following conversation took place.

Baha: It will be something relevant to insulation. (They wrote the concepts related to the scenario. They wrote temperature and heat.)

Baha: Now, they want to not cool down the tea. So, we will do something about isolation.

Yakup: Is it about the structure of thermos bottle?

Baha: It is like it...We wrap cup with something like aluminum foil.

Yakup: Okay, but what then?

First conversations indicated that the group understood the scenario and think about their experiment without forming a hypothesis. They focused directly on a similar situation (thermos bottle) that can provide a solution to the scenario.

Yakup: What else can we do?

Baha: Let's look at equipment cabinets. Which equipment do we have? (They went to the cabinets and took some laboratory equipment. They took a thermometer, a heat source, a beaker, and a tripod.)

Yakup: We can do something with these.

Group went to look at equipment without having a hypothesis. Although they did not know what they would do exactly, they needed to look at equipment to form a hypothesis. They thought that the equipment they found in the laboratory would shape their hypothesis.

As the conversations revealed, participants' major concern was not to identify the physical concepts hidden in the scenario and come up with a context independent hypothesis, instead their major concern was seem to generate a solution to the scenario in its own context.

Baha: We can do something about solubility. If we said let's put salt or something else into the tea…

Yakup: It spoils the taste of tea.

Baha: Yes, it spoils the taste of tea, but it is not important. The important thing is presenting a hypothesis and trying it here. It maybe salt or another chemical substance. (They called TA1)

Baha: We have an idea. If we put sugar into the tea, there will be something like keep the temperature constant. It is related to solubility.

TA1: Okay.

Baha: We can put a soluble substance like sugar into the water. Than we look the temperature decrease of water.

This time group thought about another phenomenon to find a solution to the problem. However, they still could not get rid of the contextual elements. In this dialogue, they focused on some particular substances such as salt and sugar rather than a physical concept such as density. In the following script, group focused on the size of the teapot. Although it can be considered as a physical concept, they could not come up with other physical concepts because they completely restricted themselves to the context of the scenario.

Yakup: Let's think what else can we do?

Baha: We can change the glass.

Yakup: The man's problem with teapot, not with the glass.

Baha: Ok. Then we change the teapot. It is about the surface feature… he should buy a small teapot. We boil water with a large cup, when we boil it with a large cup, it cools down quickly.

Yakup: Look at the scenario. It says half of teapot.

Baha: This is the tricky part anyway. We will say why you use a big teapot. Take a small teapot. The more surface area it has, the more it cools down.

Yakup: Ok. Let's do this.

After the pre-lab discussion they decided to investigate the effect of size of the container on cooling time. Their physics concepts related to the situation were "*temperature and heat*". Their problem was "*How can we reduce temperature* *decrease of teapot?*" Their hypothesis was "*If we use smaller teapot, we can* reduce *temperature decrease of tea*."

Their choice of words in problem and hypothesis supported that they formed hypothesis with contextual elements. They frequently used contextual elements such as teapot, tea, and water during the formation of hypothesis and their use of physical concepts was very limited.

Although they wrote temperature and heat as the concepts related to the situation, they used only the temperature in the conversation. When looked their overall hypothesis formation process, they did not use heat concept ever. They used some other concepts like surface area, but they did not discuss these concepts in a physical framework. It was seemed that students were not interested in physical characteristics of the situation. Their major concern was seemed to provide a solution to the scenario. Their conversations indicated that they did not have enough physical knowledge about heat and temperature topic. They thought with similar situations that can have productive characteristics for the scenario. They proposed a hypothesis with these productive characteristics.

4.1.4 Types of Hypothesis Formation Used by Different Groups in Each Activity

In this section of the study, types of hypothesis formation were examined in each activity. When looked at the groups' performance, it was seen that they did not use one type of hypothesis formation in all activities. In each activity, they activated different type of hypothesis formation. It can be claimed that characteristics of the problem situation was more important than characteristic of group members. Table 4.1 was presented to show the type of hypothesis formation used by each group in each activity.

At the Table 4.1, some groups' hypothesis formation coded as not observable because it was impossible to determine participants' thinking process during the hypothesis formation processes for these cases. The reasons for not attaining any data for these cases were different. For example, in Spearfishing activity first group did not discuss the situation. After group members read the scenario, Baha wrote the hypothesis and explained the experiment that they would do to his group friend. Yakup admitted the hypothesis and they performed the experiment without any particular discussion. At the same activity, eighth group came to laboratory session approximately half an hour late. When they entered the laboratory, the other groups already had written their hypothesis and begun their experiments. Engin and Nalan did not think about the situation and discuss between each other. They asked one of the other groups and wrote their hypothesis with the help of that group's comments.

Table 4.1 Types of hypothesis formation used by different groups in each activity

	Competitive Fathers	Tea Pleasure	Junkyard	Journey to the Mars	Spearfishing
G1	EqB	CxB	Not Obs.	EqB	Not Obs.
G2	EqB	CxB	CpB	EqB	Not Obs.
G3	EqB	CpB	CpB	EqB	Not Obs.
G4	CpB	CpB	Not Obs.	EqB	CpB
G5	CpB	CpB	CpB	EqB	CpB
G6	CpB	CxB	EqB	EqB	CpB
G7	CpB	CpB	CpB	EqB	CpB
G8	Not Obs.	CxB	CpB	EqB	Not Obs.

G: Group
CpB: Concept-Based
CxB: Context-Based
EqB: Equation-Based
Not Obs.: Not Observable

Participants worked on the Competitive Fathers activity at the first week of this study. Concept-based hypothesis formation was performed by four groups for this activity. They thought with concepts like period, applied force or maximum angular displacement of pendulum, mass, length of pendulum, and mass while forming a hypothesis. They determined period as the responding variable and investigated the effect of one of the other variable on period. Equation-based hypothesis formation was performed by three groups. Three groups formed hypothesis based on equations. Most frequently used equation was the period of simple pendulum, $T = 2\pi\sqrt{\frac{l}{g}}$. Although this equation was consistent with the behavior of pendulums, the participants could not realize that this equation works under the condition of small maximum angular displacements of pendulum.

At the second week of the study, Tea Pleasure activity was conducted. Concept-based hypothesis formation was performed by four groups for this study. They thought with the concepts like temperature, heat, and conductivity. Firstly, they defined the dependent variable as rate of heat transfer and then tried to decrease the rate of heat transfer by experimenting with one of the variables that they thought would affect the rate of heat transfer. Context-based hypothesis formation was performed by four groups. They did not consider physical characteristics of the situation. They only think about similar situations or materials that can provide a solution to the problem of situation. For example, sixth group formed hypothesis based on the idea that boiling point of water with sugar is more than pure water and their hypothesis was "*If we increase boiling point, difference between boiling point and last temperature will decrease.*". In other example, eighth group decided their hypothesis by thinking travel mug's visual characteristics without considering its physical characteristics. Their hypothesis was "*Rate of change of temperature may be controlled by surround conditions (like air circulation and temperature, isolation).*"

In the Junkyard activity, most of the groups preformed concept-based hypothesis formation. Only one group needed to look at physical equation from their notebook during the hypothesis formation process. Groups, that formed their hypothesis based on concepts, used many concepts about the topic such as current, potential difference, resistance to electricity, current loop, electromagnetism, magnetic flux, and magnetic area during their pre-lab discussion. They discussed the relationships of these concepts and decided to investigate the effect of one variable on strength of electromagnet. The investigated variables were current, potential difference, size of the iron core of electromagnet, and number of turns of wire.

The Journal to the Mars activity was the most challenging activity among all of the activities for the participants. Writing a hypothesis took approximately one hour for this activity, while for the other activities the mean was 20 minutes. Because this activity required a hypothesis about measurement, not a causal relationship, participants thought about how they measure mass without the effect of gravitation. During the pre-lab, participants tried to apply their prior knowledge about laboratory activities and known physical equation to the situations. The solutions came from different topics. Applied topics and used formulas were as the followings; Newton's Second Law ($F = ma$), Centripetal Force ($F = \frac{mV^2}{r}$), Period of a Spring ($T = 2\pi\sqrt{\frac{l}{k}}$), and Momentum ($m_1v_1 = m_2v_2$).

At the last week of the study participants worked with Spearfishing activity. All the observed groups performed concept-based hypothesis formation related to the geometrical optics. Although, the scenario could be associated with two physics topics, geometric optic and relative motion, participants conducted investigations about the geometric optics. They hypothesized with the geometric optics concepts like light rays, reflection, refraction, and refraction index.

4.2 Designing and Conducting Experiments

Participants designed and conducted experiments to test their hypothesis. All participants agreed that best way of testing their hypothesis is controlled experimentation strategy while testing their hypothesis. During the implementation of this strategy, they tried to determine all variables that can affect the situations and they kept all variables constant except one variable based on their hypothesis. To guide the designing and conducting experiment processes, participants were asked to categorize all variables under different headings: manipulated variable, responding variable, controlled variables, and uncontrolled variables. After that, they designed and conducted experiment with the equipment they found in the laboratory. During the experimentation process, participants were asked to write the magnitudes of controlled variables of their experiment. In order to check their hypothesis, they were asked to change the magnitude of the manipulated variable periodically to get more reliable results. Participants were also required to record their data to the tables and draw graphs at the end of the experiments to generate a conclusion. During the whole process of designing and conducting experiments help was provided according to participants' demands.

The data used for the designing and conducting experiment consisted of participants' laboratory work, post-lab discussion sessions, and laboratory worksheets. During the analysis of data, particular attention was given to the participants' use of variables rather than lab equipment because use of equipment completely depends on the use of variables. Analysis of data revealed that the participants did not always use the variables as expected. The participants were expected to perform their experiments with a systematic manipulation. However they failed to perform a systematic manipulation in quite a number of experiments.

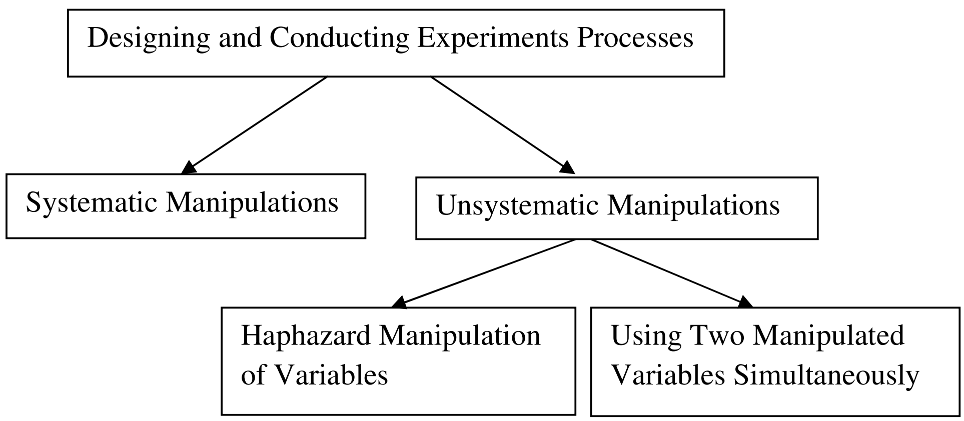


Figure 4.3 Types of designing and conducting experiments processes

In the following sections, the participants' processes of designing and conducting experiments were provided in details. The types of designing and conducting experiments processes were presented at the Figure 4.3. Two general categories for designing and conducting experiments were emerged after the analysis of data. The results were presented under these categories which were named as systematic manipulations and unsystematic manipulations. Systematic manipulations refers to processes that the participants designed and conducted experiments as expected, whereas unsystematic manipulations refer to some problematic situations on the use of variables during the experimentation process.

4.2.1 Systematic Manipulations

Systematic manipulation was used to describe participants' expected actions during the inquiry process. As mentioned above, during the hypothesis formation process, participants needed to determine all variables that may be considered in the experiment and wrote a hypothesis. Their written hypothesis shaped the design of the experiment. They needed to conduct a controlled experimentation according to their hypothesis. Controlled experimentation means that keeping all variables constant except one, manipulated variable, in an experiment. Systematization is the most important characteristic of controlled experimentation. Experimenters should keep all the controlled variables constant, change manipulated variable periodically, and measure the values of responding variable precisely to get trustworthy results. As a result of all of these systematic manipulations, the effect of manipulated variable on responding variable can be understandable. Participants of this study were expected to do systematic manipulation during the designing and conducting experiment. They were also expected do their best to get reliable results. They performed systematic manipulations in many activities.

For example, seventh group decided to investigate the effect of length on period of pendulum in Competitive Fathers activity. They defined the physical concepts related to the scenario as "*simple pendulum, period, and simple harmonic motion*". They identified the problem as "*The actual problem is to make the period small. To overcome this problem, we will shorten the length of the swing*" and their hypothesis was "*As the length decreases, the period of the swing decreases.*" They determined variables of their experiment as the following: manipulated variable was "*length of the swing*", responding variable was "*period*", controlled variables were "*mass and angle*", and uncontrolled variable was "*drug force*".

Group used a protractor, a desk clamp, a 100 gram mass, and rope for their experiment design. They attached the desk clamp on the bench, tied one end of the rope to the clamp, and the other end of the rope to the 100 gram mass. They displaced the pendulum to an initial angle and released. They measured the initial angle with a protractor, and fixed it to 30^0. In order to get accurate period, they measured the time for 4 oscillations and divided it by 4. Moreover, they repeated the process two more times and took average period. After they found the period of the pendulum for 30 cm, they changed the length of the rope and did the experiment again like previous measurements. They found periods for 30 cm, 25 cm, 20 cm, 15 cm, and 10 cm lengths of pendulum. They recorded their findings to the table and drew graphs to analyze findings.

When we look at this group's overall experimentation process in Competitive Fathers activity, it seems that their performance was consistent and meticulous. They designed a proper experiment in which they can test their hypothesis. They used appropriate measurement devices to get accurate data. This also ensured the comparison of results among the experiments with different values of manipulated variable. Repeating the same experiments more than one time for minimizing the experiment error was also an admirable behavior. Lastly, changing manipulated variable with constant intervals would ease the process of evidence evaluation.

4.2.2 Unsystematic Manipulations

Unsystematic manipulations refer to participants' problematic actions during their experimentation processes which can significantly affect the results of experiments. There were mainly two kinds of error sources of unsystematic manipulations which were categorized as haphazard manipulation of variables and using two manipulated variables simultaneously. The details about these errors will be provided in the following sections.

4.2.2.1 Haphazard Manipulation of Variables

Haphazard manipulation of variables was the most frequently observed unsystematic manipulation during participants' experimentation process. The phrase haphazard manipulation of variables was used as an umbrella phrase to refer to the situations in which participants did not do precise changes on the manipulated variable, did not appropriately measure the responding variable, or changed the magnitude of controlled variables during the collection of data. Most of the time, participants were unaware that they made haphazard manipulations or they were unaware that these haphazard manipulations would make big differences on the results of the experiments.

For example, fourth group decided to investigate the effect of released angle on period of the pendulum in Competitive Fathers activity. They wrote "*pendulum, period*" for physics concepts related to the activity. Their problem was "*Main problem is the difference between the periods of swinging fastly and slowly.*" and their hypothesis was "*The period of swinging fastly is lower than the period of swinging slowly.*" Group determined variables of their experiment as the following: manipulated variable was "*intensity of forces*", responding variable was "*period*", controlled variable was "*length*", and uncontrolled variable was "*weights of sons*". Although their manipulated variable was intensity of force, they manipulated released angle of pendulum in accordance with the recommendations of teaching assistants. Teaching assistants recommended this, because there was not a device that measuring force in the laboratory and these two variables are identical for pendulum system.

Yavuz and Erdal used a rope, two 500 gr weights, two stand bases, stand rods, and bossheads for their experiment design. They set up two identical experiment systems. They placed stand bases on the floor and assembled stand rods on it. They fixed up bossheads upside of the stand rods and tied ropes with weights on bossheads. The lengths of the ropes were 50cm approximately. They displaced two pendulums with different angles and released them at the same time without measuring angles with a protractor. They observed the movement of pendulums without recording the oscillation time or counting the oscillations in a time interval. Since they only watched period of each pendulum without using a measurement device like a chronometer and the periods were approximately the same, they concluded that released angle do not effect period of a pendulum. They did not pay attention to the disturbance of synchronization of pendulums. If they had noticed the disturbance of synchronization, they would have realized the effect of released angle on period of pendulum. These kinds of haphazard manipulations of variables and ignorance of little differences can make all the laboratory work worthless.

Another example of the haphazard manipulation of variables is the following. In Spearfishing activity, third group decided to investigate the effect of density on refractive index. They wrote "*optics, indices of the water, Snell's Law*" for physics concepts related to the activity. Their problem was "*The main problem* *is that he cannot determine the original place of the fish because of the difference of the indices of the water and air."* and their hypothesis was "*If the density of the matter is changed, the index of it changes.*" They determined variables of their experiment as the following: manipulated variable was "*the density of the matter*", responding variable was "*the refracted angles*", controlled variable was "*incident angle*", and uncontrolled variable was "*diffraction of the laser*".

Group used a laser, a semicircular refraction cell, an A4 paper, a protractor, water, oil, ethyl alcohol and salt for their experiment design. They placed A4 paper on a flat surface, filled the semicircular refraction cell with water, and place it on the paper. They used laser as a light source and planned to send the light beam with the 60^0 angle of incidence and measure angle of refraction. Although there was not any flaw with this intended strategy, applications did not realize it. In refraction experiment, incident ray should enter the cell at the middle of the flat side of the semicircular refraction cell. If the incident ray does not enter the medium at the middle of the cell, the angle of incidence will change. During the experimentation phase, although group had known the working principles with semicircular reflection cell, they did not pay attention on this issue. Moreover, they did not adjust the direction of incident ray exactly. They ignored little changes of angles. As a result of their behaviors, they measure the angle of refraction in water as 56^0 and they calculated refraction indices of water as 1.05, although the actual values should have been approximately 40^0 and 1.33, respectively. They also ignore little differences of position of semicircular refraction cell among trials with different matters. This also made it impossible to compare the angle of refraction of different matters.

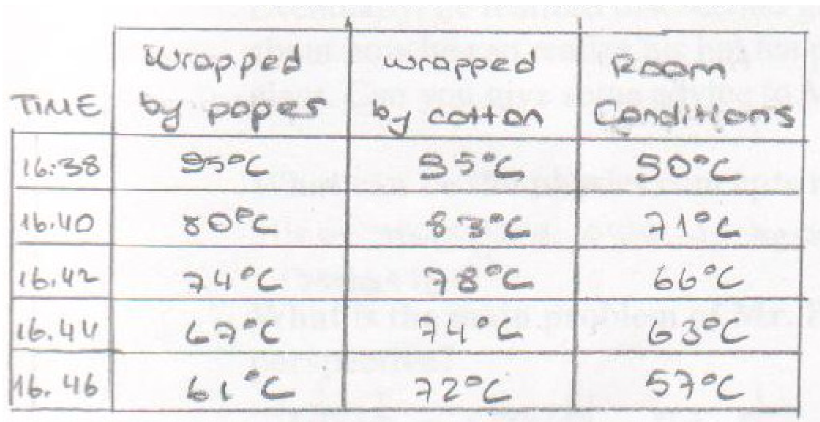
These kinds of carelessly conducting experiments caused many wrong results. Although participants warned about they need to work meticulously every laboratory sessions, haphazard manipulation of variables was seen many times. Most of the time, participants unaware of this kind of error source and attributed the responsibility to other things instead of themselves.

4.2.2.2 Using Two Manipulated Variables Simultaneously

Another error sources in the designing and conducting experiments process was using two manipulated variables simultaneously. To make a controlled experimentation, participants need to change only one variable in experiments and keep all the other variables constant. Otherwise, it is not possible to detect which manipulated variable affected the responding variable. However, participants sometimes manipulated two variables, but took into consideration only one of them. It seems that they did not think about second manipulated variable consciously or unconsciously, although they measured that variable. They did not talk or write about the effect of this variable until one of the people in the laboratory asked questions about it. Actually they could perceive that they changed more than one variable and second manipulated variables can also affect their experiment, but somehow they did not take the second manipulated variable into consideration.

For example, third group decided to investigate the effect of isolation material on cooling time in Tea Pleasure activity. They wrote "*heat transfer, area vs heat losses, material conductivity, solubility, and isolation*" for physics concepts related to the activity. Their problem was "*What should he do to minimize heat transfer?*" and their hypothesis was "*If he want to minimize heat loss, he can take the teapot near his sofa by wrapping thickly.*" They determined the variables of their experiment as the following: manipulated variable was "*isolated condition*", responding variable was "*cooling time*", controlled variable were "*water mass, time interval, air conditions*", and uncontrolled variable were "*purity of water, cleanness of beaker*".

Bedia and Canan used three beaker, three thermometers, heat source, and water for their experiment design. They filled three beakers with 50 ml water, warmed them up until they boiled. They wrapped one beaker with paper, one beaker with cotton. They did not isolate third beaker. They left the beaker in the room conditions and measured three beakers' temperature every 2 minutes for a total of 10 minutes. So far everything was going as intended way, and data could have provided deducible results. However, when looked groups data table which is presented at the Figure 4.4, we understand that they changed the beginning temperature of one beaker. This change made their experiment fuzzy and unintelligible, because they changed two variables in one experiment.



TIME	Wrapped by papers	wrapped by cotton	Room Conditions
16:38	95°C	95°C	50°C
16.40	80°C	83°C	71°C
16.42	74°C	78°C	66°C
16.44	67°C	74°C	63°C
16.46	61°C	72°C	57°C

Figure 4.4 Third group's data table at the tea pleasure activity

During the post-lab discussion, teaching assistant asked the group members the reasons for this behavior.

TA1: Why the last beaker's beginning temperature is different?

Bedia: When we measured it (beaker in room condition), it was at that temperature. We did not boil it again.

TA1: Why?

Canan and Bedia: …(No answer)

TA1: Does this (taking the last beaker's first temperature different) affect your results?

Bedia: I do not think so. It does not make too much difference.

As can be seen from the post-lab discussion, the group members were conscious about the existence of another variable which was manipulated. However, they ignored the possible effects of this variable and they did not take it into consideration during the evidence evaluation.

4.2.3 Groups' Designing and Conducting Experiments Performance in Each Activity

In this section of the study, each group's designing and conducting experiment performances were examined in each activity. When looked at the groups' performances, it can be seen that some groups' performance were better than the other groups. For example, fifth and eighth groups did systematic manipulation in all activities. It can be claimed that characteristics of group members was more important than characteristic of problem situation while designing and conducting experiments. Table 4.2 was presented to show each group's designing and conducting experiments performance in each activity.

Table 4.2 Groups' designing and conducting experiments performance in each activity

	Competitive Fathers	Tea Pleasure	Junkyard	Journey to the Mars	Spearfishing
G1	HMV	SM	SM	HMV	SM
G2	HMV	UTMVS-HMV	SM	HMV	SM
G3	HMV	UTMVS-HMV	UTMVS	SM	HMV
G4	HMV	SM	SM	HMV	SM
G5	SM	SM	SM	SM	SM
G6	HMV	UTMVS-HMV	SM	HMV	SM
G7	SM	UTMVS-HMV	SM	SM	HMV
G8	SM	SM	SM	SM	SM

G: Group
SM: Systematic Manipulation
HMV: Haphazard Manipulation of Variables
UTMVS: Using Two Manipulated Variables Simultaneously

In Competitive Father activity, three groups performed systematic manipulation while they were designing and conducting experiments. The other groups' performance had some deficiencies because of haphazard manipulation of variables. The common problems of participants who did haphazard manipulation of variable in Competitive Fathers activity was seen during the measurements of angle and counting the period of pendulum.

In Tea Pleasure activity, four groups performed systematic manipulation while they were designing and conducting experiments. The other groups not only did haphazard manipulation of variables but also used two manipulated variables simultaneously. Haphazard manipulations of variables were mostly related to inappropriate use of thermometers and purity of used beakers. Because each group formed different hypothesis and conducted different experiments, their used manipulated variables were different. For example, seventh group changed the type of isolated material with the thickness of isolated material in their experiment. While type of isolated material was their hypothesized manipulated variable, they also changed the thickness of isolated material in the experiment and they ignored the effect of thickness of isolated material.

In Junkyard activity, most of the groups performed systematic manipulation. This is probably because of the nature of experiments and measurement devices used in this activity. The Junkyard activity was about electricity and participants used multimeters to measure current and potential difference. Measurements in the electric circuit are independent of human error. Only third group used two manipulated variable simultaneously in their experiment. While their manipulated variable was number of irons (amount of iron core) in electromagnet, they also chanced the radius of electromagnet.

The Journey to the Mars activity was about measurement, so it was a good activity to understand participants designing and conducting experiment ability. Participants designed experiments in many topics. While four groups performed systematic manipulation, the other four groups did haphazard manipulation of variables in their experiments. Three of these groups designed kinematics experiments and they needed constant force or constant speed. However they experienced problems when they try to manipulate or measure force and speed. Sixth group conducted an experiment with inertia scale by measuring the period of inertia scale with different masses. However, they manipulated two variables simultaneously. Although their manipulated variable was mass, they also changed amplitude of inertia scale.

In Spearfishing activity, six groups performed systematic manipulation while they were designing and conducting experiments. Third groups` designing and conducting experiment process in this activity described under "Haphazard Manipulation of Variables" heading. Seventh groups had similar problems such as measurements of angles and adjusting the direction of light beams.

4.3 Evidence Evaluation

Evidence evaluation is the last but not the least part of the inquiry processes. It has many different aspects. Evidence evaluation includes understanding of experimental data, interpreting experimental data with the help of tables and graphs, examining strength and weaknesses of experiment design, and combining experiment results with the prior knowledge. Every experiment design and experimentation process has limitations. These limitations determine the reliability and validity of that experiment results. Participants had to provide rational judgments about these limitations.

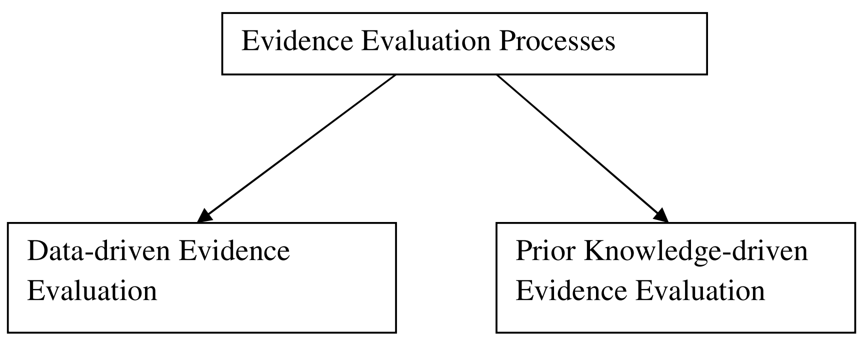


Figure 4.5 Types of evidence evaluation processes

Participants needed to evaluate their experimental results and provide a recommendation for the scenario at the last part of laboratory session. In addition, there was a post-lab discussion session in which participants explain all their lab-work of the day. The data looked for revealing evidence evaluation processes consisted of these post-lab discussion sessions, laboratory worksheets, and the group discussions during the analysis of data. There were two major types of evidence evaluation processes emerged during the data analysis as presented at the

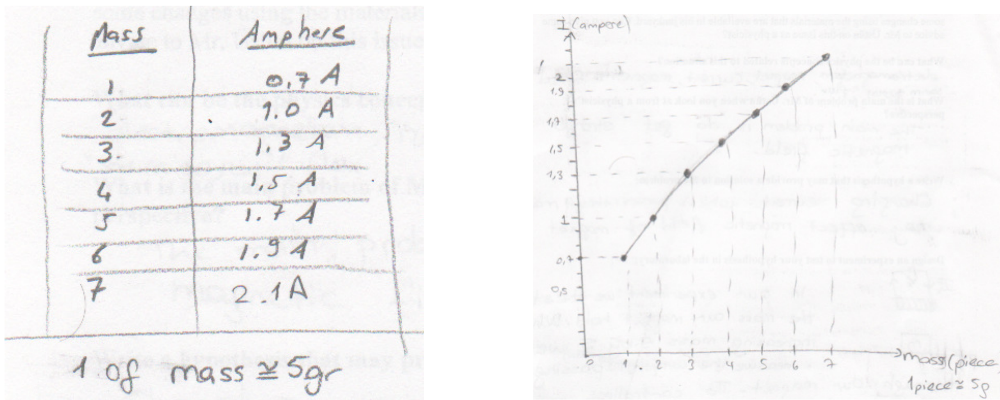
Figure 4.5; data-driven evidence evaluation and prior knowledge-driven evidence evaluation. Data-driven evidence evaluation required to look at experiment results with the pros and cons of design and experimentation process, and to reach a rational decision based on this process. Participants, who made prior knowledge-driven evidence evaluation, ignored or distorted the data and presented results according to their prior knowledge.

4.3.1 Data-driven Evidence Evaluation

Data-driven evidence evaluation refers to participants' interpretations which were generated based upon the experimental data and rational evaluation of design of the experiment and experimentation process. Participants' knowledge of their experimental data, design of experiment, and experimentation process were the sources of information for data-driven evidence evaluation. Only this information should be used as a confirmation or disconfirmation of prior knowledge. Of course prior knowledge of the participants shaped evidence evaluation process. However, participants needed to know which information came from their experiment and which knowledge came from their prior knowledge consciously. They needed to identify the weak points of their experiment and value their experimental results with the help of this information. The following is an example of data-driven evidence evaluation.

For example, eighth group decided to investigate the effect of current on strength of electromagnet in The Junkyard activity. They wrote "*electromagnetism, magnet, current, magnetic field, number of turns of wire, and flux*" for physics concepts related to the activity. Their problem was "*The main problem is to get stronger magnetic field*" and their hypothesis was "*Changing current which passes through magnet may affect magnetic field of magnet.*" They determined variables of their experiment as the following: manipulated variable was "*Ampere*", responding variable was "*the mass of electromagnet hold*", controlled variable were "*mass, resistance, number of turns*", and uncontrolled variable were "*multimeter's error, vibration of our hand*".

Nalan and Engin made an electromagnet by wrapping a nail with copper wire and set up an electromagnet with, a voltage source, a rheostat, an ammeter, a voltmeter and connecting wires. They measured the power of electromagnet by testing the mass that their electromagnet can hold. While increasing the mass by 5 gr, they measured the necessary current passing through electromagnet. They checked their data by repeating measurements. They recorded their data and drew graph of their data. Their data table and graph was presented at the Figure 4.6.



Mass	Amphere
1	0,7 A
2	1.0 A
3	1,3 A
4	1,5 A
5	1,7 A
6	1,9 A
7	2.1 A

1. of mass ≅ 5gr

Figure 4.6 Eighth group's data table and graph at the Junkyard activity

The interpretation of these data table and graph confirmed group's hypothesis that increasing current which passed through electromagnet increased the power of it. The data table and graph gave more information like electromagnet's current and magnetic power is directly proportional. They pointed out this result during the post-lab discussion.

At the interpretation part of laboratory worksheet, they evaluated their experiment logically. Their arguments on worksheet were as the following. "*Our results are acceptable because for carrying more mass we need more magnetic field so more ampere (current)."* In this part, group interpreted their experimental result with the help of their physical knowledge. In the group's hypothesis, the dependent variable was the magnetic field of electromagnet, but in the experiment the dependent variable was the mass that the electromagnet can hold. They identified the magnetic field of electromagnet with the mass of electromagnet hold. They gave a rational for their experiments while saying "for *carrying more mass we need more magnetic field*".

Group discussed their possible error sources with the following sentence. "*Vibration of our hand or multimeter's error might affect our results…"* Identifying possible error source was an important inquiry skill and highly expected from participants. Successfully identifying error sources showed that these participants cognizant of their experiment.

Group defended their experiment design with the following statement. "*Instead of changing the current in order to determine how much weight it may carry, it is more logical to change the mass to determine how much current will carry it. By this way we minimize the error.*" During the experimentation process they realized one more possible error source which is big units of measurement. To decrease the effect of this error source, they changed manipulated variable and responding variable in the experiment. They measured current with a multimeter which has less unit of measurement than masses. It seems to be beneficial for experiment results.

4.3.2 Prior Knowledge-driven Evidence Evaluation

Prior knowledge-driven evidence evaluation is highly related to confirmation bias. During their interpretation of experimental results, participants either ignored or distorted the experimental data and generated irrational evaluations about their experimentation process. Participants sometimes confused experimental data with prior knowledge. They presented their prior knowledge as experimental results. The following is an example of prior knowledge-driven evidence evaluation.

Second group decided to investigate the effect of purity of water on cooling time in Tea Pleasure activity. They wrote "*heat, conductivity, boiling point*" for physics concepts related to the activity. Their problem was "*How can we increase the boiling point of the water?*" and their hypothesis was "*The less pure the water has, the higher the boiling point it has. Therefore the less pure water cools in long time period.*" They determined variables of their experiment as the following: manipulated variable was "*purity of water*", responding variable was "*temperature*", controlled variable were "*total cooling time, and amount of water and sugar"*, and uncontrolled variable was "*purity of water we used*".

Haluk and Sadri used two beaker, two thermometers, heat source, sugar, and water for their experiment design. They filled both beakers with 100 ml water, put sugar on one of the beakers, and warmed them up until they boiled. They expected that water with sugar boils with a higher temperature. However, it did not happen as expected. Both of waters boiled at the same temperature approximately. After that group closed the heat source of water and continued to boil water with sugar. They waited until the temperature raised 2 ^{0}C. In the meantime, there was much water loss because of the evaporation. After they closed heat sources, they measured beakers' temperature every 1 minute for a total of 5 minutes. Their first and last temperatures for water and water with sugar were 97 ^{0}C-71 ^{0}C and 99 ^{0}C-73 ^{0}C, respectively. As a result of this experiment, they concluded that "*The pure water and water with sugar cool at the same rate, however the water with sugar heated to higher temperature so it had the higher temperature at the end of 5 minutes.*"

When heating water and water with sugar, group expected different boiling points, but they were the same. Thereupon, they continued to heat water with sugar. They trusted on their prior knowledge and because of this they manipulated experimental design.

Another problem with the second group's experiment was that they changed their experimental data to make it parallel to their prior knowledge. Because of heating the beaker with sugar for a long time, that beaker lost too much water. As a result of this, it cooled rapidly than beaker with water. This result contradicted with their prior knowledge and they changed the data.

At the interpretation part of laboratory worksheet they did not mentioned about boiling point problem or their work. They did not take into consideration the effects of their experimentation process. Their writings on that part were as the following. "*The situations we did the experiment were the same for pure water and also water with sugar. Thus, there weren't any effect we faced with. Finally, we rely on our data.*"

4.3.3 Groups' Evidence Evaluation Performance in Each Activity

In this section of the study, each group's evidence evaluation performances were examined in each activity. When the groups' performances were analyzed, it can be seen that some groups' performances were better than the other groups. For example, fifth and eighth groups' evidence evaluation processes were data-driven in all activities. It can be said that characteristics of group members was more important than characteristic of problem situation in evidence evaluation process. It is also worth to notice that these groups, fifth and eighth groups, did systematic manipulations in all activities. There may be correlation between systematic manipulation and data-driven evidence evaluation. Table 4.3 showed all groups' evidence evaluation performance in each activity.

Table 4.3 Groups' evidence evaluation performance in each activity

	Competitive Fathers	Tea Pleasure	Junkyard	Journey to the Mars	Spearfishing
G1	PKDEE	PKDEE	DDEE	PKDEE	DDEE
G2	PKDEE	PKDEE	DDEE	PKDEE	DDEE
G3	PKDEE	PKDEE	DDEE	DDEE	PKDEE
G4	PKDEE	DDEE	DDEE	PKDEE	DDEE
G5	DDEE	DDEE	DDEE	DDEE	DDEE
G6	DDEE	DDEE	DDEE	PKDEE	DDEE
G7	DDEE	PKDEE	DDEE	PKDEE	DDEE
G8	DDEE	DDEE	DDEE	DDEE	DDEE

G: Group
PKDEE: Prior knowledge-driven evidence evaluation
DDEE: Data-driven evidence evaluation

In Competitive Fathers activity, four groups considered experiments results and reached rational conclusion based on their experimentation process. On the other hand, the other four groups ignored their experiment results and experimentation processes. They provided their prior knowledge as the results.

In Tea Pleasure activity, data-driven evidence evaluation was observed on four groups. Prior knowledge-driven evidence evaluation was observed on first, second, third, and seventh groups. There had been many unsystematic manipulations in this activity during the participants' experimentation process. This might be the reason that the number of prior knowledge-driven evidence evaluations is quite high in this activity.

Prior knowledge-driven evidence evaluation was not seen in Junkyard activity. All groups provided their result with the help of their experiments. The systematic manipulations and confirmed hypothesis might direct participants to the data-driven evidence evaluation.

In Journey to the Mars activity, three groups did data-driven evidence evaluation. The other groups did prior knowledge-driven evidence evaluation. Because this activity is about measurement, participants who realized his\her measurements were false fabricated data and changed their experimental results.

In Spearfishing activity all groups did data-driven evidence evaluation except third group. Third group changed their experiment results according to their prior knowledge. Most groups conducted experiments systematically in this activity, and so believed in their experiment results and did data-driven evidence evaluation.

4.4 Groups' Inquiry Processes

In this section of the study, groups' inquiry processes were examined in each activity. Table 4.4 showed all groups' inquiry process in five activities according to classification of this study.

Table 4.4 indicated that one group's inquiry performances were not the same in all activities. Their performance changed activity to activity based on the interaction of participants with the activity. For example, third group formed hypothesis based on contextual knowledge and with contextual elements, did unsystematic manipulations while designing and conducting experiments, and their evidence evaluation process driven mostly by prior knowledge in Tea Pleasure activity. However, in Junkyard activity, they formed hypothesis with the concepts, did systematic manipulation, and did data-driven evidence evaluation.

Table 4.4 Groups' inquiry processes

		Hypothesis For.			Experimentation			Evidence Eva.	
		CpB	EqB	CxB	SM	HMV	UTMVS	DDEE	PKDEE
G1	A1		X			X			X
	A2			X	X				X
	A3	Not Observable			X			X	
	A4		X			X			X
	A5	Not Observable			X			X	
G2	A1		X			X			X
	A2			X		X	X		X
	A3	X			X			X	
	A4		X			X			X
	A5	Not Observable			X			X	
G3	A1		X			X			X
	A2	X				X	X		X
	A3	X					X	X	
	A4		X		X			X	
	A5	Not Observable				X			X
G4	A1	X				X			X
	A2	X			X			X	
	A3	Not Observable			X			X	
	A4		X			X			X
	A5	X			X			X	
G5	A1	X			X			X	
	A2	X			X			X	
	A3	X			X			X	
	A4		X		X			X	
	A5	X			X			X	
G6	A1	X				X		X	
	A2			X		X	X	X	
	A3		X		X			X	
	A4		X			X			X
	A5	X			X			X	
G7	A1	X			X			X	
	A2	X				X	X		X
	A3	X			X			X	
	A4		X		X				X
	A5	X				X		X	
G8	A1	Not Observable			X			X	
	A2			X	X			X	
	A3	X			X			X	
	A4		X		X			X	
	A5	Not Observable			X			X	

G: Group; A: Activity; CpB: Concept-based Hypothesis Formation;
CxB: Context-based Hypothesis Formation; EqB: Equation-based Hypothesis Formation; SM: Systematic Manipulation; HMV: Haphazard Manipulation of Variables; UTMVS: Using Two Manipulated Variables Simultaneously;

On the other hand, fifth and eighth groups' performances were mostly similar in all activities. They mostly formed hypothesis with concepts, did systematic manipulation and data-driven evidence evaluation. This showed that participants in these groups have better understanding of inquiry skills than the other participants.

The analysis of all groups' inquiry processes also showed that there can be a relation between participants' designing and conducting experiments performance and evidence evaluation performance. While participants performed systematic manipulations, they mostly do data-driven evidence evaluation. Alternatively, while participants performed unsystematic manipulation, they mostly do prior knowledge-driven evidence evaluation.

CHAPTER 5

DISCUSSION, IMPLICATIONS, AND RECOMMENDATIONS FOR FUTURE RESEARCH

This chapter is presented in three sections. Discussion of the data analysis is presented in the first section. Possible implications of the results for educators' practices are discussed in the second section. Lastly, recommendations for further research are provided in the third section.

5.1 Discussion of the Data Analysis

The aim of this study was to investigate undergraduate physics education and physics students' inquiry process in a physics laboratory. A framework for inquiry processes were defined according to Klahr and Dunbar's (1988) Scientific Discovery as Dual Search (SDDS) model to gain better understanding. SDDS model proposed that inquiry process includes hypothesis formation, designing and conducting experiments, and evidence evaluation. 16 prospective physics teachers' inquiry performances, in 8 groups, in five different problem-based activities were investigated. The variations on inquiry processes were analyzed and categorized for each phase of inquiry.

During hypothesis formation process, several variations on the hypothesis formation were observed based on the nature of sources used by the participants and how these sources were used. These variations were classified as concept-based hypothesis formation, equation-based hypothesis formation, and context-based hypothesis formation. Concept-based hypothesis formation means that participants used physical concepts to form a hypothesis. They conceptually linked problem situation with a physical framework. They determined their hypothesis with the help of physical framework to identify the physical concepts. They generated their hypothesis based upon the possible relations among the identified concepts. On the other hand, equation-based hypothesis formation means that participants used physical equations to form a hypothesis. During the equation-based hypothesis formation process, participants associated the problem situation with a physical framework to find a productive physical equation which would provide a solution to the problem. However, the relationships among the variables hypothesized by the participants were reduced to the relationship within the equations. Context-based hypothesis formation means that participants used contextual elements of scenarios without considering the physical characteristics to form a hypothesis. During the context-based hypothesis formation process, participants thought about a few contextual characteristic of the situation and tried to find a solution to the problem with the help of similar situations. Instead of relating the problem situation with a physical framework, they only focused similar situations that can provide a solution to the problem.

The studies aiming to describe hypothesis formation process were not common in the literature. This process is usually dealt with under the heading of "generating research questions" in science education literature. These studies show that younger students can successfully generate inquiry questions (Kuhn & Dean, 2005; Metz, 1995; Zimmerman, 2007). Roth and Roychoudhury (1993) stated that students' questions become more specific and examined variables and relationships become more complicated over time with the continuous engagement in inquiry tasks. However, Krajcik et al. (1998) reported that middle school students' generated questions mostly stemmed from personal experience rather than from the need of understanding scientific relationship. This assigns teachers a critical task during inquiry activities. They need to guide students' explorations by introducing scientific concepts in the context of the inquiry task and encouraging them to explore relations among these concepts. However, teachers firstly need to have related experience about challenges of inquiry before guide students' through their inquiry processes.

The results of this study also indicated that prospective physics teachers' hypothesis formation processes vary in different activities, so in different topics.

When groups' hypothesis formation processes observed, it was perceived that they performed different type of hypothesis formation in each activity. It can be claimed that characteristics of the activities was more important than characteristic of group members in the hypothesis formation process. This does not mean that characteristics of the participants did not affect hypothesis formation process. Actually, hypothesis is totally formed by interaction between prior knowledge and understanding of the problem situation. The characteristics of participants may affect the hypothesis formation process in some degree in the interaction process.

Prospective physics teachers, like all teachers, must have strong content knowledge. The content knowledge of physics embraces concepts and relationships among concepts. Physics should be seen as the conceptual understanding of the world not as an inert body of information to be memorized (Hewitt, 2010; McDermott, Shaffer & Constantinou, 2000). The linkages between everyday situations and physics concepts should be established. In this study, some participants successfully linked some problem situation with physics concepts. They discussed problem situation in a physical framework and formed their hypothesis with physical concepts. It can be said that participants who performed concept-based hypothesis formation in an activity had strong physical frameworks on that topic. Concept-based hypothesis formation was mostly observed in the activities related to electricity and geometric optics. They used concepts in these activities productively.

Another type of hypothesis formation identified in this study is equation-based hypothesis formation. Although participants were used physical concepts in equation-based hypothesis formation process, they did not discuss the attributes of the concepts qualitatively and possible relationships among concepts. They only focused on results of their experiment with the help of physical equations. Thinking with physical equations not only shapes their hypothesis but also indicates what should be the result of their experiment. Actually, using physical equations do not cause any problem in physics education, on the contrary, it is highly recommended in problem solving situations. Moreover, some researchers are working to have students possess sound mathematical models with conceptual understanding in physics education (e.g. Hestenes, 1987). However, using physical equations to form a hypothesis and investigating relations which is stated by equation is inappropriate for an inquiry task. It is contrary to the nature of inquiry. Inquiry is an inductive process in which unknown characteristics of or relations within a situation are investigated. In equation-based hypothesis formation, participants investigated a relationship which is stated in the equation, so a known relationship. This makes it a deductive process in which a well-known fact is tested with an experiment which blocks the originality and generation of new ideas. Literature on self-directed experimentation suggested that the perceived goal of inquiry activities may affect students' performance during the activities (Klahr & Dunbar, 1988; Schauble, 1990; Schauble, Klopfer, & Raghavan; 1991). Although the activities designed as inquiry activities in this study, participants might perceive them different than aimed. This could influence participants' performance in inquiry activities.

At the university level physics courses, students usually learn physics topic in lectures and then conduct experiments related to the learned topics. In addition, most of time laboratory worksheets include theoretical knowledge and related equations related to the experiment and describe step-by-step what they need to do during the experimentation process. The basic aim of these laboratories is confirmation of learned relationship which is symbolized by physical equations. Participants of this study were accustomed to this kind of traditional physics laboratory. The followed steps in equation-based hypothesis formation were very similar to traditional laboratory activities. Because of experimentation routine experienced in traditional laboratory, participants may tend to convert inquiry laboratory to a confirmatory laboratory. Especially, in the Competitive Fathers activity which was used at the first week of the study, most of the groups performed equation-based hypothesis formation. These groups might form hypothesis based upon their old habits gained in traditional laboratory.

At the Journey to the Mars activity, all the groups formed hypothesis based on physical equations. This activity was about inertial mass and had a distinct property. While all the other activities designed for students to investigate causal relationship, this activity designed for students find a way of measurement in restricted circumstances. Participants were required to measure the density of a solid in an environment in which the effect of gravitation is absent. Because the effect of gravitation is mostly on the measurement of mass not on the volume, participants stuck in measurement of mass. Participants were expected to think and talk about characteristics and applications of inertial mass in this activity. However, participants hypothesis formation process did not happen as expected, they think with physical equations in which mass (m) is present. All participants' use of equation-based hypothesis formation in this activity may have two reasons. First, their physical framework on inertial mass might not sufficient to find a way to measure inertial mass. Second, they might associate the activity with problem solving tasks. They were used to apply physical equations to the problem situations.

Context-based hypothesis formation was seen only in the Tea Pleasure activity which is about heat and temperature topic. Heat and temperature topic is one of most challenging topics in physics because the words heat and temperature are used interchangeably in everyday life and there are different definitions of heat concept in the textbooks (Sözbilir, 2003). Moreover, studies on misconceptions about the heat and temperature topic revealed that many university students have similar misconceptions about heat concept like young students (Aydoğan, Güneş, & Gülçiçek, 2003; Eryılmaz, 2010; Lewis & Linn, 1994). Although prior knowledge of the participants of this study did not determined, some of them probably have some misconceptions about heat and temperature topic, parallel to these studies. Lack of coherent conceptions on the topic might prevent them from associating the problem situation with a physical framework. Instead of discussing what can be done to affect speed of heat conductivity and relations among concepts like heat, temperature, and conductivity, they searched similar situations like thermos bottle that can provide a practical solution to the problem.

Another aspect of using similar situations in the hypothesis formation process is that it decreases the cognitive load of the inquiry experience. During the concept-based hypothesis formation, participants associate problem situation with a physical framework, use conceptual knowledge, and reach a predictions (which is hypothesis) within the constraints of "conceptual ecology" (Toulmin, 1972). When hypothesis is formed, the cognitive task has not finished, they need to design an experiment with the equipment in the laboratory to test their hypothesis. This cause another cognitive load, because choosing appropriate equipment and measurement devices for experiment and deciding how to use all of them are not easy jobs. On the other hand, using similar situations by-pass most of these cognitive task. It is not only providing a practical solution to the problem situation but also reducing the necessary cognitive load.

During the second phase of their inquiry, participants designed and conducted experiments to test their hypothesis. Experimentation can be done in order to test an existing hypothesis under consideration or to confirm a well-known knowledge. Whether it is done for hypothesis testing or confirmation, the only way of experimentation strategy that provides a reasonable result is controlled experimentation which is also known as “vary one thing at a time” (VOTAT) (Tschirgi, 1980) or “control of variables strategy” (Chenn & Klahr, 1999). Controlled experimentation means that keeping all variables constant except one, manipulated variable, in an experiment. The controlled experimentation is a basic domain general strategy that allows valid inferences (Klahr, 2000). In this study, all participants decided that best way of testing their hypothesis is controlled experimentation strategy. All the experiment designs were established to put into practice this strategy.

Systematization is the most important characteristic of controlled experimentation. In addition to being essential for investigation, doing systematic manipulations provide evidence that is interpretable and therefore it enables valid inferences. Unsystematic manipulation yields indeterminate evidence, therefore making valid inferences and subsequent knowledge gain are impossible. In this study, participants performed systematic manipulation in approximately half of the experiments. They kept all the controlled variables constant, changed manipulated variable periodically, and measured the values of responding variable precisely to get trustworthy results. Moreover, they repeated the same experiments more than one time for minimizing the experiment error. Each group performed at least one time systematic manipulations in experiments. This indicates that all the participants knew conducting experiments with systematic manipulation. However, most of the groups did not performed systematic manipulation throughout all activities.

Most of the groups performed systematic manipulation in Junkyard activity. This is probably because of participants' strong conceptual knowledge and the nature of experiment design and measurement devices used in this activity. The Junkyard activity was about electricity and participants had to wire a closed circuit with the circuit components like wire, switch, and resistance. They used multimeters to measure current and potential difference. Measurements in the electric circuit are mostly precise and independent of human error. All of these provided a compact system to conduct experiment. Integration of properties of experiment design and strong conceptual knowledge may offer systematic manipulations.

Haphazard manipulation of variables was the most frequently observed unsystematic manipulation during experimentation processes. When participants did not do precise changes on the manipulated variable, did not appropriately measure the responding variable, or changed the magnitude of controlled variables during the collection of data, it was regarded as haphazard manipulation of variables. Although these actions seem to be ordinary mistakes that can be done in an experimentation process inadvertently, prospective physics teachers who had myriad experience in the laboratory should not have made too many such mistakes. Moreover, some groups did haphazard manipulation of variables more than the other. Based on these findings it can be argued that personal characteristics of the participants caused doing haphazard manipulation in the experiments. There may be some deficiency of experimentation skills of these participants which can be seen only in some particular experimentation situations.

Although there is not any finding about sources of haphazard manipulation of variables in this study, maybe it is worth to mention about a laboratory habit that students develop during confirmatory physics laboratory sessions (based on the previous personal experience of researcher in the laboratory instruction). Possessing this habit can cause haphazard manipulation of variables. When the assessment of a physics laboratory course is based on solely filled out laboratory worksheets, students sometimes pretend that they are conducting experiments in the laboratory but actually they do not conduct it. They fill the laboratory worksheet with the theoretical knowledge and fabricate data based upon the theoretical knowledge and equations. Because most of the time the aim of laboratory instruction is confirming mathematical model of a physical phenomenon, it is possible to observe students fabricating or calculating the expected results rather collecting and analyzing data. This behavior becomes habit with repeated practices. Possessing this habit can cause the observation of haphazard manipulation of variables in this study with two ways. First, it prevents the development of experimentation skills, so if participants had this habit, their experimentation skills would not be developed insomuch as expected. Second, they might adapt this habit to the inquiry activities by pretending doing experiments and fabricating results according to prior knowledge.

Using two manipulated variable simultaneously is another kind of unsystematic manipulations. Controlled experimentation requires manipulating only one variable and keeping all the other variables constant in an experiment. Otherwise, it is not possible to understand which variable affected the responding variable. Participants sometimes manipulated two variables simultaneously, but took into consideration only one of them. Actually they knew that second manipulated variables can also affect their experiment, but somehow they manipulated this variable. This may be the result of limitation of working memory. According to Kirschner, Sweller and Clark (2006), the capacity of working memory is limited during the processes of new information. Participants' working memory may restrict their perception and they may be unaware of manipulating two variables simultaneously. Kirschner et al. also stated that working memory and long term memory interact in a way that limitation occurs only when processing new information, limitation disappears when dealing with familiar information. The activity in which participants mostly used two manipulated variables simultaneously is support this view. It was mostly observed in the Tea Pleasure activity which is about heat and temperature topic. Participants' conceptual understanding in heat and temperature topic was very week; as a result of this, there were much information to process in this activity than be in the other activities. Processing in the Tea Pleasure activity might force the capacity of participants' working memory and cause manipulating more than one variable unconsciously.

Evidence evaluation is the last but not the least important phase of the inquiry processes. It requires the coordination of hypothesis space and experimentation space. Evidence evaluation includes understanding of experimental data, examining strength and weaknesses of experiment design, and linking experiment results with the prior knowledge. Every experiment design and experimentation process has limitations. These limitations determine the reliability and validity of results, therefore these limitations should be considered during evidence evaluation process. In this study, the categorization of evidence evaluation processes is based upon used sources which dominantly shaped evidence evaluation process; data obtained from the experimentation and prior knowledge. Data-driven evidence evaluation refers to participants' evaluation of experiment results with the pros and cons of design and experimentation process, and to reach a rational decision based on this process. Prior knowledge-driven evidence evaluation refers to participants' ignorance or distortion of data and to present results according to prior knowledge. The same or parallel categorizations of evidence evaluation processes exist in the developmental psychology literature (Amsel & Brock, 1996; Kuhn, Amsel & O'Loughlin, 1988).

Participants' prior knowledge-driven evidence evaluation was mostly occurred because their experiment results were not consistent with their belief. When the results did not happen as expected, participants ignored or distorted the experimental data and consequently the results, which is referred as confirmation bias. Schauble (1990) also reported that fifth and sixth grade students' invalid inferences are resulted from distortion or misinterpretation of the data to support a prior belief. Kuhn, Amsel and O'Loughlin (1988) and Schauble, Klopfer, and Raghavan (1991) also reported parallel finding and concluded that students tendency of ignorance and distortions are increased when students have strong prior beliefs like misconceptions. Observing such an evidence evaluation strategy in this study, which were seen on elementary level students, indicates that confirmation bias seems to be independent from educational level.

Coordinating theory and evidence is regarded as the core of the scientific thinking (Kuhn, 1989). Science teachers, firstly, need to distinguish theoretical knowledge from experiment results and combine them properly, after that they need to find ways of helping students gain these skills. Unfortunately, participants performed data-driven evidence evaluation approximately in one third of the experiments in this study. This indicates that they have not gained necessary evidence evaluation skills at the expected level yet at the university level. If they will begin teaching without improving their evidence evaluation level, they can guide students improperly.

The analysis of all groups' evidence evaluation processes showed that some groups' performances were better than the other groups. Two groups performed data-driven evidence evaluation in all activities. These groups also performed systematic manipulations in all activities too. On the other hand, while participants performed unsystematic manipulation in designing and conducting experiments, they mostly do prior knowledge-driven evidence evaluation. There seems to be a correlation between participants' designing and conducting experiments performance and evidence evaluation performance or a different factor was affected both of them.

When reviewing participants' general inquiry skills, it showed variance in different activities. This may indicate that inquiry skills are context dependent. While participant can demonstrate appropriate performance in one activity, they cannot demonstrate the same performance in another activity. They cannot activate their inquiry skills in all activities. Although participants can be regarded as semi-experts in physics and all the activities was related to physics topics, their performance was seemed to be affected by the characteristics of activities anyway. Literature claimed that inquiry skills can be developed with intensive exposure of experiencing inquiry activities in meaningful contexts (Krajcik et al., 1988, Roth & Roychoudhury, 1993). Participants' limited experiences in inquiry activities might cause this great variation among the activities.

5.2 Implications for Practice

The data analysis of this research showed that scientific inquiry skills of prospective physics teachers have some deficiencies in some physics related contexts. This should be considered as a serious issue because teachers cannot be expected to guide students in inquiry activities when they cannot do it properly. We need to improve prospective physics teachers scientific inquiry skills, at least enough to use in physics related contexts. This can be done with plenty of experience in which they conduct inquiry activities related to different sub-topics of physics. So, we should increase the role of inquiry in the university courses, especially in physics laboratory. If education is regarded as “enculturation process” (Brown, Collins, & Duguid, 1989), prospective physics teacher should have chances to experience scientific inquiry with appropriate guidance. Thus, they can have the necessary culture of doing scientific inquiry and gain the merits and abilities of it.

The instructional design and the role of instructor are important constructs of inquiry activities. In inquiry activities, generally, the responsibility of the instructors is defined as guidance. The application of guidance is usually defined in the form of “when students need help, it should be provided by the instructor”. However, the data analysis of this study indicated that guidance alone is not sufficient for students to reach the intended outcomes, especially for situations in which controlled experimentation is the way of inquiry. Sometimes, students’ inquiry processes may not be compatible with controlled experimentation and they do not ask for help for these situations. The instructors should monitor students’ inquiry process to locate the improper actions and provide guidance according to characteristic of ideal controlled experimentation.

First of all, students’ hypothesis should include physical concepts and the relationships among these concepts. The investigated relationship should not crystal clear for the students. Instructor should be careful on this issue. Students may have tendency to investigate a well-known relationships and to convert an inquiry based laboratory activity to a confirmatory based laboratory activity. During the hypothesis formation process, instructor should discuss the investigated topic with students, and identify the known relationships. The guidance can be done toward the unknown relationships with the help of discussion.

Another tendency of the students is using similar situations as the source in hypothesis formation process, especially when they do not have coherent conceptual understanding about the investigated topics. Although using similar situations is not a problem, even supported by many researchers (Duit, 1991; Treagust, Harrison, & Venville, 1998), the similarity should be conceptually linked. However, in this study participants did not focused on concepts while constructing a similarity with another situation. When the conceptual links between different situations are not constructed, students use contextual elements instead of concepts. To prevent this tendency, instructor and students should discuss the investigated topic conceptually before focusing on possible relationships. The discussion can include meaning of concepts and matching the contextual elements with the concepts.

Systematic manipulation of variables is a crucial characteristic of inquiry activities. It should be provided in all experiment designs. Instructors should check the experiment designs and experimentation processes of students for identifying unsystematic manipulations. Instructor can warn students immediately when the problems are identified or use this knowledge to enrich post-lab discussion session. Monitoring experimentation processes may decrease haphazard manipulation of variables.

Evidence evaluation is a hard process. In evidence evaluation process, prior knowledge and data are intertwined; and students need to reach a decision by resolving this complex structure. Moreover, they need to consider the pros and cons of the experiment design. Therefore, students may have difficulty during the evidence evaluation process. Instructors should provide scaffolding to the students during evidence evaluation process. In the scaffolding process, instructors should ask questions about data and interpretation of data.

The data analysis of this research indicated that inquiry skills are context dependent. This makes measuring inquiry skills difficult. In science education, inquiry/science process skills are generally measured with multiple choice tests. However, this application contradicts with finding of this study. It is hard to measure a variable with multiple choice tests, if it is context dependent. Alternative assessment methods like observation can be used as supplement to multiple choice tests.

5.3 Recommendations for Further Research

In the science education literature, the number of studies that investigate students' scientific inquiry skills qualitatively is limited. It should be increased with different age groups and in different domains like physics, chemistry, and biology. This may provide us an understanding of students' scientific inquiry skills and variations of it with different age groups and in different domains. The results of these studies can help instructors to determine effective strategies for different groups in different domains.

Reasons of variation on inquiry processes should also be identified to improve students' scientific inquiry skills. The data source of this study was mainly based on observations and the reasons of students' specific behaviors could not be examined in detail. Future studies can get data with think-aloud protocol to understand reasons of specific behaviors. The reasons would give educators the opportunities about how to provide guidance as well as how to design the inquiry oriented activities to overcome the specific difficulties.

The interaction between hypothesis formation process and conceptual prior knowledge should also be detailed. Students' conceptual knowledge can be measured and then their inquiry processes can be observed. Hypothesis formation processes can be examined in the light of students' conceptual prior knowledge. Moreover, this kind of research studies can assist studies that investigate the effect of inquiry activities on conceptual understanding.

Lastly, the effect of different inquiry designs on inquiry processes can also be studied. In this study, participants experienced an open inquiry activities in a problem-based learning environment and their inquiry processes in this environment was reported. Structure of a course and settings may reveal different variations on inquiry processes. Conducting similar studies with different inquiry designs in different settings give us more opportunities to elaborate students' inquiry skills and possible variations.

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APPENDIX A

LABORATORY WORKSHEET OF THE COMPETETIVE FATHERS ACTIVITY

COMPETITIVE FATHERS

In a playground, children are swinging and their fathers are pushing them. The fathers are not pushing their son randomly, but periodically. Every time they push their son, they get one point. In 5 minutes, the father getting more points will be the winner of the competition. The fathers try to develop strategies to win the competition. Can you give some advice to them on this issue as a physicist?

What can be the physics concepts related to this situation?

What is the main problem of the father when you look at from a physicist's perspective?

Write a hypothesis that may provide a solution to the problem:

Design an experiment to test your hypothesis in the laboratory:

What are the variables that can affect your experiment?

Manipulated:

Responding:

Controlled:

Uncontrolled:

Your results and observations:

Interpretation of your results and observations:

What is your recommendation to the fathers?

APPENDIX B

LABORATORY WORKSHEET OF THE TEA PLEASURE ACTIVITY

TEA PLEASURE

Like most of the Turkish man, Mr. Peşman loves drinking hot tea. He prepares half a pot of tea every evening and drinks it while watching television. However, he has not got an electric teapot and he must go to the kitchen to refill his slim-waisted glass. He bored up travelling between kitchen and living room and decided to bring teapot near his sofa. Eventually, he realized that second glasses of tea were not hot enough. He is thinking about how he can satisfy his hot tea pleasure without going to the kitchen to refill his glass. Can you give some advice to Mr. Peşman on this issue as a physicist?

What can be the physics concepts related to this situation?

What is the main problem of Mr. Peşman when you look at from a physicist's perspective?

Write a hypothesis that may provide a solution to the problem:

Design an experiment to test your hpothesis in the laboratory:

What are the variables that can affect your experiment?

Manipulated:

Responding:

Controlled:

Uncontrolled:

Your results and observations:

Interpretation of your results and observations:

What is your recommendation to Mr. Peşman?

APPENDIX C

LABORATORY WORKSHEET OF THE JUNKYARD ACTIVITY

THE JUNKYARD

In a junkyard, Mr. Üstün, the owner of the junkyard, uses big electromagnet cranes to move old cars. The electromagnet crane he uses is able to lift standard-sized cars easily. However, Mr. Üstün has realized that it is not appropriate for holding bigger cars, such as SUVs, which are two times heavier than usual cars. Because Mr. Üstün cannot afford to buy a new electromagnet crane, he tries to make a more powerful electromagnet crane by doing some changes using the materials that are available in his junkyard. Can you give some advice to Mr. Üstün on this issue as a physicist?

What can be the physics concepts related to this situation?

What is the main problem of Mr. Üstün when you look at from a physicist's perspective?

Write a hypothesis that may provide a solution to the problem:

Design an experiment to test your hypothesis in the laboratory:

What are the variables that can affect your experiment?

Manipulated:

Responding:

Controlled:

Uncontrolled:

Your results and observations:

Interpretation of your results and observations:

What is your recommendation to Mr. Üstün?

APPENDIX D

LABORATORY WORKSHEET OF THE JOURNEY TO THE MARS ACTIVITY

JOURNEY TO THE MARS

Mrs. Arslan is the first woman astronaut of Turkey and the geologist of the TRK1's crew. During the investigation on the surface of the Mars, she found a stone that she had never seen before. She decided to take this stone to the laboratory in the space shuttle to make a detailed examination. The space shuttle is revolving around the Mars. At the beginning of the examination process, she wants to find the density of the stone. However, she does not know how to measure the density of the stone exactly. Can you give some advice to Mrs. Arslan on this issue as a physicist?

What can be the physics concepts related to this situation?

What is the main problem of Mrs. Arslan, when you look at from a physicist's perspective?

Write a hypothesis that may provide a solution to the problem:

Design an experiment to test your hypothesis in the laboratory:

What are the variables that can affect your experiment?

Manipulated:

Responding:

Controlled:

Uncontrolled:

Your results and observations:

Interpretation of your results and observations:

What is your recommendation to Mrs. Arslan?

APPENDIX E

LABORATORY WORKSHEET OF THE SPEARFISHING ACTIVITY

SPEARFISHING

Uncle Salih is a former dart player and the owner of a trout farm. Every afternoon, he puts one big trout on a pool, sits on a chair near the pool, and hunts that trout with a fish spear for dinner. After these spearfishing sessions, he realized that his dart accuracy was decreased. Moreover, he also felt that he could not do spearfishing as well as he played dart. He decided to investigate the possible reasons of these problems. Can you give some advice to Uncle Salih on this issue as a physicist?

What can be the physics concepts related to this situation?

What can be the source of problem when you look at from a physicist's perspective?

Write a hypothesis related to your idea:

Design an experiment to test your hypothesis in the laboratory:

What are the variables that can affect your experiment?

Manipulated:

Responding:

Controlled:

Uncontrolled:

Your results and observations:

Interpretation of your results and observations:

What is your recommendation to Uncle Salih?

APPENDIX F

GUIDELINES FOR INSTRUCTORS DURING THE ACTIVITIES

1. Competitive Fathers Activity

Competitive Fathers activity is about simple harmonic motion. In this activity, swing is used as an application of pendulum. The hidden dependent variable of the scenario was period of a pendulum. Students were expected to investigate the effect of one variable of pendulum like length, mass, or maximum angular displacement on period of it.

Warning: Students may choose the applied force as the independent variable. Applied force for periodic motion of a swing can be associated with maximum angular displacement of simple pendulum for this activity, because frictional forces of simple pendulum are too weak.

The physics of simple pendulum

A simple pendulum is an idealized model consisting of a point mass suspended by a massless, unstretchable string. If a simple pendulum swings through a small angle, the period of pendulum can be found with the equation,

$$T = 2\pi\sqrt{\frac{L}{g}}$$

Period (*T*)*:* Time for one complete oscillation
Length (*L*): Length of pendulum
Gravitational Acceleration (*g*): The acceleration of an object caused by gravity

This equation indicates that period of pendulum is directly proportional to square root of length of pendulum and inversely proportional to square root of gravitational acceleration. This equation is also interpreted as period is independent of the mass and maximum angular displacement of the pendulum. However, this equation works with small angular displacements. The period of pendulum increases with the increasing maximum angular displacement. The equation for period of simple pendulum is indeed,

$$T = 2\pi\sqrt{\frac{L}{g}}(1 + \frac{1^2}{2^2}\sin^2\frac{\theta}{2} + \frac{1^2 \times 3^2}{2^2 \times 4^2}\sin^4\frac{\theta}{2} + \cdots)$$

On the other hand, mass does not affect the period of simple pendulum. However, if students investigate the oscillation of a rigid body like a ruler without hangs it with a string; its mass may affect the period. The equation for physical pendulum when maximum angular displacement is small,

$$T = 2\pi\sqrt{\frac{I}{mgh}} \qquad (3)$$

(*I*): Rotational Inertia of Pendulum (about an axis through its point of support perpendicular to its plane of swing

(*h*): The distance between the point of support and the center of mass of the swinging pendulum.

2. Tea Pleasure Activity

Tea Pleasure activity is about transfer of heat. The hidden dependent variable of the scenario was rate of cooling time. Students were expected to investigate the effect of one variable like first temperature, mass or surface area of cooling matter, or type or thickness of isolated material on rate of cooling time.

Warning: Students may have misconception about the meanings of concepts such as heat and temperature. The review of these concepts may be helpful in activities.

The physics of transfer of heat

Temperature is a measure of the average kinetic energy of the molecules or atoms in a substance. Heat is the energy that is transferred between a system and its environment because of temperature difference that exists between them. There are three transfer mechanisms: conduction, convection, and radiation.

Heat conduction is a mode of transfer of energy within and between bodies of matter due to temperature difference. If you leave a metal spoon in hot water for any length of time, its handle will get hot. Energy is transferred from the hot water to the handle by conduction. The vibration amplitudes of the atoms and electrons of the metal at the hot end of the spoon take on relatively large values, reflecting the elevated temperature of its environment. These increased vibrational amplitudes are passed along the spoon, from atom to atom, during collision between adjacent atoms. In this way, a region of raising temperature extends itself along the spoon to your hand.

Heat transfer by convection occurs when a fluid, such as air or water, is in contact with an object whose temperature is higher than that of the fluid. The temperature of the fluid that is in contact with the hot object increases and in most cases the fluids expands. Being less dense than the surrounding cooler fluid, it raises because of buoyant forces. The surrounding cooler fluid falls to take the place of the rising warmer fluid, and a convictive circulation is set up.

Heat transfer by radiation occurs every time because objects emit electromagnetic radiation. Energy is carried from the sun to us by radiation. If you stand near a bonfire or an open fireplace, you are warned by the same process. All objects emit such electromagnetic radiation simply because their temperature is about absolute zero, and all objects absorbs some of the radiation that falls on them from other objects.

3. The Junkyard Activity

The Junkyard activity is about electromagnetism. The hidden dependent variable of the scenario was magnetic strength of an electromagnet. Students were expected to investigate the effect of one variable like current, potential difference, size of the iron core, or number of turns of wire on magnetic strength of an electromagnet.

Warning: Time can be an independent variable when low potential difference is used in the activity.

The physics of electromagnets

An electromagnet consists of a coil of insulated current-carrying wire wrapped around a piece of iron. Magnetic field of coil of current-carrying wire magnetizes the iron, thus creating a magnet.

Materials that are highly magnetic are called ferromagnetic. Ferromagnetic materials include the elements iron, nickel, and cobalt, as well as certain alloys of these and a few other elements. In ferromagnetic materials, the magnetic fields of many atoms combine to give rise to magnetic domains, or local regions of alignment. A single magnetic domain acts like a tiny bar magnet.

In iron, the domains can be aligned or non-aligned. A piece of iron with the domains randomly oriented is not magnetic. When the iron is placed in a magnetic field, such as that produced by a current carrying loop of wire, the domains line up, or those parallel to the field grow at the expense of other domains, and the iron is magnetized. The aligned domains make the magnetic field about 2000 times stronger. When the magnetic field is removed, the domains tend to return to a mostly random arrangement do to heat effects that cause disordering. The amount of domain alignment remaining after the field is removed depends on the strength of the applied magnetic field.

4. Journey to the Mars Activity

The Journey to the Mars activity is about inertial mass. This activity mainly focused on measurement. Students need to establish an experiment design in which they can measure the mass of a matter without the effect of gravity. There is not a topic restriction in this activity; students can use inertial property in different topics such as mechanics, rotational motion, and simple harmonic motion of springs.

The physics of inertial mass

Inertial mass is the mass of an object measured by its resistance to acceleration. According to Newton's second law, we can say that a body has a mass m if, at any instant of time, it obeys the equation of motion,

$$F = ma$$

where F is the force acting on the body and a is the acceleration of the body. This equation illustrates how mass relates to the inertia of a body. Consider two objects with different masses. If we apply an identical force to each, the object with a bigger mass will experience a smaller acceleration, and the object with a smaller mass will experience a bigger acceleration. We might say that the larger mass exerts a greater "resistance" to changing its state of motion in response to the force.

On the other hand, gravitational mass depends on Newton's law of gravitation. Let us suppose we have two objects A and B, separated by a distance *r*. The law of gravitation states that if A and B have gravitational masses m_A and m_B respectively, then each object exerts a gravitational force on the other, of magnitude,

$$F = G\frac{m_A m_B}{r^2}$$

where *G* is the universal gravitational constant.

5. Spearfishing Activity

The Spearfishing activity is about relative motion and light. The aim of this activity is to have students predict a reason which may cause the problem. In the scenario, there were two problems (decreasing dart accuracy after spearfishing sessions and not doing spearfishing as well as he played dart) and the possible dependent variables were not clear. Students determine their dependent variable according to chosen problem and their possible reason for that problem. They could do a wide variety of experiments about topics of refraction of light and relative motion.

The physics of relative motion

When two observers measure the velocity of a moving body, they get different results if one observer is moving relative to the other. The velocity seen by a particular observer is called the velocity relative that observer, or simply relative velocity.

$$V_{PA} = V_{PB} + V_{BA}$$

This equation is the relation between the velocities of the same object (P) as measured in the two frames, those measured velocities are different. In words, equations says: “The velocity of P as measured by A is equal to the velocity of P as measured by B plus the velocity of B as measured by A.”

The physics of refraction of light

Snell's law is a formula used to describe the relationship between the angles of incidence and refraction, when referring to light or other waves passing through a boundary between two different medium, such as water and glass. Snell's law states that the ratio of the sines of the angles of incidence and refraction is equivalent to the ratio of phase velocities in the two media, or equivalent to the opposite ratio of the indices of refraction:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_1}{n_2}$$

with each θ as the angle measured from the normal, v as the velocity of light in the respective medium (SI units are meters per second, or m/s) and n as the refractive index (which is unitless) of the respective medium.

CURRICULUM VITAE

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PUBLICATIONS

Şenocak, E., & Ünal, C. (2006). Turkish undergraduate students' perceptions on the factors affecting the process of their learning. *Journal of Baltic Science Education, 1*(9), 50-60.

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