EPISTEMOLOGICAL BELIEFS OF PHYSICS UNDERGRADUATE AND GRADUATE STUDENTS AND FACULTY IN THE CONTEXT OF A WELL-STRUCTURED AND AN ILL-STRUCTURED PROBLEM

DISSERTATION

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by

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This study examines epistemological beliefs of physics undergraduate and graduate students and faculty in the context of solving a well-structured and an ill-structured problem. The data collection consisted of a think aloud problem solving session followed by a semi-structured interview conducted with 50 participants, 10 participants at freshmen, seniors, masters, PhD, and faculty levels. The data analysis involved (a) identification of the range of beliefs about knowledge in the context of the well-structured and the ill-structured problem solving, (b) construction of a framework that unites the individual beliefs identified in each problem context under the same conceptual base, and (c) comparisons of the problem contexts and expertise level groups using the framework.

The results of the comparison of the contexts of the well-structured and the ill-structured problem showed that (a) authoritative beliefs about knowledge were expressed in the well-structured problem context, (b) relativistic and religious beliefs about knowledge were expressed in the ill-structured problem context, and (c) rational, empirical, modeling beliefs about knowledge were expressed in both problem contexts.
The results of the comparison of the expertise level groups showed that (a) undergraduates expressed authoritative beliefs about knowledge more than graduate students and faculty did not express authoritative beliefs, (b) faculty expressed modeling beliefs about knowledge more than graduate students and undergraduates did not express modeling beliefs, and (c) there were no differences in rational, empirical, experiential, relativistic, and religious beliefs about knowledge among the expertise level groups. As the expertise level increased the number of participants who expressed authoritative beliefs about knowledge decreased and the number of participants who expressed modeling based beliefs about knowledge increased.

The results of this study implied that existing developmental and cognitive models of personal epistemology can explain personal epistemology in physics to a limited extent, however, these models cannot adequately account for the variation of epistemological beliefs across problem contexts. Modeling beliefs about knowledge emerged as a part of personal epistemology and an indicator of epistemological sophistication, which do not develop until extensive experience in the field. Based on these findings, the researcher recommended providing opportunities for practicing model construction for students.
Dedicated to my wife Rahsan and my son Eyup
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CHAPTER 1

INTRODUCTION

What do I know? How do I know what I know? Can I be certain of what I know? These questions have occupied philosophers for thousands of years. Recently researchers have begun to explore how these questions are part of knowledge for individuals. The research on beliefs about knowledge suggests that these beliefs influence how individuals evaluate knowledge claims and accept or reject ideas (Kuhn, 1991; King and Kitchener, 1994). Similar to the questions about knowledge in general are questions about knowledge in science. How is scientific knowledge generated and evaluated? How is relative importance of evidence weighted in science? How do scientists coordinate theory and data? These questions also have occupied philosophers of science. Recently science educators took an interest in how students’ and teachers’ answers to such questions shape their learning and teaching (Hammer, 1994; Roth and Roychoudhury, 1994; Tobin and McRobbie, 1997). Moreover, helping students reach an understanding of the practices of scientists and standards for generating and evaluating scientific knowledge have been
included in the goals of science education (National Research Council [NRC], 1996; American Association for the Advancement of Science [AAAS], 1993).

**Statement of the Problem**

During the last three decades the content and development of personal epistemology (individuals’ beliefs about knowledge) has been a topic that attracted researchers from various fields. Personal epistemology has been characterized in diverse ways. According to Pintrich (2002), the research on personal epistemology can be located on a continuum of three research traditions. On one end of this continuum are the developmental models, which characterize personal epistemology as a process of progression through stable stages of epistemological development. In the middle of this continuum lie the cognitive models, which conceptualize personal epistemology as consisting of multiple independent dimensions. On the other end of this continuum are the situated or contextual models, which characterize personal epistemology made up of a repertoire of beliefs or resources that are used differently in different contexts.

Initially, personal epistemology was described as a cognitive developmental process in which individuals start from dualistic views of knowledge and progress to a relativistic view of knowledge (Perry, 1970; Belenky, Clinchy, Goldberger, and Tarule, 1986). Other researchers conceptualized personal epistemology as consisting of distinct beliefs about knowledge (Schommer, 1990). Yet, others viewed personal epistemology as a repertoire of beliefs, ideas, or resources that are used according to context (Bell and Linn, 2002; Ryder, Leach, and Driver, 1999; Hammer and Elby, 2002). Although there
have been attempts to synthesize all the existing models of personal epistemology (e.g. Benedixen and Rule, 2004), there is still a lack of conceptual clarity on what personal epistemology is as a construct. Therefore, the portrayal of personal epistemology by the existing models may not be complete or accurate.

Two problems have challenged researchers’ in the field of personal epistemology. One persistent problem in this field has been the *domain specificity* of personal epistemology. By domain, personal epistemology literature refers to an academic discipline or school subject. Domain specificity means that individuals hold different sets of beliefs about knowledge with respect to different content domains. For instance, Hofer (2000) found that college students held different beliefs about knowledge about psychology and science. Brickhouse, Dagher, Letts, and Shipman (2002) found that college students’ beliefs about the relationship between theory and evidence, justification of beliefs, and nature of evidence vary depending on the particular scientific discipline and topic. Therefore, domain general investigation of personal epistemology may not be applicable to beliefs about knowledge in specific domains.

Another persistent problem has been the *context sensitivity* of personal epistemology. Context sensitivity refers to the variation in beliefs about knowledge with respect to social and cultural surroundings or the specifics of the topic or the task. Roth and Roychoudhury (1994) stated, “it might be more appropriate to speak of epistemological positions only in specific contexts rather than as descriptors of an individual’s views in general” (p. 17).
Some researchers formulated the task context as part of the context sensitivity problem in personal epistemology. Leach, Millar, Ryder, and Sere (2000) explored the problem of context sensitivity by comparing the consistency of high school students’ responses to decontextualized statements about the nature of knowledge in science to their responses to questions about nature of knowledge in the context of an ill-structured problem. They found that there was no evidence for consistency of these students’ epistemic beliefs across these two contexts.

Although the importance of domain and context has been increasingly recognized among researchers, delineating the salient aspects of domain and context remains an important issue for understanding personal epistemology (Pintrich, 2002). One such aspect is the problem type as task context. The kinds of problems that are routinely faced in both scientific research and science classrooms can be conceptualized as well-structured or ill-structured problems. The research on how people solve well-structured and ill-structured problems identified that well-integrated conceptual knowledge is essential for successfully solving both kinds of problems (Larkin, McDermot, Simon, and Simon, 1980; Chi, Feltovich, and Glaser, 1981; Shin, Jonassen, and McGee 2003). In addition, ill-structured problems require making subjective assumptions that are influenced by individuals’ beliefs about knowledge (King and Kitchener, 1994; Shin, Jonassen, and McGee 2003). Although ill-structured problems are recognized as useful to explore personal epistemology, well-structured problems are considered inconsequential to investigating beliefs about knowledge.
This study rests on the argument that well-structured problems beside ill-structured problems are important aspects of context and are integral to investigating personal epistemology. The first part of this argument deals with the nature of ill-structured problems. During the solution process, ill-structured problems are transformed into well-structured ones (Reitman, 1964; Simon, 1973; Voss and Post, 1988). For example, Fortus (2005) found that physics faculty solved ill-structured problems in mechanics by reducing them into well-structured components. Similarly, well-structured problems often appear as components of an ill-structured problem. For example, Parks (2006) described five real life research areas that are inherently ill-structured problems. Parks (2006) found that in these ill-structured real life research areas, well-structured problems in basic electricity and magnetism topics routinely arose.

The second part of the argument for the importance of well-structured problems in personal epistemology research is related to the instruction practices in physics education. Well-structured problems constitute a considerable portion of physicists’ education and research (Maloney, 1994; Redish, 2000). As undergraduate and graduate students, physicists learn physics content through solving end of the chapter problems and controlled laboratory experiments. Both of these tasks inherently are well-structured. Therefore, investigating individuals’ beliefs in solving well-structured and ill-structured problems within a single academic discipline is necessary.
Purpose of the Study

The purpose of this study was to explore individuals’ epistemological beliefs in physics. Based on the argument that epistemological beliefs vary within a single academic domain with respect to the context, this study intended to investigate such variation in terms of problem-type for different expertise levels. Problem-type, which includes ill-structured and well-structured problems, is the aspect of context that was included in the study. By expertise level this study includes the groups of freshmen, seniors, masters, and doctoral students, and faculty. Expertise level refers to years of education that individuals have in physics beyond secondary school. The purpose of including different groups of expertise in this study is twofold. First, representing beliefs about knowledge in physics would not be inclusive if the participants were chosen among individuals at a specific educational level. Second, by identifying epistemological beliefs of individuals at each of the five expertise levels, it became possible to characterize beliefs about knowledge for each expertise level separately and compare them. Therefore, this study aimed to explore personal epistemology in physics in the context of a well-structured and an ill-structured problem across five expertise levels.

Research Questions

This study seeks to explore the following questions:

1. What is the range of epistemological beliefs (beliefs about knowledge) in physics across the five different expertise level groups?
2. What are the differences in epistemological beliefs in physics in the context of a well-structured problem and in the context of an ill-structured problem?

3. What are the differences in epistemological beliefs in physics among five different expertise level groups?

Significance of the Study

This study contributes to the research and theory in personal epistemology. By bounding the domain with physics, this study addresses the domain specificity problem in personal epistemology research. In similar lines, by constraining the context with well-structured and ill-structured problems, this study addresses the context sensitivity problem in personal epistemology research. By identifying epistemological beliefs at different expertise levels, this study provides a cross-sectional account of the epistemological development of individuals in physics. Although there is extensive research on domain general epistemological development, this study provides documentation and explanation of epistemological development in physics as an academic domain.

Definition of Terms

Personal epistemology: Individuals’ beliefs about knowledge, used interchangeably with epistemological beliefs and beliefs about knowledge.

Expertise level: Years of education in physics beyond secondary school.

Well-structured Problems: Problems that have sound procedures for organizing information and arriving at correct answer.
Ill-structured Problems: Problems that are characterized as problems about which “reasonable people reasonably disagree” (King and Kitchener, 2002, p. 37). These problems are truly vexing and cannot be solved by applying algorithms. They require making judgments based on the strength of available evidence and the adequacy of argument.

Summary/Overview

The demand for a clearer understanding of individuals’ beliefs about knowledge in physics motivated this study. Chapter 2 provides the theoretical rationale for this study. As the discussion in Chapter 2 illustrates, researchers’ understanding of personal epistemology is at present blurry. Chapter 3 describes the theoretical rationale and methodological procedures involved in the study of personal epistemology discussed in the introduction. Chapter 4 provides a description of the findings for each of the research questions. Chapter 5 discusses the study’s findings in the light of the existing research, present implications of this study for science education, and provides recommendations for future research.
CHAPTER 2

REVIEW OF LITERATURE

The purpose of this chapter is to review research on personal epistemology and situate the current study in the broader literature. In this chapter, first, existing models of personal epistemology are reviewed in order to introduce the field. Then, issues surrounding domain specificity and context sensitivity of personal epistemology are discussed. Next, the nature of the task as a salient aspect of context in personal epistemology is discussed. Finally, research on problem solving that includes well-structured and ill-structured problems is reviewed.

This review includes the most commonly cited models of personal epistemology. The models reviewed are selected with respect to historical evolution of personal epistemology as a research area. Other studies reviewed are selected with respect to their relevance of the issues discussed in this literature review, such as domain specificity and context sensitivity. Inclusion criteria for these studies also include domain of the studies: Science education and physics education related studies are included; other content areas
such as social science related studies are excluded. Figure 1 shows the organization of this chapter.

Figure 1. Organization of Chapter 2 - Review of Literature.

Personal Epistemology Models

Epistemology is generally regarded as a branch of philosophy that deals with nature, origin, structure and validity of knowledge. Personal epistemology, on the other hand, is a psychological construct that deals with an individual’s beliefs about
During the last three decades the content and development of individuals’ beliefs about knowledge has been a topic that attracted researchers from various fields. Generally discussed under the concept of personal epistemology, beliefs about knowledge have been characterized in three perspectives, namely, developmental models, cognitive models, and situational/contextual models.

Figure 2. Personal Epistemology Models
The first of these is a developmental perspective (e.g. Perry, 1970; Baxter-Magolda, 1992; Kuhn, 1991), which examined the changes in personal epistemology in terms of a developmental trajectory, beginning from basic dualistic views of knowledge and progressing towards a relativistic stance. The second one is the cognitive perspective (e.g. Schommer, 1990; Hofer and Pintrich, 1997), which conceptualized personal epistemology as a collection of more or less independent beliefs about knowledge and learning. Finally, the third one is the situational/contextualist perspective (e.g. Leach, Ryder, and Driver, 1999; Bell and Linn, 2002), which conceptualized personal epistemology as a repertoire of resources that are highly sensitive to context.

**Developmental Models**

The earlier models for personal epistemology adopted a developmental perspective. In this section four developmental models are reviewed. The first model reviewed is the “Perry Scheme” (Perry, 1970), the second one is “Women’s Ways of Knowing” (Belenky, Cinchy, Goldberger, and Tarule, 1986), the third one is “Epistemological Reflection” (Baxter-Magolda, 1992), and the final model is “Argumentative Reasoning” (Kuhn, 1991).

Almost all of the existing psychological and educational research on epistemological beliefs can be traced back to Perry’s (1970) groundbreaking work on college students’ intellectual and ethical development. Perry set out to collect accounts of Harvard undergraduate students’ experiences as they interacted with the pluralistic intellectual and social environment of the university. This research lead to the
development of a scheme of intellectual and ethical development that consisted of a sequence of positions: dualism, multiplicity, relativism, and relativism with commitment.

*Dualism* is characterized by viewing the world in absolute and polar terms: we versus they, good versus bad, and right versus wrong. Correct answers for everything in the world exist in the absolute, which are known to the authority. Knowledge is seen as quantitative accretions of discrete elements to be collected by hard work and obedience to authorities.

*Multiplicity* is the modification of dualism by recognition of uncertainty and diversity of opinion. Diversity and uncertainty is accepted as legitimate but still temporary in areas where authorities has not found the answer yet. In these areas, every view is equally valid and everyone has a right to his or her own opinion.

In *relativism* diversity and uncertainty is perceived as an intrinsic property of all knowledge. Self is considered as the active maker of meaning. The binary opposites in dualism are now seen as a subclass of relativism. Knowledge is perceived as relative, contingent, and contextual. At this stage the need to choose one’s own commitments is realized.

*Relativism with commitment* emphasizes responsibility and engagement of commitment within relativism. Individuals make and affirm commitments to values, careers, relationships, and identity. Individuals progress through these stages sequentially as they mature and interact with their environment. Therefore, every next stage is more sophisticated than the previous ones. The higher the stage an individual is in the further along the individual in epistemological development.
The second developmental model is *Women’s Ways of Knowing* (Belenky, Clinchy, Goldberger, and Tarule, 1986). After Perry, characterizing personal epistemologies as ordered stages of development have become some kind of a research tradition. One of the unique studies in this tradition conducted by Belenky et al. (1986) investigated epistemological beliefs using an exclusively female sample. They criticized Perry (1970) for claiming that his scheme was equally valid for males and females while his sample almost entirely consisted of men. Belenky et al. (1986) described five ways of knowing: silence, received knowledge, subjective knowledge, procedural knowledge, and constructed knowledge.

In *silence*, women experience a passive, voiceless existence, where they only listen to the authority. This position is nonexistent in the Perry scheme. *Received knowledge* is viewing the world through binary opposites, with questions having either right or wrong answers. Received knowledge almost entirely overlaps dualism in Perry scheme with the exception that women did not identify themselves with the authority as the male sample of Perry did. *Subjective knowledge*, though still dualistic, identifies the source of knowledge within the self. It resembles Perry’s multiplicity position, allowing multiple perspectives to be equally valid. However, the meaning involves gender with men asserting a right to their own opinion and women seeing truth as intuition.

*Procedural knowledge* involves the ability to use reasoned reflection and objective, systematic procedures of analysis. It has two sub categories: separate and connected knowledge. Separate knowledge is impersonal and detached, in contrast to subjective knowledge. Connected knowledge is still procedural. However, it is personal,
stresses the importance of the capacity for empathy, and emphasized understanding over judgment.

*Constructed knowledge* is an integration of subjective and objective ways of knowing. In constructed knowledge all knowledge and truth is seen as contextual and depends on the frame of reference. Frames of reference can be constructed and reconstructed by the knower as an active participant in the making of knowledge.

The third developmental model is *Epistemological Reflection* (Baxter-Magolda, 1992). Baxter Magolda (1992) conducted a longitudinal study with college students on gender related patterns of epistemology and produced the Epistemological Reflection model. Epistemological reflection model contains four qualitatively different ways of knowing. As in Belenky et al. (1986) the ways of knowing that Baxter Magolda proposed are aligned with Perry’s positions. *Absolute knowers* see knowledge as certain and believe that authorities have all the answers. *Transitional knowers* come to understand that authorities do not have access to all knowledge and begin to accept uncertainty of knowledge. *Independent knowers* question the authority and hold their own ideas as equally valid with those of authorities. *Contextual knowers* construct their own perspectives by judging evidence in context.

The final developmental model of personal epistemology reviewed is *Argumentative Reasoning*. Dianna Kuhn’s (1991) work on individuals’ responses to ill-structured everyday problems led her to produce a model with three levels that resembles the forms described in Perry scheme and stages described in reflective judgment model. Individuals in her model are characterized as *absolutists, multiplists, and evaluativists*. 15
Absolutists believe that knowledge is certain and absolute. For them the basis of knowing is facts and expertise. Absolutists also express high certainty about their beliefs. Multiplists do not accept expert certainty and are skeptical about expertise, since experts tend to disagree and are inconsistent over time. Multiplists are radical subjectivists who value emotions and ideas over facts. For multiplists, beliefs are personal possessions, everyone is entitled to have his or her own beliefs, and all views are equally valid. Evaluativists, although deny the possibility of certain knowledge, recognize expertise and view their ideas as less certain than experts’. In contrast to multiplists, evaluativists do not believe that all viewpoints are equally valid. For evaluativists, different perspectives can be compared and evaluated for relative merits.

*Common Features of Developmental Models*

The developmental approach to epistemological beliefs is heavily based on Piagetian formal cognitive developmental theory. According to Hofer and Pintrich (2002), in the developmental perspective an individual progresses through “an invariant sequence of hierarchically integrated structures” (p. 91) of epistemological beliefs. These structures are often labeled as positions (Perry, 1970), epistemological perspectives (Belenky et al., 1986), epistemological views (Kuhn, 1991), ways of knowing (Baxter Magolda, 1992), and reflective judgment stages (King and Kitchener, 1994).

Almost all of the models of personal epistemology in the developmental tradition treat individuals’ beliefs about knowledge and knowing as general and context independent. Epistemological beliefs are similar to schemas, i.e. generalized knowledge structures, in Piagetian developmental theory. These beliefs are considered to apply the
same to any domain and any context. Individuals interact with their environment that results in changes in their beliefs. The mechanism for change is cognitive disequilibrium in which “individuals interact with the environment and respond to new experiences by either assimilating the new experience to existing cognitive frameworks or accommodating the framework itself” (Hofer and Pintrich, 1997, p. 91).

Developmental models in their core, describe personal epistemology as coherent stages that individuals progress through. The stages are hierarchically ordered, typically starting from basic dualism and progressing towards relativism. An individual cannot be a dualist in one setting and a relativist in another. Developmental approach cannot account for the apparent variation of epistemological stances of an individual in different domains and contexts. The evidence for such variation is reviewed later.

Cognitive Models

The second family of models for personal epistemology is the cognitive models. The developmental tradition provided the framework for most of the early work in epistemology research. Later, some researchers approached personal epistemology as a psychological construct that consists of separate and independent dimensions. In this section two such models “Epistemological Belief System” (Schommer, 1990, Schommer-Aikins, 2004) and “Epistemological Theories” (Hofer and Pintrich, 1997) are reviewed.

Schommer’s (1990) critique of the unitary depiction of personal epistemology led her to a different kind of conceptualization of the construct of personal epistemology. For Schommer (1990), personal epistemology consisted of several more or less separated and independent beliefs that are not organized into stages or levels. The choice of beliefs over
knowledge or cognition is due to the lower epistemic status attributed to beliefs. Epistemological beliefs do not reflect a reasoned cognitive structure, rather they are simply personal convictions or unverified opinions. Conceptualizing epistemology as beliefs resulted in treating the construct as a group of personal traits.

Schommer (1990) posited that personal epistemology could best be understood as a collection of beliefs about knowledge and learning. Schommer (1990) suggested that the beliefs about knowledge are independent, rather than existing in the form of one-dimensional developmental stages. Schommer (1990) produced a model that described personal epistemology with five discrete dimensions: *source of knowledge, certainty of knowledge, organization of knowledge, ability to learn, and speed of learning*.

The first dimension in Schommer’s (1990) model is “source of knowledge.” Source of knowledge involves a range of beliefs from knowledge is handed down by authority to knowledge is reasoned out through objective and subjective means. The second dimension, “certainty of knowledge” is conceptualized as a continuum between viewing knowledge as absolute and certain to seeing knowledge as tentative and evolving. The third dimension “organization of knowledge” presents a continuum from viewing knowledge is compartmentalized to consists of unrelated bits to viewing knowledge as highly interrelated and interwoven. The fourth dimension “ability of learning” involves a continuum for seeing the ability to learn as genetically predetermined to seeing the ability to learn is acquired through experience. The fifth dimension “speed of learning” involves a continuum for seeing learning as quick or not at all to seeing learning as a gradual process.
The second cognitive model for personal epistemology is “epistemological theories” (Hofer and Pintrich, 1997). Hofer and Pintrich (1997) emphasized the need for conceptual clarity and argued that only the components directly related to knowledge should be retained in defining the construct of personal epistemology. Hofer and Pintrich (1997) posited a four-dimensional model for personal epistemology in their comprehensive review of the literature. Their model included certainty of knowledge and simplicity of knowledge, and justification for knowing and source of knowledge.

“Certainty of knowledge” refers to the degree to which a person sees knowledge as fixed or fluid. This dimension is conceptualized as a continuum from a view of knowledge as absolute to viewing knowledge as tentative and evolving. Openness to interpretation and considering the possibility of modifying personal theories with genuine interchange is considered as the most sophisticated position in this continuum.

“Simplicity of knowledge” refers to the continuum of seeing knowledge as facts to highly interrelated concepts. At the lower end of the continuum one sees knowledge as discrete, concrete, and knowable facts. At the higher end of the continuum one sees knowledge as relative, contingent, and contextual.

“Source of knowledge” refers to the views where the knowledge comes from and resides. On the lower end of this continuum, the source of knowledge is authority and knowledge resides outside of the self. On the higher end of this continuum, the self is the maker of meaning. Self is seen as both maker and holder of meaning.

“Justification for knowing” includes how individuals evaluate knowledge claims, how they use evidence, how they make use of expertise and authority, and how they
evaluate experts’ views. Individuals at lower levels justify their beliefs through observation and authority, or by intuition and what feels right, when knowledge is uncertain. At higher stages individuals personally evaluate and integrate the views of the experts.

Inspired by the conceptual change literature, Hofer and Pintrich (1997) proposed that individuals’ beliefs about knowledge and processes of knowing could be considered as personal theories. Characterizing personal epistemology in the form of personal theories is a compromise between “overly general stage models and models that suggest epistemological beliefs can be orthogonal dimensions and do not necessarily cohere into some more comprehensive structure” (p.117).

Hofer and Pintrich (1997) were convinced that the construct of personal epistemology satisfies the criteria for a body of knowledge to be considered as a theory (Wellman, 1990). According to Hofer and Pintrich (1997), first of all, individuals’ beliefs about knowledge seem to be interconnected in complex and coherent ways. Secondly, individuals appear to make ontological distinctions between entities and processes in their epistemology. For instance, an individual will distinguish between “certainty of knowledge” and “source of knowledge.” After making an ontological commitment to a certain position, an individual will use that commitment as a guide in their subsequent thinking. The third criterion for a theory is the requirement for providing a causal-explanatory framework for phenomena in the domain. Hofer and Pintrich (1997) stress that they “are not suggesting that individuals have a formal epistemological theory as would a professional philosopher, rather that individuals’ ideas about knowledge are
towards the theory end of the continuum and are not just discrete, unrelated bits of
knowledge” (p. 118).

Common Features of Cognitive Models

The major distinguishing feature of cognitive models is their treatment of
personal epistemology as consisting of separate and independent dimensions. Some of the
research that can be placed in the developmental tradition can also be considered as
positing dimensions for epistemology, such as the source and certainty of knowledge
(e.g. King and Kitchener, 1994, Kuhn, 1991). However, these dimensions have never
been described as discrete elements. Rather, they have been presented as intertwined and
inseparable parts of the whole. By teasing apart aspects of previous thick descriptions of
developmental models, cognitive models conceptualized epistemological beliefs as
unique entities consisting of separate and independent dimensions.

A second feature of cognitive models is that personal epistemology is
characterized as frequency distributions rather than dichotomies. For example, an
individual’s beliefs about certainty of knowledge consist of viewing a certain percentage
of knowledge as tentative, a certain percentage as unchanging, and a certain percentage
as yet to be discovered. The difference between sophisticated and unsophisticated
personal epistemology is the percentage attributed to each category. With this discrete
characterization of dimensions of personal epistemology, cognitive models were able to
account for domain specific differences in individual’s beliefs about knowledge (e.g.
Hofer, 2000). However, context sensitivity problem remained to be explained by other
models.
Situational/Contextual Models

The final family of models for personal epistemology is contextual models. Contextual models for personal epistemology emerged as a response to the problems of earlier models. Earlier models characterized personal epistemology as consisting of essentially stable components that developed in a one-dimensional way (Pintrich, 2002). With the increasing evidence for context sensitivity of epistemological beliefs, several models have been put forward to explain these differences in individuals’ epistemological beliefs in different contexts. In this section two such models, “knowledge integration” and “views of epistemology of science” are reviewed.

“Knowledge integration” is based on the assumption that students hold a repertoire of ideas about science, which are often connected to specific contexts or problems, rather than a cohesive view (Bell and Linn, 2002). According to Bell and Linn (2002), students may say that everything in the science text is true and at the same time they may say science is always changing. For Bell and Linn (2002), the reason for such varied responses is that students’ answers vary depending on the specific question or science topic.

Building blocks of “knowledge integration” are ideas about or images of science. Students develop these ideas from a variety of sources including the popular press, personal experience, and science courses. Bell and Linn (2002) argue that students might think that science is perverse when they are faced with popular news’ accounts of science. The popular press tends to emphasize controversies in scientific research, focus on personalities of scientists, depict different theoretical camps in polarized terms, and
ignore methodological limitations of the field. Popular press masks the idea that a controversy may be a rational aspect of scientific endeavor. On the other hand, textbooks devote very little space to scientific controversy. Experiments in textbooks often reinforce the idea of straightforward scientific discovery.

In the face of this repertoire of ideas, an epistemologically sophisticated stance involves being able to prioritize, link, and explore these ideas in diverse contexts. According to Bell and Linn (2002), knowledge integration aims to help students develop a cohesive and coherent view of scientific inquiry. To do this, students “need to integrate, connect, sort out, and combine their repertoire of ideas as well as incorporate the different images of science they encounter” (p. 322). Bell and Linn (2002) conclude that when epistemological development is viewed as knowledge integration, development does not occur naturally. According to Bell and Linn (2002), epistemological development has to be scaffolded with carefully designed instruction that aimed at exposing students to a variety of contexts and topics in science.

Bell and Linn (2002) state that not only most students hold static, dynamic, or mixed beliefs about scientific inquiry and explanations, but also “typically, the same student can express all three of these perspectives” (p. 333). According to Bell and Linn (2002), individuals holding “static beliefs” view science as a collection of established and correct ideas, which do not change. Individuals who hold “dynamic beliefs” see scientific knowledge as changing and developing and acknowledge the importance of evidence in reaching scientific conclusions. Individuals who hold “mixed beliefs” have a combination of static and dynamic beliefs. According to Bell and Linn (2002), most secondary school
students hold “mixed beliefs” because “students hold a vast array of perceptions of scientific inquiry and draw on (or enact) them depending on the context of the problem” (p. 327).

The second contextual model for personal epistemology is that is Ryder, Leach and Driver’s (1999) “views about the epistemology of science”. This model starts with the assumption that personal epistemology is domain bound, and is a depiction of individuals’ epistemological views in science. Ryder, Leach and Driver (1999) identified three aspects of individuals’ views on the relationship between scientific knowledge claims and data. The first aspect is “data focused reasoning” in which measurement and data collection processes are seen as copying from reality, and drawing conclusions is considered as simply stating what happened in an experiment. The second aspect is “radical relativist reasoning” in which everyone is considered to be free in choosing whatever they want to believe in drawing conclusions from an experiment. The third aspect “theory and data related reasoning” is characterized as viewing theories, beliefs, practices, and data interrelated and capable of influencing each other. Ryder, Leach, and Driver (1999) describe views about the epistemology of science as involving ideas about:

- the role of scientific investigations in establishing valid and reliable data,
- the ways in which data are used to test the validity of scientific ideas and to generate new scientific knowledge claims, the ways in which our understanding of the world can be enriched by interpreting data using theoretical models, and the role of social processes in validating knowledge claims (p. 215)

Leach and Lewis (2002) assert that individuals’ views about the epistemology of science are context dependant. For example, individuals may use “data based reasoning”
in the context of an experiment involving the motion of carts on rails, they may use “theory and data related reasoning” when talking about different models of superconductors, and “radical relativistic reasoning” when discussing the existence of extraterrestrial life. Therefore, according to Leach and Lewis (2002), speaking of “epistemological knowledge in isolation from the situations in which that knowledge becomes manifest” (p. 211) is not appropriate.

*Common Features of Situated Models*

Context dependence of individuals’ personal epistemologies have been argued on the lines that individuals use different epistemological beliefs, knowledge, ideas, views or resources depending on the features of a situation. All of these models situate knowledge in a social or cultural context, or in the context of a topic or task. For these models personal epistemology consists of elements that are not naïve or sophisticated per se. These models describe epistemological sophistication as being able to recognize, sort out, and apply epistemological beliefs appropriately in different contexts.

What differs among these models is the content of the repertoire of the beliefs about knowledge. Bell and Linn (2002) focus on ideas or images, which are characterized as beliefs that individuals acquire from a variety of sources whereas Ryder, Leach and Driver (1999) focus on the ways individuals coordinate data and knowledge claims and justification of scientific knowledge. Ryder et al. (1999) characterize these ways of reasoning with the patterns of thinking and action that students in science classroom often display.
What is common among these contextual models is that they all point out the importance of domain specificity and context sensitivity of personal epistemology. They all endorse that current domain general and decontextualized models of personal epistemology fail to account for the differences in epistemological beliefs in different domains and contexts. Next, research that details the arguments on domain specificity and context sensitivity of personal epistemology are reviewed.

Domain Specificity of Personal Epistemology

Earlier models of personal epistemology described and explained epistemological beliefs in domain-general terms. As the research on personal epistemology expanded, many models came to implicitly or explicitly endorse that epistemological beliefs are domain specific. Pintrich (2002) argues, “even stage models began to accept the general premise that thinking and beliefs could be domain-specific” (p. 399). Pintrich (2002) also notes that domain is a vague term, which shifts meaning with respect to the various research traditions. For example, for developmental models domain refers to larger areas of life, such as academic, work, personal, or social. For cognitive models domain refers to academic disciplines or school subject areas, such as mathematics, physics, or social studies.

The underlying assumption for bounding the domain with the subject area is that individuals’ epistemological beliefs in a discipline parallel epistemological standards of that discipline. A discipline is distinguished from another in part by their different epistemological standards in evaluating knowledge claims, adequacy of argument, and the role of evidence. For example, what constitutes a good theory and what counts as
evidence in science is different than those in history. Therefore, individuals’ beliefs about knowledge might as well be varying with respect to different domains.

To address the domain dependence of epistemological beliefs, Hofer (2000) investigated epistemological beliefs of first year college students about science (Hofer did not specify a specified discipline under science, such as physics, chemistry, or biology) and psychology. Hoffer’s sample included 326 students enrolled in an introductory psychology course. Students’ epistemological beliefs were measured using a Likert-type *Discipline-focused Epistemological Beliefs Questionnaire*. Hofer (2000) concluded that there were strong disciplinary differences in students’ epistemological beliefs. First, students saw science as more certain and unchanging than psychology. Second, students viewed authority and experts as the source of knowledge in science more than psychology. Third, students believed that truth is more attainable in science than psychology. Finally, students were more likely to regard personal knowledge and firsthand experience as the justification of knowledge in psychology than science.

Although by showing the differences of undergraduate students’ epistemological beliefs in science and psychology Hofer (2000) provided evidence that epistemological beliefs were domain dependent, her definition of domain as science was too general. Although science as a domain boundary makes a certain amount of sense when compared to history or psychology, there are many disciplines subsumed under science.

Addressing the disciplinary differences in science Brickhouse, Dagher, Letts, and Shipman (2002) investigated the variation of college students’ epistemological beliefs with science content. They interviewed 20 undergraduate students enrolled in a non-
science major astronomy course. During the interviews the researchers gave each student a list of topics including Darwin’s ideas on evolution, Big Bang theory, and gravity. The researchers asked each student whether he or she believed each topic to be a theory, which theory he or she strongly believed in, and whether he or she had trouble believing in any of the topics. Brickhouse et al. (2002) found that only one student distinguished between the evidence for gravity and gravity as a theory, whereas in the case of evolution, students convincingly separated explanation and evidence. In the case of the Big Bang Theory, only two students conflated explanation and evidence and the rest of them convincingly separated evidence from explanation. They concluded students’ beliefs about the relationship between theory and evidence, warrants for belief, and nature of evidence differs depending on the particular scientific discipline and topic. These findings bring about the question: Do epistemological beliefs differ in a finer scale, namely the context?

**Context Sensitivity of Personal Epistemology**

Context sensitivity of personal epistemology has been problematized in very much the same way as domain sensitivity of epistemological beliefs. In domain sensitivity the argument is that individuals’ epistemological beliefs vary with respect to different disciplines. In context sensitivity individuals’ epistemological beliefs are considered to vary with respect to different contexts. For example, when evaluating a socio-scientific issue such as the consequences and merits of genetic engineering a person may believe that knowledge is uncertain and situated in the social and economical environment. The same person may think that knowledge is certain and derives from
authority when thinking about smoking causes death and is bad for the individual and the society. Similarly, a person may be certain about the outcome of a missile fired at an airplane, whereas he or she could be completely uncertain whether extra terrestrial life exists.

Whether epistemological beliefs differ across contexts is an issue that has attracted researchers interest, especially in science education. Several researchers reported that epistemological beliefs varied even within the same discipline. For instance, Songer and Linn (1991) investigated how students’ views of science influenced their knowledge integration. Songer and Linn’s (1991) sample consisted of 153 eighth grade students. Using a 21 short-answer and true-false item questionnaire Songer and Linn (1991) measured students’ views of science. Students’ responses were categorized as static, dynamic, and mixed beliefs. The most striking result of this study was that 63% of the students were categorized as holding mixed beliefs.

Two years later to replicate their findings Linn and Songer (1993) investigated 168 eight-grade students’ views of science before and after a one-semester course featuring integrated understanding of science. Linn and Songer (1993) described the views of science with four categories: scientific explanations, parsimony, relevance to everyday life, and learning by memorization or understanding principles. The first of these categories, the nature of scientific explanations, was clearly directed to assess students’ beliefs about knowledge, knowing, and justification in science. Linn and Songer (1993) classified students’ as having static, dynamic, or mixed beliefs. Students with static beliefs viewed science as a collection of established and correct ideas, which do not
change. Students with dynamic beliefs saw scientific knowledge as changing and
developing and acknowledged the importance of evidence in reaching scientific
conclusions. Students with mixed beliefs held “some static ideas, some dynamic ideas,
and some ideas that were difficult to categorize” (p. 48).

Strikingly, Linn and Songer (1993) found that 63% of the students held mixed
beliefs about science in the pretest, which was the exact value they have found in the
previous study (Songer and Linn, 1991). In the post-test the 50% of the students held
mixed beliefs about science. More importantly there were no changes in the beliefs of
students about scientific explanations. More than two thirds of the students held mixed
beliefs about scientific explanations despite the instruction.

In order to refine the nature of mixed beliefs Linn and Songer (1993) conducted
15-minute interviews with 25 students. Linn and Songer (1993) pointed out that some
students seemed to believe that all explanations are equally plausible and they had no
criteria for judging explanations. Their point overlaps with Perry’s (1970) multiplicity
position, in which undergraduate students believed every view is equally valid and
everyone has a right to his or her own opinion. Linn and Songer (1993) concluded that
this multiplicity stance has its roots in students’ difficulty in distinguishing established
and controversial ideas in science. These students tended to “often group all scientific
assertions together rather than viewing some as conjectures and others as based on large
amounts of evidence” (p. 64). The conclusion of the research program that Songer and
Linn (1991) conducted was that students’ of beliefs about scientific knowledge varied
widely.
In another study of domain specific personal epistemology, Roth and Roychoudhury (1994) investigated epistemological beliefs of 42 high school students enrolled in three sections of an introductory physics course. The researchers used a written essay, short-answer responses to statements, Constructivist Learning Environment Scale, and interviews with 11 students, to investigate the students’ beliefs about the nature of scientific knowledge, the nature of physics, and the student’s views of learning science. They had three important findings. First, they found that a majority of students (69%) held views that are inline with objectivism, that they thought scientific knowledge was correct, certain and, not artificial but based on facts. Second, they found that 11 of the 42 students held relativist views about the social influence on scientific knowledge, that scientific knowledge was based on a priori assumptions, that the content of scientific knowledge is influenced by society, culture, and language. Third, they found that a considerable number of students concurrently held objectivist views on the nature of scientific knowledge and relativist views on the social influence over scientific knowledge.

Roth and Roychoudhury (1994), describe the apparent inconsistency of students views:

A student who believed that scientific knowledge is absolute, that laws and theories exist independent of human observers and scientists get closer and closer to the truth also believed that science is based on presuppositions, scientists work is affected by the social environment, and science cannot be absolutely objective” (p. 17).

They conclude, “it might be more appropriate to speak of epistemological positions only in specific contexts rather than as descriptors of an individual’s views in general” (p. 17).
Roth and Roychoudhury’s (1994) findings underscored the importance of attending to context in characterizing individuals’ epistemological beliefs beside the discipline specificity.

The most important distinction between domain specificity and context sensitivity of epistemological beliefs is that domains are often limited by disciplines whereas contexts do not offer such a boundary. Perhaps the reason behind the lack of a definitive bounding context is the very definition of it. Generally, context refers to the set of circumstances that surround a situation. Therefore, context may include the domain, the topic, the particular problem, the social relationships in which a particular activity is embedded, and many other aspects that we may or may not recognize in a situation. If one can identify certain aspects of context that has some range of applicability, then one may investigate one of these contexts and infer that findings may apply to similar situations. One such aspect of context is the task, with which individuals’ epistemological beliefs are tapped.

Task as a salient aspect of context in Personal Epistemology

Researchers who investigated personal epistemology have highlighted attending to context in characterizing individuals’ beliefs about knowledge. A few studies identified the tasks that individuals engage in as an aspect of context. One such study is Leach, Millar, Ryder, and Sere’s (2000) investigation of students’ images of science. The participants of the study were 731 students studying physics, chemistry and biology at the levels of upper secondary school (age 16-18 years) and the first two years of undergraduate study (age 18-20 years). The complete data set for the study consisted of
responses of the students to five written survey items addressing issues of the treatment of measured data in laboratory work and the role of theory and data in experimental design and analysis. Leach et al. (2000) analyzed responses of the students to two of the five survey items to investigate the consistency of epistemological representations of students across contexts. They investigated three issues. First, they investigated whether students had coherent and stable epistemological positions when they responded to questions in which no context was specified. Second, they investigated whether students had coherent and stable epistemological positions if their responses were elicited in a specified context. Finally, they compared students’ responses across the two kinds of questions in order to find out whether students’ had coherent and stable epistemological positions.

Leach et al. (2000) chose two survey items based on the similarity of the epistemological issues addressed by participants. The first survey item consisted of seven pairs of statements derived from opposing philosophical viewpoints. The statements gave no indication of context and were worded in general terms. An example of these statements is that scientists interpret data without being influenced by their theoretical assumptions or scientists’ theoretical assumptions interpretation of data. Students rated their position on a 5-point scale between these opposing statements. The first survey item aimed to tap students’ conceptualizations of the relationships between theory and data.

The second survey item presented an ill-structured problem on the topic of superconductivity. In this problem, there was one graph showing the resistance of a material at various temperatures. The graph included data points and associated error
bars. Two different curves were drawn on the graph, both within the error bars of the measurements, to illustrate the relationship between resistance and temperature. Each curve was based on a theoretical model. In this item, the participants were asked to imagine that there were two research groups at a scientific conference. One of the groups collected the data, but both groups agreed upon the quality of the data. Each group supported one of the two theoretical models, which corresponded to the curves on the graph. However, because each group at the conference held one of two different theoretical models of superconductivity, the groups did not agree on the relationship between resistance and temperature represented with the curves.

After presenting the context the second survey item students were asked to express their opinions by choosing one of six statements or writing their opinion if none of the statements matched their view. The statements included that one of the curves is correct, both curves are wrong, more data are necessary, and details of each model has to be examined in order to say anything about which curve is correct. Then, the students were asked to rate eight statements, as appropriate, not appropriate, and not sure, about the course of action that scientists should take next. These statements included drawing conclusions on acknowledging one of the groups for explaining the data correctly, collecting more data to conclude which group is right, or accepting that there may be more than one interpretation of this data. The last part of the second survey item asked the students to pick one of four closed statements about what should be done next after data for a different material is collected. The statements included, joining each data point with a curve since each measurement is known with confidence, considering underlying
models, and allowing each group to make its own decision as there is no way of knowing which is the best curve.

Leach et al. (2000) analyzed students’ responses to the two survey items with three distinctive forms of epistemological reasoning as conceptual categories, which have been adopted from “views of epistemology of science” model (Ryder, Leach, and Driver, 1999). The first category is data focused reasoning. In this category, measurement and data collection processes are seen as copying from reality, and drawing conclusions are considered as simply stating what happened in an experiment. The second category is radical relativist reasoning in which everyone is accepted to be free in choosing whatever he or she wants to believe in drawing conclusions from an experiment. The third category, theory and data related reasoning, is characterized as viewing theories, beliefs, practices, and data interrelated and capable of influencing each other.

In their analysis of the students’ responses to the first survey item, Leach et al. (2000) found that only 6 out of 731 students use data focused reasoning in a stable or consistent way. On the other hand, they also found that 125 students used theory and data related reasoning consistently, which was statistically significant. In their analysis of the second survey item, Leach et al. (2000) found that 100 students chose data related reasoning responses consistently. Students were not consistent in choosing theory and data related reasoning and radical relativist reasoning.

Their most dramatic finding was that there were no consistency in students’ responses across the two survey items. They asserted students’ responses to the decontextualized survey item cannot be used to predict students’ responses to the context
specified item. Leach et al. (2000) concluded that the lack of consistency of students’
epistemological positions across contexts indicates that students draw upon more than
one form of epistemological positions when responding to different kinds of questions.

Leach et al. (2000) provided some empirical support for the importance of the
context of the task in students’ epistemological beliefs and reasoning. However, they also
admit the limitations of eliciting student responses with closed questions. Moreover,
Leach et al. (2000) only compared students’ responses to a set of decontextualized
statements and an ill-structured problem. The kinds of problems that are routinely found
in scientific research and science classrooms can be described as well-structured and ill-
structured problems.

Well-structured versus Ill-Structured Problems

When problem context is recognized as an important aspect for individuals’
epistemological beliefs, the kinds of problems that individuals are asked to solve arise as
an important issue. The basic argument in this section is that both well-structured and ill-
structured problems are important for understanding individuals’ beliefs about
knowledge.

The types of problems in physics can be classified as well-structured and ill-
structured. Well-structured problems are presented with all the information needed,
solved with sound procedures for organizing information, and have a correct answer
(Simon, 1978). For example, standard or routine textbook problems in physics are well-
structured. Standard textbook problems require applying a finite number of concepts,
rules, solutions, and principles being studied to a constrained problem situation (Luszcz, 1984).

The other type of physics problems is ill-structured problems. Ill-structured problems are characterized as problems about which “reasonable people reasonably disagree” (King and Kitchener, 2002, p. 37). Ill-structured problems often provide inadequate information on the outset (Wood, 1983), lack defining guidelines such as an accepted algorithm (Kitchener, 1983), and lack assurance that the problem has been solved (Simon, 1978). Whether using chemicals in food production is safe, whether the origin of life on earth is evolution or creation, and whether news reporting is objective (King and Kitchener, 1994) are among the most commonly cited examples of ill-structured problems.

Early research in problem solving in physics explored how people solved well-structured physics problems. A considerable amount of these studies explored the differences between the processes employed by experts and novices in solving standard textbook problems. The results of these studies highlighted two important points. First, experts possess an extensive knowledge base and they can readily access relevant knowledge in a problem situation, whereas novices lack such a knowledge base (Larkin, McDermot, Simon, and Simon, 1980). According to Larkin et al. (1980) using their extensive domain knowledge, experts first conduct a qualitative analysis of the problem, and then they construct a rich and productive representation of the problem and work forward from the given information. By contrast, novices work backward. They start
immediately with the equation that contains the unknown and if they cannot solve that
equation they pick a second equation.

The second point is that experts focus on deep structure of a problem whereas
novices focus on surface structure. Chi, Feltovich, and Glaser (1981) found that experts
categorize problems according to underlying physical principles and their representations
involve physical entities such as forces, energy, and waves. In contrast, novices’
categorizations involved surface features such as the physical objects and the
arrangement and interactions of these objects. The major conclusion of the early research
on physics problem solving is the necessity of a conceptual understanding of physical
principles for solving physics problems (Maloney, 1994).

Following the research on problem solving that focused exclusively on well-
structured problems, some researchers pursued how individuals solved both well-
structured and ill-structured problems. These researchers focused on processes and
strategies that individuals engage in solving these two types of problems. The results of
these studies underscored that while conceptual knowledge and justification skills were
essential for solving both well-structured and ill-structured problems, solving ill-
structured problems required making subjective assumptions which are influenced with
emotions, values, and beliefs related to science and scientific knowledge. For example,
Shin, Jonassen, and McGee (2003) investigated 124 ninth grade students’ problem
solving skills as they solved two well-structured and two ill-structured astronomy
problems. Shin et al. scored the students’ solutions with a predetermined rubric system.
They found that solving well-structured and ill-structured problems required well-
integrated domain knowledge and skills for coordinating claims and evidence. Shin et al also found that solving ill-structured problems required consideration of emotions, values, and beliefs related to science and scientific knowledge.

Following Shin, Jonassen, and McGee (2003), Fortus (2005) investigated the differences between the strategies people use to solve well-structured and ill-structured physics problems. Fortus asked eight individuals’ with physics degrees (two with PhD, six with BA) to solve three well-structured physics problems and one ill-structured problem in the same domain. Fortus found that although most of the participants had the domain-specific knowledge needed to solve the ill-defined problem and recognized the need to make assumptions, only two participants made any relevant assumptions, and only one of them implemented these assumptions to solve the ill-structured problem. Fortus concluded that making subjective assumptions relevant to the problem context were essential to solve ill-structured problems.

The research that compared how individuals solve well-structured and ill-structured problems implied that ill-structured problems required consideration of beliefs about knowledge in addition to conceptual knowledge and justification skills. The argument that ill-structured problems are better suited to capture individuals’ beliefs about knowledge has been advanced by two of the most influential research programs in personal epistemology. King and Kitchener’s (1994) “Reflective Judgment” and Kuhn’s (1991) “Argumentative Reasoning” (Kuhn, 1991) research programs focused exclusively on individuals’ perception and resolution of ill-structured problems. The major
The conclusion of these research programs was that epistemological beliefs could only be tapped by analyzing individuals’ responses to ill-structured problems.

Such a conclusion implies that well-structured problems are of little value epistemologically, but this is debatable on two grounds. First, not all ill-structured problems are equally ill-structured. Second, well-structured problems constitute a considerable part of the instruction practice in physics education.

The first reason for the epistemological relevance of well-structured problems has to do with the nature of ill-structured problems. Ill-structuredness of a problem is a matter of degree and not of kind. Reitman (1964) pointed out that well-structured and ill-structured problems are not opposites; instead they represent points on a continuum. According to Reitman (1964), the same problem may be well-structured at some point in the solution process and ill-structured at another point. Extending Reitman’s (1964) analysis, Simon (1973) argued “much problem solving effort is directed at structuring problems, and only a fraction of it at solving problems once they are structured” (p. 187). Hence, for Simon (1973), an initially ill-structured problem became a well-structured one during the solution process.

Moreover, the degree of structuredness of a problem is related to how different individuals perceive a particular problem. Voss and Post (1988) pointed out “for an expert a problem may be relatively well-structured but for a novice the same problem may be quite ill-structured” (p. 283). Along the same lines, Arlin (1989) stressed the need to take a participant’s perception of the certainty with which a solution to an ill-structured problem can be obtained. According to Arlin (1989), “a problem that the researcher
intends to be an ill-structured problem may be to the subject a well-structured problem that he or she solves with ease and certainty.” (p. 234). Schultz and Lochhead (1991) illustrated the difference in perceived structredness of problems in physics:

The great majority of studies use problems which for the expert are trivial. You do not see real problem solving, but a kind of tutorial mode (mostly on autopilot), the result of years of explaining this kind of problem to uncomprehending students. To see what the differences in problem-solving procedure are between experts and novices, one must present problems to the experts which for them are as novel and as difficult as the problems presented to the novices are to them (p. 111).

An example of the differences of the perceived structredness of problems comes from engineering design challenges. Svarovsky and Schaffer (2003) investigated how experts and novices solved two ill-structured engineering design problems. The first problem involved building a cantilevered structure out of small stone blocks, and the second problem asked participants to build a structure out of index cards that could support a load. Svarovsky and Schaffer (2003) reported experts first categorized the problem, then planned a solution path, and finally tested their solutions. She observed:

The experts acted like planners through creating a defined solution plan and moving forward, which the novices acted like bricoleurs (Turkle & Papert, 1990) through not planning ahead and experimenting with the materials to solve the problem (p.16).

Svarovsky and Schaffer (2003) concluded that the participants’ solution strategies in solving ill-structured problems were consistent with those used for well-structured problems.

The second reason for the epistemological relevance of well-structured problems is the place of well-structured problems in the instruction practice in physics education.
When Maloney (1994) reviewed the research conducted in 1980s on problem solving in physics, he pointed out that in the physics instructors of the period believed that solving problems was the way to learn physics. Schultz and Lochhead (1991) tell the following story to illustrate this belief:

Physics teachers like to tell this story: A student comes for help, saying “I understand the concepts. I just can’t do the problems.” The physicist somewhat smugly replies it is precisely by solving problems that you show you understand the concepts. Whether or not this statement is completely true, the fact is that the solving of problems is the preferred, almost universal, means of demonstrating mastery in physics (p. 100).

Similarly, Redish (2000) observed “the quality of physics instruction has not changed significantly from earlier days”. Redish (2000) argued that most physics instructors teach the way they were taught, which implies in most cases learning physics is still seen as solving standard physics problems.

The view that students can only learn physics by solving standard physics problems is challenged throughout. Ruesser (1988) observed that students get almost no experience in solving ambiguous or unsolvable problems. According to Ruesser (1988), “almost every systematic dealing with ambiguity and insolvability is factually excluded from textbooks [and] from curriculum” (p. 328). He pointed out ambiguous and unsolvable problems are common in real life situations. In a similar vein, Garret, Satterly, Gil-Perez, and Martinez (1990) argued most of the tasks assigned to students in physics classrooms are puzzles and not authentic problems. Garret et al. (1990) further argued that standard textbook problems are not reflective of scientific reasoning. They contended problem solving should be approached as investigations and standard problems should be
modified into open-ended qualitative tasks that more closely resemble the kinds of activities that scientists engage in when doing scientific research.

In response to research that showed the importance of developing conceptual understanding and science skills several instructional approaches were developed. For example, Van Heuvelen (1994, 1995) developed a course in which students are guided by worksheets in interactive lectures. The course emphasizes analysis of physical situations in which the first encounter with a topic is qualitative followed by quantitative analysis. McDermott and the Physics Education Group at the University of Washington (1996) developed a set of laboratory-based modules called “Physics by Inquiry”. “Physics By Inquiry” emphasizes the development of concepts and scientific reasoning skills. These modules are based on structured inquiry approach in which students seek answers to conceptual questions about a particular topic by designing experiments. According to McDermott et al. (1996), the goal of “Physics By Inquiry” is to help students construct scientific models based on their observations.

Even in inquiry-based approaches to physics instruction, well-structured problems have a prevalent place. For example in “Physics By Inquiry” the students are expected to construct scientific models, not just any model. Although in many cases students start with an ill-structured problem, i.e. understanding a particular physical phenomenon, in the process of designing an experiment and interpreting the data the problem is transformed into a well-structured problem. The problem’s constraints, such as selecting equipment to measure or looking for a mathematical relationship between variables, are bounded with available equipment in the laboratory and instructors directions. In most
cases there is a well-defined answer to the problem, which is the scientific model of the particular phenomenon. The goal is to guide students to construct their own models that are similar, or exactly the same as the scientific model. These tasks clearly bear properties of well-structured problems.

In conclusion, well-structured problems are found throughout physics and physics instruction. In one form, ill-structured problems are transformed into well-structured ones. In another form well-structured problems appear as parts of an ill-structured problem.

Summary

This study was designed to expand upon the body of literature that examines beliefs about knowledge. The basic argument that underlies this study is that individuals hold different epistemological beliefs in different domains of knowledge and in different contexts. Therefore, it is necessary to delineate salient aspects of context in order to understand epistemological beliefs in a specific context.

This study takes a contextual approach to personal epistemology, but does not endorse a specific model. The purpose of this study is to identify individuals’ beliefs about knowledge. Starting with a well-defined model counteracts this purpose, because the meaning in the model would be imposed upon participants’ responses. Instead, in this study a qualitative approach is taken in order to allow participants to express their thoughts and beliefs in their own words.
CHAPTER 3

METHODOLOGY

A qualitative approach was adopted in this study in order to attain a deeper understanding of epistemological issues through an interactive process between the researcher and the participants in the context of problem solving. This chapter describes the setting in which the study was conducted including the characteristics of the site and the participants. The chapter also provides a description of the data collection procedures and concludes with discussion of data analysis and trustworthiness of the study. Figure 3 shows the organization of Chapter 3.

![Figure 3. Organization of the Chapter 3 - Methodology](image-url)
The Participants

This study investigated personal epistemologies of individuals with different levels of expertise in physics. The nature of the study required that the subjects were at some level of expertise in physics. Therefore, only physics majors and physics faculty were eligible for participation. Expertise levels were defined with respect to the years of engagement with physics beyond secondary education. To represent the differences of expertise in physics the population was divided into five groups: Physics majors at (a) freshmen, (b) senior, (c) masters, and (d) doctoral levels and (e) faculty who held research or teaching positions in physics departments. Table 1 shows the demographics of the participants. The number of participants in each group was 10 and the total number of participants was 50.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshmen</td>
<td>10</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Seniors</td>
<td>10</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Masters</td>
<td>10</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>PhD</td>
<td>10</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Faculty</td>
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<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>36</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 1. Number of study participants by expertise level group and gender.

The participants were recruited by contacting two universities in Turkey. First the members of faculty in physics departments of these universities were contacted for participation. The researcher traveled to Turkey and made personal contacts with the members of the faculty. Afterwards the graduate and undergraduate students in physics
departments were contacted and asked for their participation in the study. The selection of subjects was based on voluntary participation.

Research Setting

Data collection took place in two universities in Turkey. The reason for choosing Turkey as the location for research was twofold. First, conducting this research in Turkey provided an opportunity to study personal epistemology in a different culture than the standard Western setting. Second, the researcher was a native Turkish speaker, which maximized the communication between the researcher and the participants during the interviews. Being raised in the same culture the researcher had access to the meanings of different kinds of analogies and metaphors that are unique to the Turkish culture.

The study was conducted in two universities in a metropolitan area of Turkey. One of the universities was a large state funded institution with over 40,000 students. The Physics Department of the state university serves about 100 undergraduate and 30 graduate students. The second university is a more recently established private school with about 12,000 students. It has about 50 undergraduate and 15 graduate students in the Physics Department. Nearly half of the undergraduate students in the Physics Department of the private university are on scholarship, based on their higher scores in the University Entrance Exam.

Data Collection Procedures

In this study an individually conducted think-aloud protocol followed by a semi-structured interview was utilized to collect data. Each participant completed one interview session in which each participant solved a well-structured problem and an ill-
structured and answered follow up questions. The duration of the interview sessions were
between 30 minutes to one hour. All interview sessions were audio and video recorded.
Audio recordings were transcribed verbatim for analysis. Video recordings were used as
a backup in case of audio taping failure as well as to help the researcher to understand the
meaning in ambiguous situations by using the non-verbal cues which could not have been
recorded otherwise.

In this study, a think-aloud protocol was utilized. Traditionally, think-aloud
protocols have been used to identify problem solving assumptions, procedures, and
misconceptions. The major strength of think-aloud protocols is that they enable the
researcher to collect and analyze data on “mental processes at the level of a subject's
authentic ideas and meanings that could not be detected by less open-ended techniques”
(Clement, 2000, p. 549).

Typically, the output of a think-aloud protocol is a verbal model represented as a
sequence of steps or stages that the participant follows to solve a problem (Jonassen,
Tessmer, Hannum, 1999). However, think-aloud protocols are frequently used in personal
epistemology research to assess individual’s beliefs about knowledge (e.g. King and
Kitchener, 1994; Kuhn, 1991). The focus on think-aloud protocols when used in personal
epistemology research is on the identification and use beliefs, rather than the stages and
processes of problem solving.

The general procedure for think-aloud method is that the participants are asked to
talk aloud while they are solving a problem. The researcher repeats the instructions if the
participant remains silent for some time, to encourage them to tell what they are thinking
at that moment (van Someren, Barnard, & Sandberg, 1994). The researcher also asks the participants about their cognitive processes after they complete the problem solving, which are referred to as retrospective questions (Ericsson & Simon, 1993).

The inclusion of well-structured and ill-structured problems in the think-aloud protocol aimed to tap individuals’ epistemological beliefs in different contexts. Coupled with the interview questions that followed the think-aloud protocol, the think-aloud protocol data enabled the production of a rich representation of individuals’ epistemological beliefs.

The think-aloud protocol was followed by a semi-structured interview. The semi-structured interview allowed the participants’ to articulate their epistemological beliefs, which could not be observed or tapped as detailed by any other measure (Baxter-Magolda, 2004). Semi-structured interviews offer the researcher the flexibility to probe further into participants’ meanings of the world while maintaining the focus on the topic of the research (Merriam, 1998). Semi-structured interviews are guided by a list of questions to be explored. Neither the exact wording nor the order of questions is determined ahead of time. Such a format, Merriam (1998) argues, provides the researcher the flexibility to respond to events taking place during the interview. For example, the researcher can stay on an issue for a shorter or longer time with respect to his or her assessment of the completeness of his understanding. The researcher can capture new ideas that are exposed as the participant talks on a topic. The researcher can also reach an understanding of the emerging worldview of the respondent (Guba and Lincoln, 1981).
The interview session included one well-structured problem and one ill-structured problem (see Appendix). The well-structured problem was about the buoyancy of solids in liquids which was selected with respect to the following criteria: The problem (a) is interesting and challenging to the participants so as to motivate them to come up with a solution and (b) does not require complex mathematical manipulations. The ill-structured problem was about the ultimate fate of the universe, which presented two competing scientific models that explained how the universe would come to an end. Ill-structured problems in physics are either about socio-scientific issues or about the problems at the frontier of the field. The ill-structured problem was chosen from the frontier of astronomy in order to minimize the influence of external domain knowledge.

During the interview sessions, first, the participants were presented with the well-structured problem. In order to elicit the participants’ beliefs about knowledge in the context of the well-structured problem, after they completed the solution of the well-structured problem they were asked the following questions:

- What leads you to reach that answer?
- How confident are you with your answer?
- Can you ever know that your answer is correct? How or why not?
- How confident are you about the principles you have used in solving this problem?

Then the participants were presented with the ill-structured problem. After the participants solved the ill-structured problem they were asked the following questions:

- What do you think about this problem?
• What leads you to hold that point of view?
• On what do you base that point of view?
• How confident are you about your point of view?
• Can you ever know that your point of view is correct? How or why not?
• Can one of the models be right? What do you mean by right?
• Can one of the models be better? What do you mean by better?
• How is it possible that experts in the field disagree about this subject?

Data Analysis

The data analyses involved cyclic processes of data reduction, data display, and conclusion drawing/verification, which are characteristics of qualitative analysis (Miles and Huberman, 1994). The data reduction started with transforming the data into a manageable form. First, the interviews were transcribed verbatim in Turkish. Then the researcher translated the transcriptions to English. Another graduate student whose native language is Turkish verified 20% of the English translations. All of the translated transcripts were included in the analysis.

All translated transcripts were imported to the qualitative analysis software NVIVO to manage and organize the data as well as to keep track of the analytic progress. Once the data was imported to NVIVO the data reduction continued with coding. Coffey and Atkinson (1996) describe coding as “condensing the bulk of our data sets into analyzable units by creating categories with and from our data” (p. 26). In this part, constant comparative method (Glasser and Strauss, 1967) was employed to identify categories, themes, and patterns in the data through iterative readings of the data.
According to Strauss and Corbin (1990) constant comparative method relies on three stages of coding: open coding, axial coding, and selective coding. In open coding textual data from field notes or transcripts are conceptualized line by line. Open coding results in identification of categories that are recurrent in the data. Axial coding is the structuring of the categories identified in open coding around central categories. In axial coding the researcher tried to find out how central categories and subcategories fit together. The codes are compared as more data is processed, and merged into new concepts, and eventually renamed and modified. In selective coding the data are coded selectively with the central categories identified in axial coding guiding the coding process.

The coding process started with open coding in which the transcripts were read and coded line-by-line. The first round of coding did not have any conceptual structuring as it was meant to capture as many different codes as possible. Open coding was meant to be descriptive with minimal inference on the researcher’s part. The names of the open codes included “we have learned principles and laws as correct”, “religious sources”, “incomplete data”, and “based on theoretical models”. Detailed descriptions of and examples from the participants’ responses for the open codes are presented in Chapter 4. In many cases open codes were named with participants’ actual expressions. For example, in the following excerpt a participant talks about the reasons that he is confident in Newton’s laws and buoyancy principles.

Buoyancy principles are something that we constantly use in everyday life, even if someone didn't learn about this knowledge. It is something plausible to a homemaker and she can teach this to her child. It just makes sense because I see it work (FRESHMAN5).
This segment was coded as “I see principles and laws work in everyday experience”. The unit of analysis throughout the open coding was statements that ranged from one to several sentences in length. The previous excerpt consisted of three sentences whereas the following segment was only one sentence long: “I can verify Newton’s laws with my own experience” (MASTERS9).

The first round of coding also involved partitioning the text of the transcripts into administrative codes, which marked the context of the talk. Two administrative codes were used: well-structured problem context and ill-structured problem context. The “well-structured problem context” administrative code marked the segments of text where the participants solved and talked about the first problem and the interview questions related to the first problem in the problem solving session. The “ill-structured problem context” administrative code marked the segments of text where the participants solved and talked about the second problem and the interview questions related to the second problem in the problem solving session. (See Appendix for the two problems).

The second step of the coding process was axial coding. Axial coding is structuring the codes around more general categories. At the beginning of axial coding two problem-solving maps one for the well-structured problem and one for the ill-structured problem for each participant was constructed. These maps showed the sequence of the open codes in the process of each participant’s responses in the interviews. After the problem solving process maps were produced for each participant, generalized problem-solving maps were constructed for well-structured and ill-structured
problem contexts. These generalized maps intended to capture the complete range of responses of all of the participants.

In the construction of the generalized maps the researcher started with one individual’s map and compared it to the next individual’s map. Elements from both of the maps were included in the working generalized map. Every next individual map either overlapped with the existing elements in the working generalized map or added new elements to it. For example, the problem solving process map for the well-structured problem context for FRESHMAN3 contained “confidence in principles”, “principles are foundation of new knowledge”, “principles are not refuted”, and “supported with systematic empirical observations”. The problem solving process map for SENIOR4 contained “confidence in principles”, “supported with systematic empirical observations”, and “I see principles work in everyday experience”. The problem solving process map for MASTERS2 contained “confidence in principles” and “principles and laws are theoretical models”. The generalized map for the well-structured problem context included overlapping elements across the individual maps such as “confidence in principles” as well as each element that added to the map with each individual map such as “principles are foundation of new knowledge”, “principles are not refuted”, “supported with systematic empirical observations”, and “principles are theoretical models”.

When the iteration through all individual problem solving process maps was completed, the first version of generalized maps were produced. In the generalized maps the frequency of each element was recorded. For example, “confidence in principles” had a frequency of 50; all participants stated that they were confident in buoyancy principles
and Newton’s laws. “I see principles work in everyday experience” had a frequency of 16, total 16 participants stated that they were confident in buoyancy principles and Newton’s laws because they witnessed in their everyday experience that these principles and laws were working. In the final version of the generalized problem solving process maps only elements that had a frequency of 2 or above was retained. All elements that were present in a single individual map were dropped. The decision not to include elements that occurred only in single individual maps was made for two reasons. First, if a statement was made by only one person it would not be representative of the 50 participants, and second, the resulting generalized map would contain too many elements that would make the interpretation difficult.

In the generalized problem-solving process maps four themes were identified, one in the well-structured problem context (confidence in principles), and three in the ill-structured problem context (correctness of a theory, betterness of a theory, and diversity of opinion). These four themes contained the bulk of the discussions about knowledge in the two problem contexts.

After the identification of the themes, the open codes were structured around seven conceptual categories, which were named epistemological belief types. The seven epistemological belief types are authoritative, rational, empirical, experiential, relativistic, religious, and modeling epistemological belief types. The construction of these seven epistemological belief types was a process of grouping the open codes around more general concepts. In thinking about how the open codes could be related to more general concepts the researcher turned back to the literature. Following Coffin and
Atkinson’s (1996) advice for reading in and out of the field, the researcher adapted and extended constructs from two studies (a) Gilbert and Mulkay (1984) and (b) Roth and Lucas (1997). Both of these studies focused on the social aspects of the generation and validation of scientific knowledge and emphasized the discourse of scientists and students.

Gilbert and Mulkay (1984) investigated scientists’ strategies for establishing the factual nature of knowledge claims and build a framework consisting of empirical and contingent interpretive repertoires. According to Gilbert and Mulkay (1984), scientists deployed an empirical repertoire in their publications in which “Laboratory work is highly conventionalized manner, as instances of impersonal, procedural routines, which are generally applicable and universally effective,” (p. 56). In the context of informal talk scientists used a contingent repertoire in which “Scientists’ actions are no longer depicted as generic responses to the realities of the natural world but as the activities and judgments of specific individuals acting on the basis of their personal inclinations and particular social positions” (p. 57). Roth and Lucas (1997) investigated high school students’ discourse on the nature of scientific knowledge. They have started with characterization of scientists’ strategies for establishing the factual nature of knowledge claims. Roth and Lucas (1997) expanded Gilbert and Mulkay’s (1984) framework to include intuitive, religious, rational, empiricist, historical, perceptual, representational, authoritative, and cultural repertoires. In this study authoritative, rational, and religious labels for three epistemological belief types were adapted and extended from Roth and
Lucas (1997) and “empirical” label for one epistemological belief type was adapted from Gilbert and Mulkay (1984).

The researcher coined experiential, relativistic, and modeling labels for the remaining three epistemological belief types. After the construction of the seven epistemological belief types the data was selectively coded to test the conceptual categories against the participants’ responses. Finally, the seven conceptual categories were conceptualized as a framework named epistemological belief types.

Trustworthiness

Trustworthiness is concerned with the question "How can an inquirer persuade his or her audiences that the research findings of an inquiry are worth paying attention to?" (Lincoln and Guba, 1985, p. 290). In this study the question of trustworthiness is whether the researcher’s accounts of the participants’ personal epistemologies were consistent with the participants’ experiences. To enhance the trustworthiness of this study two strategies were used: member checking and inter-rater reliability.

Member checking strategy was deployed throughout the interviews with all participants to ensure that the researcher’s interpretations of their statements are what the participants actually meant. The participants and the researcher were native Turkish speakers and the interviews were conducted in Turkish language, which enhanced the clarification of participants’ meanings. The researcher frequently rephrased the participants’ responses and asked following questions to prevent any misunderstanding. The following excerpt illustrates the kind of rephrasing and questioning conducted to clarify the participants’ responses.
Interviewer: Can one of these two theories (the Big Rip and the Big Crunch) be correct?

Freshman10: It (one of the two theories) may be correct but it is always possible that new ideas always be added to these (ideas) in the future. One theory may make more sense, but I can't say it is correct.

Interviewer: So you are saying that we can’t say that one theory is correct and the reason for that is that new ideas may be added to these existing ideas.

Freshman10: Yes, new ideas will be added, perhaps correct ideas.

The second strategy that was employed to enhance trustworthiness was inter-rater reliability. This strategy involves making segments of the raw data available for others to analyze (Lincoln & Guba, 1985). A colleague of the researcher who has a PhD in education and interested in epistemology independently coded 20% of the transcripts. Ten transcripts, two from each of the expertise level groups, were randomly chosen for the inter-rater reliability check. The inter-rater reliability was calculated with the ratio of the number of agreements to the sum of number of agreements and number of disagreements. The initial inter-rater reliability was %75. After the initial round of inter-rater reliability check the researcher and the independent rater discussed the disagreements in coding. In this discussion the researcher and the independent reader explained the reasons of their choice of codes in the disagreed sections. As a result of this discussion some of the disagreements were resolved and the final inter-rater reliability for the epistemological belief type codes was calculated 82%.
CHAPTER 4

FINDINGS

This study had three objectives. The first objective was to identify the range of beliefs about knowledge. The second objective was to identify similarities and differences between beliefs about knowledge in the context of a well-structured problem and an ill-structured problem in physics. The third objective was to identify similarities and differences in beliefs about knowledge among different expertise level groups.

In this chapter, the findings of this study are presented in the order of the objectives. The first two sections are written to meet the first objective, to identify the range of beliefs about knowledge in physics. The third section is written to meet the second objective, to identify similarities and differences between beliefs about knowledge in the context of a well-structured problem and an ill-structured problem in physics. The fourth section is written to meet the third objective, to identify similarities and differences in beliefs about knowledge among different expertise level groups.

In the first section, the range of beliefs about knowledge is presented in the context of the well-structured problem. In the second section, the range of beliefs about
knowledge is presented in the context of the ill-structured problem. In these two sections, the data are presented in a descriptive form with minimal interpretation and conceptual analysis. After each of the two problem contexts is presented, participants’ responses are grouped into seven epistemological belief types. These epistemological belief types were constructed to combine participants’ responses in the context of the well-structured problem and the ill-structured problem under the same conceptual base. This conceptual base served as a metric that enabled comparisons across the problem contexts and expertise level groups. In the third section, beliefs about knowledge in the two problem contexts are compared in terms of the belief types. In the fourth section, beliefs about knowledge are compared across the expertise level groups. The chapter ends with the summary of findings. Figure 4 shows the organization of Chapter 4.

Figure 4. Organization of Chapter 4 - Findings
Context of the Well-structured problem

In the context of the well-structured problem the participants were asked to solve a textbook problem on buoyancy of solids in liquids topic. (See Appendix for the well-structured problem). In this problem, a beaker filled with water was shown. There was a wooden block placed in the beaker. Two thirds of the wooden block was immersed in the water. There was a tap above the beaker from which vegetable oil could be poured in the beaker. Three figures displaying different combinations of the wooden block, vegetable oil, and water were shown in the problem. The participants were asked which ones of these three figures could occur if the tap was turned on and vegetable oil was slowly added to the beaker.

In the well-structured problem context typically a participant would read the problem, look at the three figures, and then consider each figure. At this point, the participant would classify the problem as an empirical real world problem or a textbook problem. Participants who registered the well-structured problem as an empirical problem would first try to visualize the situation and then they would apply buoyancy principles to reach a solution. Other participants who treated the well-structured problem as a textbook problem would directly apply the principles to solve the problem.

The participants’ responses focused on their beliefs about knowledge in physics when they talked about their confidence in buoyancy principles and Newton’s laws. Therefore, confidence in principles emerged as the major theme in this problem context. In this section, the well-structured problem context is explored around the theme,
confidence in principles, to delineate the range of beliefs about knowledge in physics that the participants held.

Figure 5. The range of beliefs about knowledge in the context of the well-structured problem.

Confidence in Principles and Laws

The discussions about knowledge with the participants in the well-structured problem context were centered on their confidence in buoyancy principles and Newton’s laws. After the participants completed solving the well-structured problem, in order to elicit their views about the underlying principles, they were asked about their level of
confidence in the principles they have used to solve the problem. The participants identified buoyancy principles and Newton’s laws as the underlying principles of the well-structured problem and virtually all participants expressed that they trusted these principles and laws.

The participants expressed a variety of beliefs about confidence in buoyancy principles and Newton’s laws. Among these beliefs are “we have learned principles and laws like that”, “principles and laws are not refuted”, “principles and laws are foundation of new knowledge”, “I see principles and laws work”, “principles and laws are supported with systematic empirical observations”, and “principles and laws are theoretical models.”

*We have learned Principles and Laws as correct*

When explaining their high degree of confidence in buoyancy principles and Newton’s laws some participants said that they have learned these principles as correct through their schooling and for this reason they believed that these principles and laws were correct. Fifteen participants (30%) said that they have learned buoyancy principles and Newton’s laws as correct through their schooling. Four participants in the freshman group, seven participants in the seniors, two participants in the masters group, two participants in the PhD group stated that they have learned buoyancy principles and Newton’s laws as correct. None of the participants in the faculty group expressed that they have learned these principles and laws as correct.

These participants expressed that they had been learning about the principles and laws involved in the well-structured problem for many years and they thought that their
teachers would not teach them anything wrong. According to these participants, buoyancy principles and Newton’s laws constituted the basic knowledge in physics and they simply accepted them as correct without questioning. They were expected to learn these principles and master their applications in textbook problems in order to be successful in school physics courses and in the university entrance exam. For example, a freshman stated:

We have been learning these for many years. Since high school even middle school. I mean, I am sure about those too. They have been taught to us until now. We have seen their correctness I think. I think there is no law of Newton's that has not been completely proven to be correct (FRESHMAN10).

Similarly, a senior said:

All I can say is this is what has been taught to us. We accept what is taught to us. This has been proven to us they said that this is such and such and we accept that. We don't say no it's not like that. I mean nothing like that has ever happened. They tell us F=ma and we accept it. And in this topic there's the buoyant force and the weight of the mass so we say it is in equilibrium and we accept that (SENIOR2).

The graduate students in contrast to the undergraduates were aware that they accepted the basic laws as correct and saw this as a flaw in the educational system. For example, a PhD student said:

After dealing with quantum mechanics it is not appropriate to say that anything is one hundred percent certain. But as for the basic laws we use them without questioning. And in fact they don’t teach us to question these... We are not trained to question these basic laws. Our educational system does not allow for questioning these things. We accept many things without questioning them. We hardly ever question the basic laws, we accept them as correct and apply them (PHD8).
Principles and Laws are not refuted

The second belief about knowledge expressed in the confidence in principles theme was principles and laws are not refuted. For some participants buoyancy principles and Newton’s laws were correct because they had not been refuted. Eleven participants (22%) said that buoyancy principles and Newton’s laws had not been refuted. Two participants in the freshman group, five participants in the seniors, two participants in the masters group, two participants in the PhD group stated that they have trusted buoyancy principles and Newton’s laws because these principles and laws had not been refuted. None of the participants in the faculty group expressed that these principles and laws were not refuted.

According to these participants, these basic physics principles and laws withstood all falsification attempts and therefore, they were accepted as correct. These participants thought that through the history all the attempts to show that these principles were wrong failed. Nobody was able to find counter cases to these principles and laws. According to these participants, the lack of refuting evidence was one reason to accept these principles and laws were correct. Logically, these participants thought, if these principles were not refuted they must be treated as correct. However, these participants were also cautious that there was a possibility that these principles and laws could be refuted. For these participants this was the case not only for buoyancy principles and Newton’s laws, but for scientific laws in general. For example, a freshman said:

Now in general Newton's laws I know this. Newton refuted a few previous laws, I mean partially. I haven't researched Newton's life. But for scientific
laws, each refutes the one before it and the latest one prevails. And this prevailed. It has not been refuted yet. (FRESHMAN1).

These participants pointed out that scientific laws obtain the status of a law by withstanding the falsification attempts. For example, a senior stated:

Newton’s Laws are well laws. A law is something proven because no cases has been found to falsify it (SENIOR3).

According to these participants these principles and laws were not falsified and hence were treated as correct. For example, a PhD student said:

We can say that Newton’s laws are correct because there isn’t anything that proves it is otherwise. Once something is proven as long as you can’t refute it, it is difficult to say that it is wrong. Now since 1600s since Newton’s time the physics laws that he formulated are still used today. So I can’t say that they are incorrect (PHD5).

**Principles and Laws are Foundation of new knowledge**

The third belief about knowledge that the participants expressed in the confidence in principles theme was principles and laws are foundation of new knowledge. Some participants stated that they were confident in the buoyancy principles and Newton’s laws because these principles were “foundation” or building blocks of other knowledge in physics. Six participants (12%) said that they have learned buoyancy principles and Newton’s laws as correct through their schooling. Three participants in the freshman group and three participants in the PhD group stated that these principles and laws were foundation of new knowledge in physics. None of the participants in the seniors, masters, and faculty group expressed that they have learned these principles and laws as correct.
According to these participants, since the body of knowledge in physics that we use is built on these principles and that body of knowledge is accepted to be correct, these principles must also be correct. For example, a freshman stated:

I mean I can say 100% sure. Not only in here (in this situation) also I think about it in everything I see. If there were errors they would turn up until now. Because there has been many new things that were built upon these (principles). There would be problems with these new things that we have reached. There would be many problems. I mean it wouldn't develop and live up to now (FRESHMAN2).

These participants also pointed out that the application of these principles enables humans to build structures and machines. Since these structures and machines work the principles must be correct. For example, a PhD student said:

I think that these physics laws are correct. Because physics laws are in nature and they directly affect our lives. Using these principles engineers build structures and many other machines, right. And these (structures and machines) give us the expected values and they work. And many of these laws are the basis for other theories and laws in physics. Therefore if one of Newton’s laws were wrong it would have been detected by now (PHD5).

I see Principles and Laws work

The fourth belief about knowledge expressed in the confidence in principles theme is I see principles and laws work. Some participants stated that they trusted buoyancy principles and Newton’s laws because they witnessed that these principles work in their everyday experiences. Sixteen participants (32%) said that they trusted buoyancy principles and Newton’s laws because they saw these principles work in everyday experience. Five participants in the freshman group, three participants in the seniors, four participants in the masters group, three participants in the PhD group, and
one participant in the faculty group stated that they had seen these principles and laws work in their everyday experience.

For these participants their own observations and experience were the grounds they trusted buoyancy principles and Newton’s laws. Their emphasis was not on the observation alone, but on the observations they have made. For example, a freshman said: “I accept these principles because I can adequately support them with my observations. As long as they match my observations they are correct” (FRESHMAN4).

According to these participants, their sensory experience indicated buoyancy principles and Newton’s laws worked. For instance, for these participants, seeing that ships cruise over the ocean was one reason to believe that buoyancy principles were correct. Similarly, feeling the pressure of a wall against their hands when they pushed a wall was a reason to believe in Newton’s third law. Hence, the personal observations and experiences of these participants was one reason for them to believe that buoyancy principles and Newton’s laws were correct. For example, a masters student said:

I can’t know whether it would work in every situation but I’m sure of its existence. Because when we are crossing Bosphorus we ride on ferries. And when I ride on the ferry I watch the shape of the boats, and how much of its volume is immersed, like the boats’ width and length and weight increases I see that the volume immersed also increases. Therefore there is something like the buoyant force and it is related to the volume immersed and it is already related to the buoyant force of water (MASTERS1).

In similar lines a senior stated:

I mean we accept these laws of course they are correct. Why are they correct, why do I say that Newton’s laws are correct. Because I see that when I take and object and exert a force on it, it pushes back. Like if I push this wall it pushes me back I feel the force on my hand. Newton says that if you exert a force on a stationary object it will accelerate. And if I
Principles and Laws are supported with systematic empirical investigations

The fifth belief about knowledge expressed in the confidence in principles theme is principles and laws are supported with systematic empirical investigations. Some participants believed that buoyancy principles and Newton’s laws were trustworthy because they were produced through systematic empirical investigations. Nineteen participants (38%) said that they trusted buoyancy principles and Newton’s laws because these principles and laws were supported with systematic empirical investigations. Three participants in the freshman group, four participants in the seniors, three participants in the masters group, five participants in the PhD group, and four participants in the faculty group stated that these principles and laws were supported with systematic empirical investigations.

These participants expressed the value they have placed on scientific method. According to these participants, it was the systematic nature of scientific method that increased the credibility of these basic physics principles and laws. These participants pointed out three features of scientific method: (1) the role of replication of experimental results in establishing scientific knowledge, (2) controlling experimental conditions to prevent the effects of extraneous variables, and (3) accounting for experimental error due to measurement.

First, according to these participants, the operation of scientific method involved replication of experimental results in establishing the acceptance of a particular
hypothesis. When a hypothesis is repeatedly confirmed or not refuted by different scientists, then that hypothesis becomes an established principle or law. For example, a freshman said:

I'm pretty sure of it (Newton’s laws)... After all these have been accepted by scientists. It's a law now. I mean the truth of these facts that have been confirmed by many independent scientists. These experiments have been repeated countless times (FRESHMAN10).

Second, according to these participants, scientific knowledge was reliable because scientists were careful in trying to control experimental conditions. These participants stated that when an experiment returns anomalous results, the subsequent course of action is to check for whether the experimental conditions were controlled. If an experiment fails to confirm buoyancy principles and Newton’s laws, these participants doubted the competence of the experimenter or the adequacy of the experiment. They considered the anomalous result as a failure of the experiment and not as a flaw in the principles and laws. According to these participants, the experimental conditions introduced extraneous variables to the measurements, which resulted in discrepant results. For instance “there may be friction, there may be leaks in the setting, or something else may happen. The wooden block may have absorbed the liquid and its density may have changed (SENIOR4)”.

Third, according to these participants, buoyancy principles and Newton’s laws were reliable because scientific method required accounting for measurement error in experiments. Every measurement inherently held uncertainty due to calibration of measurement devices. The precision of apparatus was a limit on how accurate a
measurement could be taken. For example, if a ruler had one-millimeter ticks that ruler could measure within the precision of half a millimeter. If an experiment required more precision, then more sensitive measurement devices were required. However, there was no such thing as perfectly precise or error free measurement. Because there were no limits to how small the intervals of measurement could be. Nevertheless, scientists could account for the measurement error by explicitly stating their confidence interval for the measurements. For example, a masters student said:

What do you do for limiting your certainty? You say that I can do pretty well calculations up to the five decimal places. Ok, but the decimal places do not end there; they go all the way to infinity. That’s why you can never say I measured it with absolute accuracy. But within the precision boundaries you have determined, you say I’m 95% confident that this measurement is between these two values, 65% between these other two values. Often times, such precision is more than adequate for an experiment. (MASTERS1).

Principles and Laws are Theoretical Models

The final belief about knowledge expressed in the confidence in principles theme was principles and laws are theoretical models. Some participants believed that buoyancy principles and Newton’s laws are theoretical models and hence these participants’ confidence in these principles and laws were constrained by the limitations of theoretical models. Nineteen participants (38%) said that they trusted buoyancy principles and Newton’s laws because these principles and laws were supported with systematic empirical investigations. None of the participants in the freshman and seniors groups, two participants in the masters group, four participants in the PhD group, and seven participants in the faculty group stated that these principles and laws were theoretical models.
A theoretical model, for these participants, was an explanation that scientists constructed to understand and predict physical phenomena. In other words, scientists interpreted observations about a particular physical phenomenon and constructed a theoretical model that explains these observations. These theoretical models did not necessarily correspond to reality and they were not treated as being absolutely true. Instead, theoretical models explained available data. These participants stated that theoretical models were not absolute because when new data become available the models could and did change. According to these participants, every theoretical model rested on assumptions and essentially every theoretical model was an interpretation of a particular data set. For example, a faculty member said:

When we say observation, humans, physics laws, and modeling based on observations. So the laws are in fact models and they are not absolute...Model is a cover that we fit to it (phenomenon). Like a person goes to a tailor and he makes a dress for her. That is the model of that tailor another tailor may draw it differently. Similarly different models come about because of the different ways of looking at phenomena. For various problems this is a perspective. For instance we say that the gravitation force is F=ma, this is a formula a model and Einstein says that as a model gravitation is based on the deformation of space because of a mass and that deformation results in the attraction of other masses. Now is this the truth? This is a way of explanation. We cannot know how the structure of reality really is (FACULTY9).

According to these participants, theoretical models were characterized as valid rather than correct. These participants stated that theoretical models were valid within the available measurements and analysis techniques. Theoretical models could and did change when analysis techniques improved. For example, a masters student said:

When a theory is proposed and I always think that it physics, like regardless of how confident you are about physics theories even about the simplest things, they are not true but valid. They are valid within your
measurements and the mathematics you use. If you include different situations to the experiment and have a better opportunity to investigate it, if you have better experimental resources, then you can see the deviations and add correction terms to the mathematics you use. Because of this physics laws are only valid and they are not absolute (MASTERS2).

For these participants, a theoretical model was valid for a range of natural phenomena; a theoretical model did not explain every natural phenomenon. According to these participants, physics principles and laws were correct because they fitted the data available for a range of observations. But they were incomplete because they did not fit the data outside of this range. According to these participants, for buoyancy principles and Newton’s laws the range was speeds less than the speed of light and scales greater than molecular scale. At speeds close to the speed of light these principles and laws failed, they did not fit the data. In atomic scale these principles and laws also failed; they did not fit the data and could not explain the phenomena. For example, a faculty member stated:

When you ask about these principles then you are entering the realm of the philosophy of physics. We must know that all physics laws depend on our ability to read the nature. Physics laws are not like mathematics that we reach deductively. There are some laws that are deduced but we eliminate them if they don’t match the nature those laws are not valid. We look at the nature and summarize the order in nature with physics laws. Nature doesn’t have to obey these laws 100 percent. But as far as we can observe it does. That’s why we say that physics laws are valid. Even when we say they are correct we mean that they are valid. All of these have validity boundaries. In the simplest relativity, when you approach the speed of light the ordinary physics laws don’t work. But when the speed is low they work very well. For instance we don’t even consider relativity when we send rockets to the space. Similarly Newton’s laws break down when you deal with phenomena at the atomic scale. But we don’t use quantum mechanics when building cars because these laws work perfectly in our scale (FACULTY6).
Context of the Ill-structured Problem

Up to this point, the participants’ beliefs about knowledge were examined in the context of the well-structured problem. In this section, the participants’ beliefs about knowledge in the context of the ill-structured problem are explored. In the context of the ill-structured problem the participants were asked to solve a problem in astrophysics, which presented two rival theories that explain the ultimate fate of the universe. (See Appendix for the ill-structured problem and follow up interview questions). The participants were asked to state their positions about these two theories that predicts the ultimate fate of the universe. The first theory, the Big Crunch, predicts that the universe will stop expanding and start to collapse upon itself. The other theory, the Big Rip, foresees that the universe will continue expanding until all physical objects in the universe will eventually be torn to pieces and then to elementary particles.

Typically, a participant would read the problem and then state his or her position about the problem of the ultimate fate of the universe. The participants stated one of the following three positions: They either favored the Big Rip or the Big Crunch, or they suspended their judgment and did not favor either theory.

The bulk of the discussions with the participants about knowledge in the context of the ill-structured problem were organized around three themes. The first theme, correctness of a theory, encloses the participants’ beliefs about whether the correct theory between the Big Rip and the Big Crunch theories can be found. The second theme, betterness of a theory, includes the participants’ beliefs about whether the better theory between the Big Rip and the Big Crunch theories can be found. The third theme, diversity
of opinion, includes the participants’ beliefs about the reasons for the existence of different theories about the ultimate fate the universe.

**Figure 6. The themes in the context of the ill-structured problem.**

*Correctness of a Theory Theme*

The second theme in the context of the ill-structured problem was correctness of a theory. Correctness of a theory refers to whether it is possible to find the correct theory between the Big Rip and the Big Crunch. When the participants considered whether the correct theory between the Big Rip and the Big Crunch theories can be found, the participants chose either the correct theory can be found or the correct theory cannot be found. When the participants explained the reasons for why they thought the correct theory can or cannot be found, they expressed their beliefs about knowledge in physics. In the following sections, the participants’ beliefs about knowledge in physics are presented for the correct theory can be found and the correct theory cannot be found positions.
Figure 7. The response categories in the correctness of a theory theme in the context of the ill-structured problem.

**Correct theory can be found**

Few participants, in total nine participants (18%), said that the correct theory between the Big Rip and the Big Crunch theories could be found. Two participants in the freshman group, two participants in the PhD group and one participant in the faculty group said that the correct theory between the Big Rip and the Big Crunch theories could be found.

The participants who said that correct theory could be found expressed three distinct beliefs about knowledge. First, some participants said that the correct theory could be found by appealing to the knowledge of scientists and professors. Second, some participants said that finding out the correct theory between these two theories is possible by obtaining more observations. Third, some participants said that the ultimate fate of the
universe is essentially a religious problem and its answer should be sought in religious sources.

![Diagram](image)

**Figure 8. The range of beliefs about knowledge in the correct theory can be found response category of the correctness of a theory theme in the context of the ill-structured problem.**

**PROFESSORS AND SCIENTISTS KNOW**

The first belief that the participants expressed for why they thought that the correct theory could be found was that professors and scientists know the answer to the problem of the ultimate fate of the universe. Only two participants (4%) stated that the correct theory between the Big Rip and the Big Crunch theories could be found because professors and scientists know the correct theory. One of these two participants was a senior. According to this senior, one of his professors was a competent scientist. For this reason, this senior thought that that professor would be able to find out the answer to this problem. For this senior, his professor was much more knowledgeable than he was, his professor understood physics better than he did, and his professor was able to interpret
the data better than he was. This senior stated that he would believe experts’ views on topics in which he did not have adequate knowledge. He said:

Well to find the correct theory I’d ask my professor what do you think about this. Say he said it will keep expanding to eternity, then I’d believe him. He can process the data better than I, he uses the data better, understands better. I trust those who are better than I. Then I’d think it must be that theory (SENIOR8).

The other participant who said that the correct theory could be found by asking professors and scientists was a freshman. According to this freshman, the problem of the ultimate fate of the universe was a very difficult question, which was at the frontier of physics. This freshman stated that he was only at the beginning of becoming a professional physicist. This freshman pointed out that other people with more experience and knowledge in the field of physics would be at a better position to answer the question of the ultimate fate of the universe. According to this freshman, this problem was so difficult that only the best scientists who are geniuses could find out the correct theory about the ultimate fate of the universe. According to him ultimate fate of the universe problem,

…forces one's imagination. It's at the very edge. This is one of the most recent and unknown questions. In order to know the answer to this, you must be good physicists. Because I'm just a freshman. There are juniors, sophomores, professors. When we look at it physicists are on the top. I don't know his name, the scientist who put forward the Big Bang, they say he is a genius. Only geniuses can find it (FRESHMAN5).

MORE OBSERVATIONS REQUIRED

The second belief that the participants expressed for why they thought that the correct theory could be found was that more observations would lead to the solution of
the problem of the ultimate fate of the universe. Three participants (6%), one freshman, one senior, and one PhD student, said that finding out the correct theory between the Big Rip and the Big Crunch theories was a matter of obtaining more observations. According to these participants, ultimate fate of the universe problem was not solved yet because the data at hand was not adequate. If more observations could be obtained, it would be possible to find out how the universe would come to an end. For example, a freshman said:

I think this problem might be solved. I can’t say for sure. If we don’t know the answer yet it must be because we don’t have enough data. But if we make more observations we might be able to find out the correct theory (FRESHMAN10).

In similar lines, a PhD student stated:

Well, one way to know the answer (to the ultimate fate of the universe problem) is to make more observations. If we could make more detailed observations and research about the creation of the universe we may reach a result. So Big Bang should be investigated in more detail. And how can this (research) be done? Of course with more and better observations. Technology advances everyday so we might get more data to find out how the universe will end (PHD4).

According to these participants, the current technology was not advanced enough to gather the necessary data. However, these participants pointed out that technology had been advancing rapidly. As technology advances scientists could get more data and could find out which one of these theories is correct. According to these participants, the progress of science was a result of obtaining more data; science progressed as new data became available. These participants stated that as the data about the universe
accumulates, scientists would be closer to the answer to the ultimate fate of the universe problem and eventually would find the correct answer. For example, a senior stated:

I mean 200 years ago at the time of Galileo they were debating whether the earth was rotating or not. We have progressed a lot since then. If we keep progressing and get more data, like from Hubble telescope and get more precise measurements from farther distances. Step by step we will get closer to the answer as the data accumulates (SENIOR2).

The important feature of “more observations required” is the emphasis on the belief that more observations will eventually lead to the correct answer about the ultimate fate of the universe. The participants who stated that “more observations are required” to find the correct theory between the Big Rip and the Big Crunch will be found were confident that more data would lead to the truth.

RELIGIOUS SOURCES

The third belief that the participants expressed for why they thought that the correct theory could be found was that the answer to the problem of the ultimate fate of the universe should be sought in religious sources. Five participants (10%), one freshman, one senior, one masters student, one PhD student, and one faculty member, stated that the correct theory could be found in religious sources. For these participants, the ultimate fate of the universe was essentially a religious problem. Therefore, the answer to the ultimate fate of the universe should be sought in religious sources. Since Allah was the creator of the universe, Allah knew how the universe would come to an end, and Allah would reveal this knowledge in the Holy Koran. For example, a freshman stated:
Well there are books that argue that Koran can solve it. Maybe something of that sort, from ancient knowledge, using sources with higher certainty. Koran is such a source. I mean this is a divine topic after all. Allah created the universe and sent us the Koran so I’d think that the answer might be there (FRESHMAN6).

These participants believed that everything has a beginning and an end. According to these participants, since the universe had a beginning it meant that the universe too must cease to exist eventually. According to these participants, Koran stated that the universe and everything in it was created from nothing. Allah said ‘let it be’ and everything simply came into existence. Koran also said that everything would return back to nothingness. When Allah says ‘let it cease to be’ everything including the universe would cease to exist. According to these participants, in Islam the doomsday meant that everything would vanish. It was Allah’s power that ignited the universe and it would be Allah’s power that would extinguish it. To learn about how the end would come about, one should consult the divine knowledge revealed in the religious sources. For example, a masters student stated:

First of all there has been a creation, the creation of the universe. And like everything this must have an end too, the doomsday. The answer to this problem is in the Holy Koran (MASTERS9).

In similar lines a senior said:

We read about the doomsday from the Holy Koran. We can look at the Gasiyeh chapter and learn how it will come about. In short, I say the answer is in the Koran... But the answer to this problem is the doomsday. The answer is in the Holy Koran (SENROR10).

One participant stated that not only the answer to the ultimate fate of the universe was in the religious sources, but also he knew what that answer was. According to this
participant, the Big Crunch theory was correct and the Big Rip theory was false. This participant stated that the Big Crunch was the correct explanation for the ultimate fate of the universe because the Koran contained verses that implied the universe would be rolled back onto itself. He said:

Now this topic is a religious topic for me. Koran says that the universe came about with an explosion and that it will be rolled back again. And I believe that. And as far as I know the similar things are in Jewish sources and in the Bible too. If you look at the sections of these books that talk about the doomsday, you see that they say it will be rolled back. So I believe that the universe will end with a Big Crunch. And if you ask me how sure I am, I am sure personally, but I can’t say that I can prove it with physics (PHD10).

A faculty member was the last participant who said that religious sources could help us find the correct theory about the ultimate fate of the universe. This faculty member was much less certain than the other participants who said that the correct theory could be found in religious sources. According to this faculty member, religious sources should be treated as a source that would give new ideas or perspectives. According to him, the verses in religious sources should not be understood literally. These verses required interpretation and interpretations might differ for different social milieu. Therefore, one verse could not decisively prove that the Big Rip or the Big Crunch theories were correct. He said:

I think this is somewhat related to faith. Maybe we should look in religious books. If we looked at the Holy Koran the Bible and the Old Testament, do they give any information about the universe? How was the universe created, how will it end? I mean these are knowledge beyond our capacity. We can refer to the knowledge in these books...Now the physical work must be done experimentally. There must be something concrete. This is a completely different subject, at the point where we stall when we are inadequate then this gives another perspective, idea. Now your work
depends on your explanation too. Like how you understand the verse, how you look at it. You look at its interpretation based on your previous knowledge. If your work is progressing parallel to those verses then it may have some part of truth... So both the meaning and interpretation of a verse is important. Koran is not for a particular time. It doesn't only look at our time. Just like it addresses us now, it also will address following generations. People who will come after us may interpret that verse differently. Therefore the first theory might as well be correct (FACULTY2).

_Correct theory cannot be found_

The majority of the participants said that the correct theory between the Big Rip and the Big Crunch theories could not be found. Forty-one participants (82%) said that the correct theory between the Big Rip and the Big Crunch theories could not be found. Eight participants in the freshman group, eight participants in the seniors group, nine participants in the masters group, eight participants in the PhD group, and eight participants in the faculty group said that the correct theory between the Big Rip and the Big Crunch theories could not be found. The participants expressed five different beliefs for why they thought the correct theory could not be found: data was incomplete to reach a conclusion about the correct theory, there might be unknown factors and laws in the universe, only God knows which theory was correct, future cannot be known, and the knowledge about the universe is based on models. Often the same participant expressed more than one belief in why he or she thought the correct theory could not be found.
The range of beliefs about knowledge in the correct theory cannot be found response category of the correctness of a theory theme in the context of the ill-structured problem.

**INCOMPLETE DATA**

The first belief that the participants expressed for why they thought that the correct theory could not be found was that the data at hand was incomplete to decisively conclude that one theory was correct. Twenty-three participants (46%) said that the correct theory between the Big Rip and the Big Crunch theories could not be found because the available data was not adequate to reach a conclusion. Five participants in the freshman group, four participants in the seniors group, four participants in the masters group, four participants in the PhD groups, and six participants in the faculty group stated that because of incomplete data it was not possible to find out the correct theory.

According to these participants, the universe was vast and scientists’ observation opportunities were limited. These participants stated that the quantity of data was simply
not adequate to predict how the universe would come to an end. The quantity of data was not adequate because scientists had observed only a tiny part of the universe and the accumulated observations dated only a few hundred years back from the current time. For example, a masters student said:

The problem is our observation opportunity is very limited. What we can observe is mostly in the visible range. Only recently we are able to make observations on the x-ray and gamma range. So our observations are extremely limited, the data we have is very limited. That’s why I can’t say either one would happen or the other. And we don’t even know at what stage of expansion we are in now (MASTERS10).

A freshman also indicated that the universe was huge and the information we can have about the universe was limited. He noted that there could be places in the universe that we know nothing about. He said:

I mean it's the universe. When I think about it the nearest star to the earth is 4 light years away, and it's only seen from the South Pole. In the north, the nearest one is I think 8 light years. And these are things that are inside our Milkyway. The nearest galaxy to us is Andromeda and I heard that it is 2.5 million light years away. I mean these are huge quantities. I don’t think we can get enough data from such huge distances and there are places in the universe that we don’t know anything about (FRESHMAN7).

Beside the quantity of the existing data, some participants also questioned the quality of existing data. These participants noted that the existing measurements might not be accurate or complete. The quality of data was inadequate because most of the measurements were indirect and the available technology may not be adequate to obtain precise measurements. For instance, a faculty member expressed his doubts about the current data on the expansion of the universe by pointing out that it was not possible to get measurements from the very distant edges of the universe. He said:
So it's expanding instead of slowing down it's accelerating. And how do they measure that? Perhaps where they take the measurements are here, and it's accelerating. But can they measure far enough? Because these people who take the measurements can't measure distant enough, they see it like accelerating and if they measure closer distances that explosion, and we are here, then this is indeed accelerating with the impact of the initial explosion. But others have gone very fast and slowed down. Maybe these things that accelerate now will slow down. I mean nobody can claim that these measurements were taken at the edge of the universe and I don't believe them. Because we don't know where the universe ends. We don't have enough information (FACULTY5).

The distinguishing feature of “incomplete data” is the emphasis on the improbability of ever obtaining adequate data in order to reach the truth about the ultimate fate of the universe. For these participants, the amount of data that scientists could obtain was never likely to be sufficient to conclude that the Big Rip or the Big Crunch is correct; in other words, data would always be incomplete. The emphasis on the inherent incompleteness of data stands in contrast to the “more observations required” belief expressed by the participants who said that the correct theory could be found between the Big Rip and the Big Crunch theories. In “more observations required” the confidence in obtaining adequate data in the future that would enable scientists to find the correct answer to the ultimate fate of the universe problem was emphasized, whereas in “incomplete data” the doubt on ever possessing adequate data to reach the correct answer was stressed.

**UNKNOWN FACTORS**

The second belief that the participants expressed for why they thought that the correct theory could not be found was that there might be unknown physical factors and
physics laws in the universe that prevents scientists to conclude that one theory was correct. Twelve participants (24%) said that the correct theory between the Big Rip and the Big Crunch theories could not be found, because there may be physical quantities or physics laws that scientists’ are not aware of. None of the participants in the freshman and seniors groups said that the correct theory could not be found because of the possible existence of unknown factors. Four participants in the masters group, three participants in the PhD group, and five participants in the faculty group said that there might be unknown factors.

According to these participants, scientists could never be completely certain about how the universe would come to an end. Because scientists did not know whether they have discovered all of the physical quantities and physics laws. Moreover, these participants pointed out that there might be physics laws that may show their effects in distant future. For example, a faculty member said:

Both of these could be correct because we are not 100% certain. As far as we can measure or think we measured the total matter and energy density of the universe the universe will keep expanding. But if there are laws of nature that we have not recognized yet... for instance there may be a law that would show its effect 50 billion years from now. So we can never be completely sure about this (FACULTY6).

These participants stated that the expansion velocity of the universe was accelerating. According to these participants, the acceleration of the expansion velocity was an anomalous situation. If the universe was created by the Big Bang, the expansion velocity should have decreased. Because the only force that acted on the objects in large scales was gravitational force. Gravitational force was manifested as the attraction of
masses to one another. Therefore, the objects in the universe would pull each other resulting in slowing down the expansion velocity of the universe. According to these participants, if the expansion velocity of the universe was increasing instead of decreasing, there must have been some unknown factor. For example, a PhD student said:

Well since there is a positive acceleration of the expansion, there must be something that causes this expansion. We would expect it to slow down because of gravity, but it’s not (slowing down). So there may be something that we don’t know about the universe a different kind of force or something else that we don’t know. Therefore, we cannot know which theory is correct (PHD9).

According to these participants, one such unknown factor could have been dark matter. Dark matter, unlike ordinary matter, repelled masses instead of attracting them. If dark matter existed, it also meant that there were unknown physics laws. For instance, the laws of gravitational force stated that masses attracted other masses. Dark matter did not obey this law, which suggests that there may be another that governs the behavior of dark matter and explains the interactions between dark matter and ordinary matter. According to these participants, if scientists suspected the existence of at least one unknown factor, namely dark matter, by extension there might as well be other unknown factors and laws. For example, a masters student said:

Because there isn’t an opportunity to make observations or investigations in the end this is a guess. So in order to claim anything about the end of the universe they must have proven the expansion of the universe. So for the expansion to stop and then the crunch to begin, but there’s something that they call dark matter, not necessarily the matter, but a situation that is not known. As force and matter and as energy in general. What is that dark energy? I mean obviously it is not known yet. And it cannot be predicted in any way. Because we don’t know what it is, we also don’t know if it could pull the universe back together (MASTERS2).
ONLY GOD KNOWS

The third belief that the participants expressed for why they thought that the correct theory could not be found was only God knew the ultimate fate of the universe. Nine participants (18%) said that the correct theory between the Big Rip and the Big Crunch theories could not be found, because only God could know how the universe would come to an end. Three participants in the freshman group, two participants in the seniors, two participants in the masters group, one participant in the PhD group, and two participants in the faculty group stated that only God knew the ultimate fate of the universe.

The belief that only God knows the ultimate fate of the universe is very similar to the belief ultimate fate of the universe could be learned from religious sources. Both of these beliefs were based on religion. The participants who held these beliefs considered the ultimate fate of the universe as a religious problem. The participants who held either belief expressed that God created the universe and God knows how it will be terminated. The difference between these two beliefs, only God knows and religious sources, was that for the former belief the knowledge of the ultimate of the universe is in the possession of God alone and was accessible to humans. For the latter, God not only knows but also reveals the knowledge to humans in the Holy Scriptures.

For the participants who believed that only God knows the ultimate fate of the universe, this problem was fundamentally a religious problem. According to these participants, scientists could never find answers to such questions as the ultimate fate of the universe, because this was divine knowledge beyond human comprehension. These
participants stated that there were things that human mind could understand and there were other things that it simply was not capable of. The ultimate fate of the universe was such a question and “only God knows the correct answer to this” (FRESHMAN2). For example, A PhD student articulated why he thought that only the creator could know the fate of the universe by resembling the universe to a building and the creator to the architect. He said:

If you think of the universe as a building, the engineer who built the universe knows how the building was constructed, how much steel how much concrete was used in the construction. So the engineer or the architect knows when or how the building can collapse. So in the case of the universe only the creator knows when or how they universe will end. We cannot know this (PHD3).

These participants stated that scientists could not know the ultimate fate of the universe because the vastness of the universe was beyond human comprehension. According to these participants, scientists did not even know if the universe was finite or infinite. For these participants, scientists could try and explain the origin of universe and how it would come to an end, but they could never be certain. For example, a masters student said:

Now we are talking about the universe but the creator is greater than the universe. Perhaps we are only in one of the many universes. Perhaps the creation and annihilation of the universe is an ordinary event for the creator like what blink of an eye is to us. But we can’t really know anything about these. These are beyond the limits of human mind. Of course we could propose theories and do research but is impossible to be certain (MASTERS8).

FUTURE CANNOT BE KNOWN

The fourth belief that the participants expressed for why they thought that the correct theory could not be found was that future could not be known. Fourteen
participants (28%) said that the correct theory between the Big Rip and the Big Crunch theories could not be found, because future events could not be known with certainty.

Three participants in the freshman group, three participants in the seniors group, four participants in the masters group, three participants in the PhD groups, and one participant in the faculty group stated that future could not be known.

According to these participants, there were constraints on what can be known about the universe. Predicting future events with certainty was one such constraint. These participants stated future could not be known because it had not happened yet. According to these participants, the only way to be sure about the fate of the universe was to be present when the end comes and witness what would happen. Since this was not possible, these participants concluded that the correct theory between the Big Rip and the Big Crunch theories could not be found. For example, a freshman said:

We can't say that we figured it out 100%. Maybe we can reach a conclusion about past events. But about future, I can't say that we can conclude this or that 100%. Because we cannot know what the future shows. Maybe this acceleration may slow down after a while and then the Crunch may happen. As I said it may be possible to say that it was like this about the past. But about the future I can't say that. What will happen in the future cannot be known (FRESHMAN7).

A senior also indicated that the ultimate fate of the universe could not be known before it actually happened. This senior said:

No I don’t think we can (find the correct answer). I mean to find out how much the universe will expand. It’s just beyond our limits. We would have to actually be present to see the end of the universe. But it’s just not possible within our lifetime. I say it’s impossible (SENIOR5).
These participants stated that one could not know exactly how the ultimate fate of the universe would be because humans’ life span was not long enough to witness the death of the universe. For example a masters student stated:

We just can’t say much about this topic. These are the kinds of things that are beyond human mind. I mean we can propose theories but we can never be certain. Because the average lifespan of humans is, what, 70 years? We are talking about billions of years here and it’s just not enough to witness the end of the universe (MASTERS8).

And a faculty member noted:

Well because this is about something in the far future, I think that it seems impossible to decide that this one is correct. I mean in physics there are many theories that have been accepted as correct and with time many of their aspects have been proven to be wrong. I mean even if we could say this or that is correct, the certainty of it is out of question. We would have to be there to see how it ends to be sure (FACULTY10).

**BASED ON THEORETICAL MODELS**

The fifth belief that the participants expressed for why they thought that the correct theory could not be found was that the knowledge about the ultimate fate of the universe was based on theoretical models. According to some participants, all theoretical models were based on assumptions, theoretical models changed as new data became available, and theoretical models did not necessarily corresponded to the real physical system.

Ten participants (20%) said that the correct theory between the Big Rip and the Big Crunch theories could not be found, because the knowledge about the universe is based on theoretical models. None of the participants in the freshman and seniors groups said that the correct theory could not be found because the knowledge about the universe
is based on models. Two participants in the masters group, two participants in the PhD group, and six participants in the faculty group said that knowledge about the universe is based on theoretical models.

According to these participants, the knowledge about the universe was based on theoretical models. These participants said that theoretical models were explanations that scientists constructed by interpreting the data. According to these participants, theoretical models were limited by the available data and mathematical techniques and they involved assumptions that could not be proven. For these participants, nature of producing theoretical models involved generating explanations that fitted available data. As the available data, mathematical techniques, and assumptions changed so did theoretical models. For example, a faculty member said:

Can we know how the universe will end? These are all based on assumptions. Now we know that the universe is expanding, because Hubble’s observations show that. Before we thought that the universe was stationary. Hubble was able to observe distant start and galaxies. He related red shift of different stars to an expanding universe. Before the stationary universe model was accepted. Now these two models (the Big Rip and the Big Crunch) must be able to explain the expansion of the universe, otherwise they wouldn’t be discussed at all. But these two models make unproven assumptions. Like the total mass in the universe and the change in expansion velocity. (FACULTY8).

According to these participants, in the case of the ultimate fate of the universe, the available data was expected to change. These participants stated that as technology advanced new methods would be developed which would allow obtaining previously unavailable data. These participants stated that since theoretical models changed in time and it was impossible to say that a theoretical model is completely proven. For this
reason, it was not possible to say that one theory is correct and the other is wrong with certainty. For example, a masters student said:

I don’t think that the information at hand is adequate to reach a definite conclusion (about the ultimate fate of the universe). But we can build probabilistic models and interpret the data… And these are only models that we construct. We don’t know how correctly it reflects the real system. Like there is a black box, a plant and there are inputs and outputs. We are only trying to construct mathematical relationships that can satisfy the correlation between the inputs and outputs. That’s all we can do. And we can never be 100% sure of any theory (MASTERS3).

According to these participants, the predictions about the ultimate fate of the universe were based on particular theoretical models, which did not necessarily correspond to the reality. These participants stated that theoretical models were expressed in terms of mathematical relationships. According to these participants, the predictions about the future states of a physical system were calculated by using these mathematical relationships in the theoretical models. As the mathematical relationships changed from one model to another, so did the predictions. For these participants, in the absence of observations to judge whether the predictions were accurate, it was not possible to say that one model was correct and the other model was wrong. According to these participants, in the case of the ultimate fate of the universe, scientists only had the predictions calculated from the mathematical relationships in the Big Rip and the Big Crunch theories. Therefore, it was not possible to be certain about whether the universe would collapse onto itself or it would keep expanding to eternity. For example, a PhD student said:

These exist only theoretically. I mean even when we calculate the size of the universe we can only know that theoretically. We cannot prove that it
indeed is that big. We only can say that based on mathematical calculations the universe is this big or the Earth is this old. But I don't think that mere mathematical calculations will be adequate to predict things that will happen in the future. Because what's important is to be able to make observations...We move from particular models physicists and mathematicians alike. There's always a particular model and based on that model they say that the universe expands this much, the expansion velocity is this much, and the universe is this big. Because we cannot make observations, because we cannot go beyond mathematical calculations, I don't think there will be a certain answer to this question. And I don't think we can find that answer either (PHD4).

_Betterness of a Theory Theme_

The second theme in the context of the ill-structured problem was betterness of a theory. Betterness of a theory refers to whether it is possible to find the better theory between the Big Rip and the Big Crunch. When the participants considered whether the better theory between the two theories could be found, the participants chose either the better theory can be found or the better theory cannot be found. When the participants explained the reasons for why they thought the better theory can or cannot be found, they expressed their beliefs about knowledge in physics. In the following sections, the participants’ beliefs about knowledge in physics are presented for the better theory can be found and the better theory cannot be found positions.
Better theory could be found

Thirty (60%) participants said that it was possible to find the better theory between the Big Rip and the Big Crunch theories. Four participants in the freshman group, four participants in the seniors groups, seven participants in the masters group, eight participants in the PhD group, and eight participants in the faculty group stated that the better theory could be found.

The participants who said that the better theory could be found expressed two distinct beliefs. These participants expressed that the better theory could be found either by evaluating the arguments of the theories or by evaluating the two theoretical models. According to some participants, the arguments of the Big Rip and the Big Crunch could be evaluated by judging whether one of the theories could be proven or one of the theories could be refuted. On the other hand, other participants said that the better theory could be found by evaluating the two theoretical models. Evaluating models was a more
specialized form of evaluating arguments. In evaluating models, the participants expressed three criteria: degree of fit with existing data, predictions of the models, and the empirical tests of these predictions.

Figure 11. The range of beliefs about knowledge in the better theory can be found response category of the betterness of a theory theme in the context of the ill-structured problem.
EVALUATING ARGUMENTS

The first belief that the participants expressed for why they thought that the better theory could be found was that evaluating arguments of the Big Rip and the Big Crunch theories could lead to finding the better of these two theories. Eighteen participants (36%) said that the better theory could be found by evaluating the arguments of the Big Rip and the Big Crunch theories. Four participants in the freshman group, four participants in the seniors group, four participants in the masters group, four participants in the PhD groups, and two participants in the faculty group said that it is possible to judge the better theory by evaluating the arguments of the two theories.

These participants said that they would evaluate the claims made by each theory. According to these participants, one could determine the better theory on the basis of which one defends their claims better. For to these participants, there were two criteria in evaluating the arguments of the Big Rip and the Big Crunch theories: (a) if one of the rival theories could be refuted or (b) if one of the theories is proven.

The first criterion that the participants offered in evaluating arguments of the Big Rip and the Big Crunch theories was whether one of the two theories could be refuted. These participants stated that since there are two competing theories about the ultimate fate of the universe, scientists must have reasons to believe the Big Rip or the Big Crunch theories. According to these participants, the scientific community accepted neither one of the theories because neither theory had been refuted. If one of the theories could be refuted, then the other theory would be considered as the better theory. For example, a senior said:
There are two different theories and I think there can even be a third theory. I mean they have thought of only two theories but I don't know how they support it. They must have reasons because if both theories can somehow be supported then one is not able to refute the other. I mean if one (theory) can prove that the other can't happen then that one is the better (theory) (SENIOR3).

The second criterion that the participants stated in evaluating arguments of the Big Rip and the Big Crunch theories was whether one of the two theories could be proven. Some participants expressed the necessity of proof in order to judge one theory as better than the other one, however, they were puzzled about what kind of proof it would be. For example, a freshman said:

…to know the better one of them must prove their theory. How can they prove it? I really don’t know but to decide one is better there must be proof (FRESHMAN10).

For these participants, if one of the theories could be proven, that theory would be accepted as the better theory and the other theory would be eliminated. For example, a PhD student said:

This has to do what physicists do. How did physics advance? People proposed theories and tried to prove these theories and the successful ones (scientists) proved their theories. This is also similar. If one of the theories can be proven then it will be accepted as the valid theory. And the other one will be discarded. (PHD4).

Some participants stated that proof and refutation should be presented together in order to judge the Big Rip or the Big Crunch theories as better than the other. According to these participants, the better theory should both prove that the reasons underlying it are correct and show that the reasons underlying the rival theory are wrong. For example, a masters student said:
For instance supporters of Big Crunch theory could say to the others look you are saying that the universe will keep expanding, but because of such and such reasons it will not keep expanding. If they can prove that their reasons are correct, then they can say that the Big Rip theory is wrong. But they have to show that Big Rip is indeed wrong. And that can only be proven wrong using physics laws (MASTERS9).

**EVALUATING THEORETICAL MODELS**

The second belief that the participants expressed for why they thought that the better theory could be found was that evaluating the Big Rip and the Big Crunch theoretical models could lead to finding the better of these two theories. Twelve participants (24%) said that the better theory between the Big Rip and Big Crunch theories could be found by evaluating these two theoretical models. None of the participants in the freshman and seniors groups stated that the better theory could be found by evaluating models. Two participants in the masters group, four participants in the PhD group, and six participants in the faculty group said that it was possible to find out the better theory by evaluating models.

For these participants choosing one theory over the other was not simply a matter of personal opinion that cannot be compared to others’ opinions on the same topic. According to these participants, it was not only possible but also necessary to evaluate the two competing theoretical models to make a judgment. Evaluating models required adhering to particular standards. According to these participants, these standards for evaluating theoretical models consisted of three sequential steps: (a) Degree of fit between each theoretical model and existing data, (b) predictions of the theoretical models, and (c) empirical tests of the predictions of the theoretical models.
The first step in evaluating theoretical models, according to these participants, was considering the degree of fit of the theoretical models with existing data. Degree of fit of a model meant the difference between the actual data and the theoretical model. According to these participants, a theoretical model was expressed by a mathematical function. This mathematical function would be generated by analyzing the data plotted on a graph. Using the data points on the graph a curve would be drawn that connects the data points. This curve would be represented by a mathematical function. The difference between the actual data points and the curve was called the error associated with the mathematical function. The error indicated the degree of fit of the theoretical model with the data. A theoretical model was expected to fit existing data within an acceptable error range. For two theoretical models, the model with less error would be considered a better fit. For example, a faculty member said:

To find the better model, you would have to look at the data. Which model fits the data better? You look at the (mathematical) functions. Are the error bars in one model less than the other? Does one function approximate the data points better than the other? There are statistical methods for these. So first of all, the models must fit the data. If one model apparently fits the data better, then it is the better (model) (FACULTY8).

The second step in evaluating theoretical models, for these participants, was considering the predictions of the models. These participants stated that generating predictions from the models were the responsibility of the scientists who proposed the model. Simply considering the degree of match with the data was not adequate for evaluating models. According to these participants, theoretical models were required to produce empirically testable predictions. If a theoretical model could not produce
empirically testable predictions, that model would not be considered seriously in the scientific community. For instance, string theory, which proposed that all matter was indeed made of invisible strings that oscillate in multiple dimensions, had almost no credibility on the eyes of some participants in the faculty group. These faculty members maintained that string theory failed to produce predictions that could be tested empirically and faded away from the discussions in physics community. For example, a faculty member said:

For example, there are many particles and models which are purported to exist in particle physics. But today there's a standard model that is accepted. I mean up to 1 terraelectronvolts this model explains very well all the particle physics phenomena. Of course now the question is what is beyond standard model...In particle physics during 1960s something called super-symmetry has been proposed. You may have heard about this topic, now there's the extra dimensions you may have heard, everyone calls is string theory. I mean very busily papers have been published et cetera. But today none of those papers are useful. For example I ask those who work on string theory what is the main prediction of string theory? For example Einstein’s relativity’s main prediction is Mercury's perihelion. But none of them can tell me a main prediction. They only say super symmetry and we don't even know on what scale the supper symmetry will be (FACULTY9).

According to these participants, in many cases competing theoretical models would fit the data within an acceptable range of error. The competing theoretical models could explain the existing data equally well. However, these participants stated, the predictions of these models would be different. According to these participants, these predictions could be about the state of a system that had not been measured before. The states of a physical system were expressed in terms of mathematical equations. Two different models would represent the same physical system with two different
mathematical equations. Two different mathematical equations would produce different predictions for different values of a parameter in the equation. The parameters in the models corresponded to physical quantities. For a particular value of a physical quantity, each theoretical model would predict the value of another physical quantity. For example, a masters student said:

You make mathematical descriptions of a system you have observed. And then when you look at these mathematical descriptions, not directly the observations but the mathematical model, you see that the model goes beyond the observed. For instance for these models you may look at what happens when the volume of the universe is tripled. Perhaps you will find a singularity in those mathematical equations. Then you say that my theory predicts this. And you state your predictions beforehand and as that system evolves in time you test whether the system matches your predictions (MASTERS3).

According to these participants, the predictions of theoretical models could also be about a previously unobserved phenomenon. For example, Einstein predicted time dilation with the special relativity theory. Time dilation was a phenomenon that has not been known before. In several experiments time dilation had been measured, which established the status of relativity theory in physics. For example, a PhD student said:

For a theory to be accepted, it has to be confirmed by future experiments beside its mathematical consistency. Only then that theory would be a good theory. A successful theory should not only explain the experiments in the past but it has to be able to explain experiments in the future. Einstein’s relativity has been successful mostly because it has shown the way to new venues of research. Say time dilation, we didn’t know it existed before Einstein’s relativity. Then with experiments, like the half-life of muons, now we know time dilation exists (PHD7).

The third step of evaluating theoretical models, according to these participants, was comparing the predictions of the models against the results of empirical tests.
According to these participants, scientists were expected to devise experiments to empirically test the predictions of theoretical models. If the results of the empirical tests matched the predictions of the model, then the model would have an advantage over the other. However, these participants stated, a single empirical test was not adequate to support or dismiss a model. Multiple accurate predictions would enhance the status of a model and eventually lead to its acceptance by the scientific community. A faculty member expressed that this was like a game of checkers. With each verified prediction the model would win another piece in the game and after enough pieces were won, the model would be accepted. According to this faculty member, one prediction of the Big Rip and the Big Crunch models was the cosmological constant. If the value of the cosmological constant could be measured then it might have been an indication towards solving the problem of the ultimate fate of the universe. Scientists were designing experiments in space to measure this constant. This faculty member said:

A theory is like a game of checkers. You move one piece then you see this. You move another piece you see that. After you see 3 or 4 more like that you say that this theory is valid. Now as for the checker pieces of these neither has anything yet... There's something called Cosmological constant, as you know, lambda. Lambda is included in many models of the universe. I just looked at that yesterday, experiments are being designed. I didn't understand it completely. They are designing experiments in space to see if it's zero or not. That may be an indication like if the cosmological constant is not zero then that can be an indication (FACULTY3).

Better theory could not be found

Twenty participants (40%) said that the better theory between the Big Rip and the Big Crunch theories could not be found. Six participants in the freshmen group, six participants in the seniors group, four participants in the masters group, two participants
in the PhD group and two participants in the faculty group stated that it was not possible to find out the better theory. The participants who said that the better theory could not be found expressed two distinct beliefs. These participants expressed that the better theory between the Big Rip and the Big Crunch theories could not be found because (a) picking the better theory was a subjective choice or (b) conducting experiments to judge the better theory was not possible.

![Diagram](image)

**Figure 12. The range of beliefs about knowledge in the better theory cannot be found response category of the betterness of a theory theme in the context of the ill-structured problem.**

**SUBJECTIVE CHOICE**

The first belief that the participants expressed for why they thought that the better theory between the Big Rip and the Big Crunch theories could not be found was that picking the better theory was a personal choice. Twelve (24%) participants, four in the freshmen group, four in the seniors groups, two in the masters group, one the in PhD
group, and one in the faculty groups, said that the better theory could not be found because judging the better theory involves a subjective choice.

For these participants choosing between the two competing theories about the ultimate fate of the universe was a matter of taste. Since knowledge of the ultimate fate of the universe was uncertain, everyone was allowed to make his or her judgments on the basis of his or her interpretation of the problem. It was not possible to judge objectively that one theory was better than the other; what was better for some people was worse for others. For example, a senior said: “Unless it is certain, it is better for some people and worse for others. I mean you may say it's better and I may say it's worse. So it depends on taste, the way of thinking” (SENIOR8).

According to these participants, subjective choices were relative to individuals. One person’s subjective choices could not be compared with others’ choices. For example, a faculty member said:

Of course when two alternatives are presented, it is possible to say which one is better or weighs more. But this would be something very relative. For instance when you present me these two alternatives, when you say the Big Rip and the Big Crunch say I chose the Big Rip. And I have reasons for choosing that and those reasons, the reasons that I pick for the Big Rip may be different for someone else’s. So it's something relative (FACULTY1).

A PhD student also stated that deciding between the Big Rip and the Big Crunch theories involves personal interpretation. She said:

This I think is completely about personal interpretation. I mean there may be facts that you have to know in order to say anything about it. Like there are physics laws and they are completely valid. But this is almost like a
dream maybe not a dream but it is very philosophical. You can say I think this one is better but it’s only your interpretation (PHD1).

A masters student also noted the personal interpretation involved in deciding the better theory of the Big Rip and the Big Crunch theories, in the face of uncertainty. According to this masters student:

We can’t really say one is better. Because they are opposite theories one terminates the universe by cooling and the other by heating. There is no middle ground. I mean personally I can’t say one is better than the other. Because there isn’t proof you can say this is better and someone else can say the other (MASTERS10).

**EXPERIMENTS ARE NOT POSSIBLE**

The second belief that the participants expressed for why they thought that the better theory between the Big Rip and the Big Crunch theories could not be found was that experiments were not possible that would help solve the ultimate fate of the universe problem. Eight (22%) participants, two in the freshman group, two in the seniors group, two in the masters groups, one in the PhD group, and one in the faculty group said that the better theory could not be found because experiments were not possible.

According to these participants, experiments and observations could be used to determine the better theory. However, these participants did not find it likely that an experiment could be designed that would swing the betterness scale between the Big Rip and Big Crunch theories. Because experiments were extremely difficult if not impossible to conduct when the subject of inquiry was the entire universe. For example, a PhD student said:

Now in this one (problem) it’s just not possible to make an experiment. I mean if it could have been done that might have helped to one of these
(theories). Even for the Big Bang there isn’t really an experiment. They talk about the background radiation shows that the universe exploded from a point. But as for the end of the universe doing an experiment is physically not possible. Because we don’t have a system to perform that experiment and I don’t think we will ever have (such a system). If we knew how to do the experiment then we could have (reached a conclusion) (PHD6).

In similar lines a senior said:

Well because these (theories) are not experimental in the end. I mean there’s nothing visible, only certain people can see this. And because it’s not experimental it’s hard to say. When the topic is experimental we are able to get more certain results. So because it’s not experimental, we just can’t say this is better (SENIOR9).

And a faculty member noted:

..there's no such possibility to make an experiment and prove it because we are talking about a huge scale and time interval.. Like it's very difficult to prove its certainty experimentally. I don't think it's likely, I don't think it's possible (FACULTY10).

A freshman also pointed out that it would be an experiment that could decide which one of the two theories is better but it was not possible to make such an experiment. He said:

Like as an experiment we cannot take a universe and expand it. We just cannot do it. If we could then maybe we could have said that this or that is better. I can’t think of anything else (FRESHMAN8).

Diversity of Opinion Theme

Up to this point, participants’ beliefs about knowledge in the context of the ill-structured problem has been described and illustrated for the correctness of a theory theme and betterness of a theory theme. In this section, participants’ beliefs about knowledge in diversity of opinion theme in the context of the ill-structured problem are described.
The third theme in the context of the ill-structured problem was diversity of opinion. Diversity of opinion refers to the existence of multiple theories on the topic of the ultimate fate of the universe. The participants expressed three distinct beliefs when they talked about why they thought scientists proposed different theories on the same topic using the same data. The first belief was that scientists used different methods to analyze the same data and that was why they have reached different conclusions. The second belief was the theories were individual scientists’ subjective choices and hence there was a diversity of opinion on the ultimate fate of the universe problem. The third belief was diversity of opinion on the ultimate fate of the universe problem existed, because nature of building theoretical models allowed for such diversity.

![Diagram](image)

*Figure 13. The range of beliefs about knowledge in the diversity of opinion theme in the context of the ill-structured problem.*
Different Methods

The first belief that the participants expressed when they talked about the diversity of opinion among scientists on the ultimate fate of the universe problem was that scientists used different methods to analyze the data. Twelve participants (24%) said that scientists had different ideas about the same topic because the methods that scientists' had used were different. Four participants in the freshmen group, three participants in the seniors group, two participants in the masters group, two participants in the PhD group, and one participant in the faculty group stated that scientists used different methods and that was why scientists proposed different theories on the same topic.

According to these participants, one group of scientist might have employed different methods in analyzing the data than the other group. These participants said that it was possible to reach different conclusions by using different methods in analyzing the same data. For these participants, the ultimate fate of the universe problem could be resembled to a mathematics problem. In mathematics there was usually more than one way to solve a problem. For instance, there were many paths that could be taken between two points. Each of these paths represented the different methods that the scientists could have employed. For example, a senior said:

The methods each theory uses may be different. Both theories make claims about the end of the universe. One of the theories may have used the data in one way and the other in another way. Like in mathematics there is usually more than one way to solve a problem. Or if you want to go from point A to point B you can take different paths. Just like that Big Rip may be using one method for the data and the Big Crunch may be using another (SENIOR6).
A PhD student also employed the analogy between the mathematics problems and the ultimate fate of the universe problem. This PhD student said:

In the end they are talking about the same thing that the universe will cease to exist. Their methods may be different. Just like in mathematics you can say $2 + 2 = 4$. But there may be many ways to find the sum of 2 plus 2. You can do it one way and I can do it another way. So these physicists may be using solving the differential equations using different methods (PHD6).

According to these participants, different methods could also have came about by using the data selectively. The scientists could have focused on different parts of the same dataset. For example, a freshman said:

Maybe the reference systems they take, and the units they observe, the transformations they make are different. Maybe they made these theories by looking at different planets, they may have looked at different points. They may have done it at different places (FRESHMAN6).

**Individual Differences**

The second belief that the participants expressed in the diversity of opinion theme was related to individual differences among scientists. Twenty-five participants (50%) said that scientists had different ideas about the same topic because of their individual differences. Six participants in the freshmen group, six participants in the masters group, seven participants in the seniors group, four participants in the PhD group, and two participants in the faculty group stated that individual differences among scientists’ lead to the diversity of opinion.

According to these participants, the two theories about the ultimate fate of the universe were influenced by scientists’ personal interpretations of the data. The
individual differences among scientists lead the scientists to interpret the data differently.

For example, a freshman said:

This is something based more on interpretation. For example everybody can't interpret everything they see the same way. If we think about painters, if we take two painters and there was a landscape in front of them, they both would draw differently, they would include their ideas and interpretations. This may be one reason that these scientists have different styles of thinking (FRESHMAN3).

According to these participants, the differences in interpretations stemmed from scientists personal preferences. For these participants, these different preferences were shaped by a person’s beliefs, educations, and dispositions. These participants stated that even though two people could have been educated similarly, they still would have different tendencies in their choices. These personal differences would result in different ways of thinking for different people. For example, a faculty member said:

We had a professor here. He had twin sons and both of them went to college. One of them majored in physics the other majored in interior architecture. These are twins and they have chosen different disciplines. Similarly two people may have gone through a similar education and they may use the same data but their thinking is different. Even if they have had the same education their ways of going about the problem is not the same. Maybe this has to do with their inner world they have different inner worlds (FACULTY2).

According to these participants, ways of thinking would differ from person to person. As a result, in cases of uncertainty each person might end up with holding different opinions. In the ill-structured problem context, because of the uncertainty surrounding the problem, scientists’ personal ways of thinking might have a strong influence on the theories they support. For example, a masters student said:
Because it’s different people…their perspectives are different. Now let’s think that there are two windows one here and one there. One looks from the first window and the other looks from the second window. The color of the glass in the first window is red and the second is yellow. Now one person is looking out through the yellow window and the other is looking through the red window. They are in the same room and looking at the same thing but they see different things. Just like that people have different ways of looking at the world. Their upbringing, their ways of thinking are different (MASTERS5).

**Nature of Modeling**

The third belief that the participants expressed in the diversity of opinion theme was related to nature of modeling. Thirteen participants (26%) expressed that the nature of modeling was the reason for the diversity of ideas in the ultimate fate of the universe problem. None of the participants in the freshman and seniors groups said that the diversity of opinion among scientists on the ultimate fate of the universe problem was due to nature of building theoretical models. Two participants in the masters group, four participants in the PhD group, and seven participants in the faculty group stated that the nature of modeling was the reason for the diversity of opinion.

According to these participants, nature of building theoretical models allowed for constructing multiple theoretical models that explain the same phenomenon. Because it was possible for different models to fit the same data equally well. For these participants, the underlying reason for the existence of different models was not in individual differences, but the differences of the interpretations. Different interpretations lead to constructing different models. Even the same person could build two different models for the same data. For example, a faculty member said:
Different models with the same data. Perhaps this is the nature of the concept of model. You bring an explanation with your own accord and the explanations you bring may satisfy the data. They may give correct results. But if the model is not absolutely correct then another model too could match the data as well as your model did. Think about two entangled models. In order to build different models based on the same information of course different interpretation. Why will you make a different interpretation you have had similar education? … Probably rather than the person's difference, it is the difference of the interpretation. One person, yes even one person can propose two different models. And then to reduce these different interpretations to one to find the predictions of these models and to decide which prediction is more correct. If you can make an experiment and then you wouldn't have many problems. You would say this model is more appropriate. (FACULTY7)

For these participants, models referred to mathematical representations of theoretical explanations. According to these participants, constructing theoretical models meant fitting curves to data points. These participants stated that it was logically possible for many curves to pass through different data points. Therefore, even using the same dataset, it was possible to support two different theoretical models. For example, a faculty member said:

Let me tell you something very simple. Think about geometry. Only one straight line passes through two points. But millions of curves pass through the same two points. The line is the most economical of all of these (curves). Now I make an experiment and I plot the results of the experiment. I’m looking for a good clean curve. If I don’t know the theory underlying the experiment or the theory doesn’t provide me a function, then I feel the need to create that function for the curve I plotted. I fit a curve to the points on the graph based on my experience and habits. A circle, a hyperbola, or a parabola. And I try to understand which one of these curves would fit better using statistical methods. And if the curve I came up with is a good function, such as sinusoidal, exponential etc. And when I say good function, there is no such mathematical definition as a good function but if it you can take the derivatives and such. And if I can explain the function with a theory that I suspect that may underlie the phenomenon I was investigating, then I’m on the right path. And if I can predict some previously unobserved phenomenon and if the experimental physicists could measure what I predicted, and if these measurements fit
with the function I came up with, then I might even win the Nobel Prize (FACULTY6).

According to these participants, scientists who produced theoretical models were attached to their ideas. For these participants, scientists’ beliefs, values, and personal history affected their work. These participants stated that a scientist might have preferred a particular way of looking at phenomena because it might have been in line with his personal views. According to these participants, scientists’ sympathy might have biased his thinking to wish even try and force that his idea was better than other ideas on the same topic. Eventually though, if the model failed to match the nature it was destined to be abandoned. For example, a masters student said:

That's interesting, we may have different opinions on other subjects. But here on a concrete scientific topic to have different opinions. Well it's the difference in interpretation. It looks like beliefs are playing a role here. Like you may be more sympathetic to one view, you may approach with more tolerance. Maybe you ignore a weakness in that. Especially if you are one of the people who proposed the theory it becomes something like your baby. You don’t want it to be discarded. But in the end, if your theory doesn’t fit nature, you will have no choice but to abandon it (MASTERS2).

According to these participants, since models are mathematical representations of an explanation, a model should be coherent within the mathematics it employs. However, these participants stated, the coherence in mathematics did not follow that the model would be consistent with the physical world. According to these participants, explaining natural phenomena was important for a theoretical model, not producing beautiful mathematical representations. Therefore, for these participants, a model did not necessarily represent physical reality, and a model should be empirically tested to see if it

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was powerful enough to explain the particular phenomenon. For example, a PhD student said:

The models you build must be mathematically coherent, that’s a prerequisite. Then your model has to be as simple as possible. Everything else being the same, the simpler model is preferred. However, what you do is to see whether what you found matches the nature or not. If it doesn’t match, regardless of how simple or elegant your model is, it’s not worth much. Meaning, you will both explain past experiments and your predictions will turn out to be correct (PHD3).

Interpretations of the Findings of the Range of Epistemological Beliefs

The participants’ beliefs about knowledge in the context of the well-structured and ill-structured problems were described and illustrated in the previous sections of this chapter. In order to be able to relate the beliefs in the two problem contexts, the responses are grouped under seven epistemological belief types: authoritative, rational, empirical, experiential, religious, relativistic, and modeling belief type. Such grouping allowed describing the participants’ responses in both well-structured and ill-structured problem contexts with the same conceptual base, which serves as a metric that allows comparisons among the two problem contexts.

The labels for the epistemological belief types were either adopted from the literature or were constructed by the researcher. The labels authoritative, rational, and religious were adopted from Roth and Lucas (1997). The label empirical was adopted from Gilbert and Mulkay (1984). The labels experiential, relativistic, and modeling were invented by the researcher.
**Authoritative belief type** includes believing that source of knowledge is authorities and knowledge is justified by the authority of experts, teachers, books, and schools. Knowledge is taken at face value. Knowledge is accepted as correct and certain and is not questioned. The processes of knowledge production are not attended. The emphasis is on the authorities and not necessarily the methods that the authority employs in producing knowledge. In authoritative belief type knowledge is treated as received from the authorities; knowledge is transmitted from teachers to the students.

**Rational belief type** is related to exercise of sound reasoning and valid logic. Knowledge is generated through valid logical connections with previously established knowledge. New knowledge is built on previously proven knowledge. In rational beliefs knowledge is justified through confirmatory or refuting evidence. There are limits on what can be known. For example, future events cannot be known with certainty.

**Empirical belief type** is related to observational and experimental elements of knowledge production and validation. Controlling experimental conditions, minimizing experimental error, and replicating experiments are included in empirical belief type. The distinguishing feature of empirical belief type is the emphasis on systematic nature of scientific work. Empirical belief type is expressed with a formal tone, the individuals who draw on empirical reasons do not perform these observations and experiments; scientists do the experiments and observations. In empirical belief type source of knowledge is systematic empirical investigations and knowledge is justified with carefully conducted observations and experiments. Individuals who express empirical
belief type value methodological aspects of scientific work and regard empirical evidence as the way to establish a knowledge claim.

*Experiential belief type* is related to personal experiences. In experiential belief type, source of knowledge is personal observations and knowledge is justified through personal experiences.

*Religious belief type* is related to religious references to the existence of God, Holy Scriptures, and teachings of a faith. God possesses all knowledge and reveals part of his complete knowledge in the Holy Scriptures. Knowledge is justified with compatibility with religious teachings.

*Relativistic belief type* is related to subjective interpretations of individuals in evaluating knowledge claims. In relativistic belief type every person has a right to his or her opinion and the reasons for holding an opinion changes from one person to another. In relativistic belief type opinions of individuals are closely related to their personal preferences. Opinions are not comparable because knowledge judgments were considered as value judgments. Knowledge is a private possession that was justified on an individual level.

*Modeling belief type* is about building theoretical models for observed natural phenomena. Scientific knowledge is characterized as theoretical models. The focus on modeling belief type is on how data is used to build an explanation and how the constructed explanations are evaluated. In modeling belief type, theoretical models are considered with their degree of fit with existing data and their explanatory power manifested in the accuracy of the predictions of the theoretical models that reach beyond
the existing data. Theoretical models are required to produce predictions that can be empirically tested. The accuracy of a theoretical model’s predictions strengthens the model’s explanatory power. Theoretical models are characterized as valid rather than correct because every model is constrained by a range of phenomena that the model can explain.
Figure 14. Summary of the range of epistemological beliefs
Comparison of the Well-structured and Ill-structured Problem Contexts

So far, the range of beliefs about knowledge in physics was presented in the context of the well-structured and the ill-structured problem. These beliefs about knowledge were grouped into seven epistemological belief types: authoritative, rational, empirical, experiential, religious, relativistic, and modeling belief types. In this section, beliefs about knowledge in the context of the well-structured and the ill-structured problem are compared using the seven epistemological belief types as the metric. This section also serves to exemplify each epistemological belief type with the participants’ expressions in the well-structured and the ill-structured problem contexts. The comparison is made for all fifty participants; it does not pay attention to expertise level.
<table>
<thead>
<tr>
<th>Well-structured problem</th>
<th>Ill-structured problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confidence in principles</td>
<td>Correctness of a theory</td>
</tr>
<tr>
<td>Authoritative</td>
<td>We have learned principles and laws as correct</td>
</tr>
<tr>
<td>Rational</td>
<td>Foundation (building blocks), not refuted</td>
</tr>
<tr>
<td>Empirical</td>
<td>Supported with systematic empirical observations</td>
</tr>
<tr>
<td>Experiential</td>
<td>I see it work in everyday experience</td>
</tr>
<tr>
<td>Religious</td>
<td>Religious sources, only God knows</td>
</tr>
<tr>
<td>Relativistic</td>
<td>Subjective choice</td>
</tr>
<tr>
<td>Modeling</td>
<td>Principles and laws are theoretical models (correct but incomplete, valid for a range of phenomena)</td>
</tr>
</tbody>
</table>

Table 2. Epistemological belief in of the context of the well-structured and the ill-structured problem.
Authoritative belief type was expressed in both the context of the well-structured problem and the context of the ill-structured problem. In the context of the well-structured problem authoritative belief type was expressed in confidence in principles theme with “we have learned the principles and laws like that”. Authoritative belief type in this theme involved believing that buoyancy principles and Newton’s laws were correct on the basis of the authority of teachers, books, and schools. Authoritative belief type also included believing that these principles and laws were transmitted from the teachers to the students.

In the context of the ill-structured problem authoritative belief type was only expressed in the correctness of a theory theme. When whether the correct theory between the Big Rip and the Big Crunch theories could be found was considered, authoritative belief type was expressed with “professors and scientists know”. Authoritative belief type in the correctness of a theory theme involved believing that professors, scientists, and experts possess the knowledge of the correct explanation of the ultimate fate of the universe. In authoritative belief type knowledge experts’ authority justifies the knowledge about the ultimate fate of the universe.

Rational belief type was expressed in both the context of the well-structured and the ill-structured problems. In the context of the well-structured problem, rational belief type was expressed in the confidence principles theme by “foundation of new knowledge” and “not refuted”. Rational belief type in confidence in principles theme involved believing that buoyancy principles and Newton’s laws were correct because these principles and laws have withstood all falsification attempts. Rationally, if a
knowledge claim is not refuted, it is treated as correct. These principles and laws became part of the established scientific knowledge, because they have not been refuted. Additionally, buoyancy principles and Newton’s laws formed the foundation of new knowledge in physics. Since the new knowledge in physics is accepted as correct, these principles and laws also must be correct.

In the ill-structured problem context rational belief type was expressed in correctness of a theory, betterness of a theory, and diversity of opinion themes. When whether the correct theory could be found between the Big Rip and the Big Crunch theories was considered, rational belief type was expressed by “future cannot be known”. Since the death of the universe is going to happen in distant future, it is not possible to know how it will happen before it happens.

When whether the better theory of the Big Rip and the Big Crunch theories could be found was considered, rational belief type was expressed with “evaluating arguments”. Evaluating arguments means refuting or proving one of the theories. If one of the theories could be refuted, then the other theory would be considered as the better theory. Similarly, if one of the theories can be proven, that theory would be the better theory.

When the diversity of opinion among scientists on the ultimate fate of the universe problem was considered, rational belief type was expressed with “different methods”. Scientists proposed different theories on the ultimate fate of the universe, because they have employed different methods in analyzing the data. Just like a mathematics problem can be solved using a variety of methods, it is possible to propose different theories on the same topic and using the same data.
Empirical belief type was expressed in both the context of the well-structured and the ill-structured problems. In the context of the well-structured problem in confidence in principles theme, empirical belief type was expressed with “supported with systematic empirical investigations”. Empirical belief type involved believing that scientific method ensured that buoyancy principles and Newton’s laws were correct. The systematic nature of scientific method increased the credibility of these basic physics principles and laws. Replicating experimental results in establishing scientific knowledge reinforced the idea that scientific knowledge was reliable. Controlling experimental conditions and accounting for measurement error ensured that scientific knowledge was trustworthy.

In the context of the ill-structured problem, empirical belief type was expressed in correctness of a theory theme and betterness of a theory theme. When whether the correct theory between the Big Rip and Big Crunch theories could be found was considered, empirical belief type was expressed with “more observations”, “incomplete data”, and “unknown factors”. Empirical belief type included believing that more observations would lead to finding the correct answer of the ultimate fate of the universe. Empirical belief type also included believing that the data was incomplete to find out the correct answer of the ultimate fate of the universe. It also involved believing that there might be unknown physical quantities and physics laws that prevent reaching a conclusion about the correct theory about the ultimate fate of the universe.

When whether the better theory between the Big Rip and the Big Crunch theories could be found was considered, empirical belief type was expressed with “experiments are not possible”. Empirical belief type involved believing that the better theory could be
found by experiments; however, it was not possible to do experiments in the case of the ultimate fate of the universe.

Experiential belief type was expressed only in the context of the well-structured problem in confidence in principles theme. Empirical belief type involved believing that personal experience confirms buoyancy principles and Newton’s laws. Buoyancy principles and Newton’s laws are correct because anyone can witness that they work in everyday experience.

Religious belief type was expressed only in the ill-structured problem context, in the correctness of a theory theme. When whether the correct theory between the Big Rip and the Big Crunch theories could be found was considered, religious belief type was expressed with “religious sources” and “only God knows”. In religious belief type the ultimate fate of the universe problem is considered as an existential or metaphysical problem. Religious belief type involved believing that the correct answer to the ultimate fate of the universe problem could be found in religious sources. God created the universe and revealed the knowledge about the universe in religious texts. Religious beliefs type also involved believing that God created the universe and only God knew how it would come to an end. It was beyond the limits of human mind to know the ultimate fate of the universe.

Relativistic belief type was only expressed in the context of the ill-structured problem in betterness of a theory theme and diversity of opinion theme. When whether the better theory between the Big Rip and Big Crunch theories could be found was considered relativistic belief type was expressed with “subjective choice”. Choosing the
better theory between the Big Rip and the Big Crunch theories is a value judgment. One person’s value judgment cannot be compared with another person’s value judgment. Therefore, everyone has a right to opinion and there is no way to determine that one opinion is better than another. What is better for one person is worse for another person. When the diversity of opinion among scientists on the ultimate fate of the universe topic was considered, relativistic belief type was expressed with “individual differences”. Relativistic belief type involved believing that scientists’ interpretations of data are influenced by their personal preferences and ways of thinking.

Modeling belief type was expressed in both the context of the well-structured problem and the ill-structured problem. In the context of the well-structured problem in confidence in principles theme modeling belief type was expressed with “principles and laws are theoretical models”. As theoretical models these principles and laws were characterized as valid rather than correct. These principles and laws were valid for a range of phenomena. Because these laws failed to explain phenomena outside of the range of their validity they were incomplete. Buoyancy principles and Newton’s laws were correct because they explained observations within the range of speeds less than the speed of light and scales greater than molecular scale. These principles and laws were incomplete, because they failed to explain phenomena at speeds close to the speed of light and scales smaller than molecular scale.

In the context of the ill-structured problem, modeling belief type was expressed in correctness of a theory, betterness of a theory, and diversity of opinion themes. When whether the correct theory between the Big Rip and the Big Crunch theories could be
found was considered, modeling belief type was expressed with explanations about the ultimate fate of the universe are “theoretical models”. In modeling belief type correctness is not a property of theoretical models. Theoretical models evolve as new data becomes available and the assumptions involved in the models change. Therefore, it is not possible to say that one model is correct or certain.

When the better theory between the Big Rip and the Big Crunch theories could be found was considered, modeling belief type was expressed by “evaluating theoretical models”. Evaluating theoretical models means, first, considering the degree of fit of each model with the existing data. Theoretical models were required to explain available data. Second, theoretical models are expected to produce predictions about previously unmeasured states of a physical system or a previously observed phenomenon. Finally, theoretical models are judged as better by the accuracy of the predictions. If one of the theoretical model’s predictions matches empirical test results, then that theoretical model is judged as better than the other.

When the diversity of opinion among scientists was considered, modeling belief type was expressed with “nature of theoretical models”. The same phenomenon can be explained by more than one theoretical model. Mathematically it is possible that different models can fit the same dataset. The diversity is the result of the possibility of fitting different curves to the data points on a graph. However, the diversity often is resolved by the accuracy of the predictions of different theoretical models. If one model’s predictions fail, it means the model failed to match the nature. Eventually, the theoretical models that fail to match the nature are abandoned.
Comparison of Epistemological Beliefs among the Expertise Levels

Up to this point, the range of beliefs about knowledge is explored in the context of the well-structured and the ill-structured problem. The differences and similarities between beliefs about knowledge were also explored for the well-structured and ill-structured problem contexts. In this section, epistemological beliefs are compared with respect to expertise levels. These comparisons are made for the seven epistemological belief types that emerged from this study.

There was one theme in the well-structured problem context and three themes in the ill-structured problem context. The well-structured problem context is represented with the beliefs about knowledge in the confidence in principles theme. The ill-structured problem context is represented by combining beliefs about knowledge in correctness of a theory theme, betterness of a theory theme, and diversity of opinion theme. If a participant expressed an epistemological belief type in one of these three themes, the participant was considered as holding that epistemological belief type in the ill-structured problem context.

In the well-structured problem context, participants in all expertise level groups except the faculty group expressed authoritative belief type. Four participants in the freshman group, seven participants in the seniors group, and two participants in masters and PhD groups expressed authoritative beliefs about knowledge in the context of the well-structured problem. The number of undergraduate students (11) who expressed authoritative belief type was more than twice the number of graduate students (4).
In the context of the well-structured problem, participants in all expertise level groups except the faculty group expressed rational belief type. Three participants in the freshman group, five participants in the seniors group, two participants in masters group, and three participants in the PhD groups expressed rational belief type in the context of the well-structured problem. Eight (40%) undergraduate students and five (25%) graduate students expressed rational belief type in the context of the well-structured problem.

In the context of the well-structured problem, participants in all expertise level groups expressed empirical belief type. Three participants in the freshman group, four participants in the seniors group, three participants in masters group, five participants in the PhD group, and four participants in the faculty group expressed empirical belief type in the context of the well-structured problem. Seven (35%) undergraduate students, eight (40%) of the graduate students, and four (40%) of the faculty members expressed empirical belief type in the context of the well-structured problem.

In the context of the well-structured problem, participants in all expertise level groups expressed experiential belief type. Five participants in the freshman group, three participants in the seniors group, four participants in masters group, three participants in the PhD group, and one participant in the faculty group expressed experiential belief type in the context of the well-structured problem. Eight (40%) undergraduate students, seven (35%) of the graduate students, and one (10%) of the faculty members expressed experiential belief type in the context of the well-structured problem.

In the context of the well-structured problem, participants in only masters, PhD, and faculty groups expressed modeling belief type. Two participants in masters group,
four participants in the PhD group, and seven participants in the faculty group expressed modeling belief type in the context of the well-structured problem. Six (30%) of the graduate students, and seven (70%) of the faculty members expressed modeling belief type in the context of the well-structured problem.

Religious belief type and relativistic belief type were not expressed in the context of the well-structured problem.
Figure 15. The distribution of epistemological belief types with respect to expertise level groups in the context of the well-structured problem context.

Figure 16. The distribution of epistemological belief types with respect to expertise level groups in the context of the ill-structured problem context.
In the ill-structured problem context, only two participants, one in the freshman group and one in the seniors group expressed authoritative belief type.

In the context of the ill-structured problem, participants in all expertise level groups expressed rational belief type. Five participants in the freshman group, six participants in the seniors group, five participants in masters group, five participants in the PhD group, and three participants in the faculty group expressed rational belief type in the context of the ill-structured problem. Eleven (55%) undergraduate students and ten (50%) of the graduate students, and three (30%) faculty members expressed rational belief type in the context of the ill-structured problem.

In the context of the ill-structured problem, participants in all expertise level groups expressed empirical belief type. Six participants in the freshman group, five participants in the seniors group, six participants in masters group, five participants in the PhD group, and five participants in the faculty group expressed empirical belief type in the context of the ill-structured problem. Eleven (55%) undergraduate students, eleven (55%) of the graduate students, and five (50%) of the faculty members expressed empirical belief type in the context of the ill-structured problem.

In the context of the ill-structured problem, participants in only masters, PhD, and faculty groups expressed modeling belief type. Three participants in masters group, five participants in the PhD group, and seven participants in the faculty group expressed modeling belief type in the context of the ill-structured problem. Eight (40%) of the graduate students, and seven (70%) of the faculty members expressed modeling belief type in the context of the ill-structured problem.
In the context of the ill-structured problem, participants in all expertise level groups expressed relativistic belief type. Six participants in the freshman group, seven participants in the seniors group, six participants in masters group, four participants in the PhD group, and two participants in the faculty group expressed empirical belief type in the context of the ill-structured problem. Thirteen (65%) undergraduate students, ten (50%) of the graduate students, and two (20%) of the faculty members expressed relativistic belief type in the context of the ill-structured problem.

In the context of the ill-structured problem, participants in all expertise level groups expressed religious belief type. Four participants in the freshman group, three participants in the seniors group, three participants in masters group, two participants in the PhD group, and three participants in the faculty group expressed religious belief type in the context of the ill-structured problem. Seven (35%) undergraduate students, five (25%) of the graduate students, and three (30%) of the faculty members expressed religious belief type in the context of the ill-structured problem.

Summary of the Findings

The main product of this study was the construction of seven epistemological belief types, which described the range of beliefs about knowledge in physics. The epistemological belief types enable understanding beliefs about knowledge in different task contexts with the same conceptual base. Some participants expressed more than one epistemological belief type in the same problem context. Therefore, the epistemological belief types are not exclusive categories; a person can concurrently hold more than one
epistemological belief type. Moreover, the combination of epistemological belief types that a person holds can differ from one context to another.

In the comparison of the contexts of the well-structured and the ill-structured problem there were three important findings. First, authoritative belief type was expressed by considerably more participants in the well-structured problem context than the ill-structured problem context. Second, relativistic belief type and religious belief type were expressed only in ill-structured problem context. Finally, rational, empirical, modeling belief types were expressed in both problem contexts.

There were four important results of the comparison of the expertise level groups. First, undergraduate students expressed authoritative belief type more than graduate students and faculty did not express authoritative beliefs. Second, faculty expressed modeling beliefs about knowledge more than graduate students and undergraduate students did not express modeling beliefs. Third, there were no differences in rational, empirical, experiential, relativistic, and religious beliefs about knowledge among the expertise level groups. Finally, authoritative and modeling belief types are at the two extremes of the epistemological belief types. As the expertise level increased the number of participants who expressed authoritative beliefs about knowledge decreased and the number of participants who expressed modeling based beliefs about knowledge increased.
CHAPTER 5

DISCUSSION

This study aimed to explore undergraduate and graduate students’ and faculty’s beliefs about knowledge in physics. Beliefs about knowledge were explored in the context of two different problems. One of these problems was well-structured. It was a standard textbook problem on the topic of buoyancy of solids in liquids. The other problem was ill-structured. It was an astrophysics research problem about the ultimate fate of the universe.

This chapter deals with six issues. In the first section the epistemological belief types are contrasted with other models for personal epistemology. In the second section the epistemological belief types are examined as a framework by using the metaphor of a toolbox. The third issue discussed in this chapter is the role of task context in the use of epistemological belief types. Fourth, sophistication of personal epistemology among the expertise level groups is examined. The last two sections of the discussion chapter are allocated to the implications of these findings and discussions, and the issues of interests for future research. Figure 18 shows organization of Chapter 5.
Figure 17. Organization of Chapter 5 - Discussion
Epistemological Belief Types and Other Personal Epistemology Models

As a result of analysis of participants’ responses, seven types of beliefs about knowledge were constructed. These seven types of beliefs are named epistemological belief types. The epistemological belief types are authoritative, rational, empirical, experiential, relativistic, modeling, and religious belief types. The epistemological belief types were constructed through an inductive process. Some of the epistemological belief types were anticipated because similar constructs were identified in previous research. Other epistemological belief types emerged from the particular dataset that was analyzed in the current study.

The epistemological belief types constructed in this study are important because they address two problems with the previous conceptualizations of personal epistemology. The first problem is that previous conceptualizations of personal epistemology were mainly domain general. These previous conceptualizations considered individuals’ beliefs about knowledge in general. However, epistemological beliefs may vary from one domain to another. Therefore, domain general epistemological beliefs may not be sufficient to represent beliefs about knowledge in specific domains.

In this study, the epistemological belief types address the problem of domain specificity. The current study was designed specifically to address the problem of domain specificity. The two problems that the participants were asked to solve were chosen from physics and the interview questions that followed the two problems were related to knowledge in physics. The epistemological belief types were constructed based on the data collected using the two domain specific problems and the interview questions.
Therefore, the epistemological belief types are specific to physics; they are not domain
general. The epistemological belief types allow understanding what individuals believe
about knowledge in physics. By using the epistemological belief types, it became
possible to articulate personal epistemology in a particular domain, rather than speaking
of personal epistemology in general.

The second problem with previous conceptualizations of personal epistemology is
context sensitivity of personal epistemology. Previous conceptualizations did not include
social, cultural, or task contexts in their characterizations of personal epistemology.
Epistemological beliefs may not be consistent across different social, cultural, or task
contexts. Because the concept of context is too wide, it would be formidable to attempt to
cover all aspects of context. By constraining context with the type of task, this study
addresses part of the problem of context sensitivity. In physics, task contexts are mainly
either well-structured or ill-structured. If epistemological beliefs are examined without
considering both of these types of tasks, the findings might not be complete. In its
entirety the seven epistemological belief types allowed to classify the entire range of
participants’ responses in both the context of the well-structured and the ill-structured
problem.

The main finding of this study was the seven context-specific epistemological
belief types that describe beliefs about knowledge in physics. These epistemological
belief types intersect with other generic personal epistemology models at various points.
As discussed in the review of the literature, essentially all current conceptions of personal
epistemology can be reduced to three major theoretical positions: developmental, cognitive, and contextual models.

The first intersection is with the developmental models. In the developmental models individuals successively advance thorough sequential stages of epistemological development. Individuals start from absolutist views of knowledge. In absolutist stage knowledge is seen as right versus wrong and in the possession of authorities. Then, individuals proceed to multiplistic stage in which they begin to consider knowledge in subjective terms. At this stage individuals believe that everyone has a right to his or her opinion and they treat all opinions as equally valid. In the final stage, evaluativist stage, individuals see knowledge as constructed in accordance with rules of inquiry. The content of these three general stages of epistemological development correspond to authoritative, relativistic, and modeling belief types respectively.

The overlap between authoritative, relativistic, and modeling belief types with the content of the stages in developmental models implies that the developmental models partly capture personal epistemology. Developmental models are domain general whereas the epistemological belief types are constrained with the domain of physics. This similarity between the domain general and domain specific characterizations of personal epistemology means that domain general beliefs about knowledge are projected onto domain and context specific beliefs too. For example, an individual who believes that knowledge in general is in the possession of authorities is likely to believe that authorities hold knowledge in physics. Hence, this study confirms that developmental models
provide valuable information for understanding epistemological beliefs not only about
domain general knowledge, but also for domain and context specific knowledge.

On the other hand, developmental models capture personal epistemology only
partly because four of the seven belief types (rational, empirical, experiential, and
religious) are not represented in the developmental models. It is reasonable to think that
rational, empirical, experiential, and religious belief types were domain and task context
specific. Because the developmental models are domain general they might have failed to
recognize them. If this is the case, the developmental models cannot adequately explain
epistemological beliefs in physics.

Another possibility is that rational, empirical, experiential, and religious belief
types were subsumed under more general constructs. For instance, experiential beliefs
might have been subsumed under multiplistic stage in the developmental models.
Personal experience could have been considered as a manifestation of viewing
knowledge in subjective terms. Similarly rational, empirical, and religious belief types
might have been considered as manifestations of absolutist or evaluativist stages. If this is
the case, then this study refines the developmental models’ characterization of personal
epistemology.

The findings of this study partly confirmed developmental models’ description of
the content of epistemological beliefs, but they did not suggest that personal
epistemology consists of one-dimensional constructs or stages as developmental models
posited. The epistemological belief types constructed in this study are not characterized
as stages. Occupying two stages simultaneously is inconsistent with the developmental
models. By definition an individual cannot be at two different stages simultaneously. In the developmental models stages are exclusive, an individual can be only in one stage at a time in a given domain. However, the findings of this study suggest that an individual might be classified as being in one stage in the context of the well-structured problem while the same individual might be classified as being in a different stage in the context of the ill-structured problem.

The second point of intersection of the findings of this study is with the cognitive models. The cognitive models posit that there are independent dimensions of personal epistemology. The cognitive models criticize one-dimensional definition of personal epistemology. By dividing personal epistemology into four dimensions the cognitive models attempted to present a more detailed account of beliefs about knowledge. In the cognitive models there are four dimensions of personal epistemology: source of knowledge, certainty of knowledge, structure of knowledge, justification for knowing. Source of knowledge refers to viewing knowledge as originating and residing in external authority or as constructed by individuals in interaction with the environment and others. Certainty of knowledge dimension refers to the degree to which one views knowledge as fixed or more fluid. Structure of knowledge dimension refers to the degree to which one views knowledge as discrete and concrete facts or as relative and contingent conjectures. Justification of knowing dimension refers to how individuals explain and evaluate their own knowledge and that of others.

Among the four dimensions of personal epistemology that has been posited in the cognitive models, justification for knowing is evident in this study. The other three
dimensions did not fit the data. When the participants talked about source of knowledge they justified their beliefs about knowledge. For example, when the participants expressed authoritative belief type in the context of the well-structured problem they used authority to justify their confidence in buoyancy principles and Newton’s laws instead of offering authority as source of knowledge these principles and laws. In the case of structure of knowledge dimension, the data did not include anything that implied whether the participants have seen knowledge as independent pieces or as a coherent structure. As for certainty of knowledge, the participants’ responses were inconsequential. For instance, all participants viewed knowledge as certain in the context of the well-structured problem while they saw knowledge as uncertain in the context of the ill-structured problem. Justification of knowledge was evident throughout the data. In justification of knowledge dimension,

Individuals may justify beliefs through observation or authority or on the basis of what feels right, or through the evaluation of evidence, expertise and authority, and the assessment and integration of the views of experts. (Hofer, 2004, p. 131)

Consequently, three of the seven epistemological belief types were present in the justification of knowledge dimension. Authoritative belief types maps on to justification through “authority”, rational belief type maps onto justification through “evaluation of evidence”, experiential belief type maps onto justification through “observation” and “on the basis of what feels right”.

However, the participants also used the remaining four epistemological belief types (empirical, relativistic, religious, and modeling) to justify their beliefs about
knowledge. For example, empirical belief type was expressed when the participants justified why they trusted buoyancy principles and Newton’s laws. For these participants systematic empirical observations were the reason for trusting these principles and laws. Relativistic belief type was expressed when the participants justified why there were different explanations about the ultimate fate of the universe. For these participants different explanations were natural because of individual differences among scientists. Religious belief type was expressed when the participants justified why they believed that the correct explanation of the ultimate fate of the universe could or could not be found. For some participants the correct explanation could be found because God reveals the answer in religious sources. For other participants the correct explanation could not be found because only God knew how the universe would end. Modeling belief type was expressed when the participants justified why they trusted buoyancy principles and Newton’s laws. For these participants, because principles and laws were theoretical models that are constructed by scientists, these models are valid until they fail to explain new phenomena.

As described, only justification of knowledge dimension that cognitive models posited was evident in this study and not source of knowledge, certainty of knowledge, and structure of knowledge dimensions. Therefore, the current study does not provide evidence that personal epistemology consists of multiple independent dimensions.

The third point of intersection of the findings of this study is with the contextual models of personal epistemology. The contextual models posit that individuals have a repertoire of beliefs that they resort to depending on context. For example, even in the
same domain a person may believe that knowledge is certain and handed down from authorities when talking about established scientific knowledge, whereas the same person may believe that knowledge is subjective opinion and opinions are not comparable when talking about controversial issues in science. The contextual models are powerful because they can account for the domain specificity and context sensitivity problems. The contextual models are able to account for these problems because they are not constrained with stages of development or dimensions of personal epistemology. Holding different beliefs about knowledge in different contexts is not seen as a deficit of individuals’ epistemological sophistication, rather it is seen as an inherent property of personal epistemology. For the contextual models, it is natural that individuals hold different set of beliefs about knowledge in different contexts. The contextual models define epistemological sophistication as being able to recognize and apply beliefs about knowledge appropriately in changing contexts.

The epistemological belief types constructed in this study fits with the contextual models. The epistemological belief types were expressed in different combinations in different problem contexts. For example, when talking about buoyancy principles and Newton’s laws some participants expressed authoritative belief type, whereas when talking about the ultimate fate of the universe the same participants expressed relativistic belief type. This means that the epistemological belief types were utilized with respect to context. Therefore, the epistemological belief types constructed in the current study can be located among the contextual approaches to personal epistemology.
The problem with the contextual models of personal epistemology is the content of the repertoires of beliefs are not clear. The nature of repertoires differs from one particular contextual model to another. For example, Bell and Linn (2002) argue that the repertoire of beliefs range from static views of knowledge to dynamic views. Static views of knowledge refer to seeing knowledge as fixed and in final form. Dynamic views refer to seeing knowledge as fluid and always in progress. On the other hand, Ryder, Leach, and Driver (1999) claim that students’ views of scientific knowledge consist of data focused view, radical relativistic view, and data and theory related view. Data focused view refers to seeing knowledge as a copy of reality. Radical relativist view refers to seeing knowledge as subjective opinions that are equally valid. Data and theory focused view refers to seeing knowledge as constructed with the interaction of theories, practices, and data. This inconsistency makes it necessary to elaborate the content of repertoires posited by the contextual models in order to paint a more complete picture of personal epistemology.
<table>
<thead>
<tr>
<th>Developmental Models</th>
<th>Rational belief type</th>
<th>Authoritative belief type</th>
<th>Religious belief type</th>
<th>Relativistic belief type</th>
<th>Experiential belief type</th>
<th>Empirical belief type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perry (1970)</td>
<td>Dualism</td>
<td>multiplicity</td>
<td>commitment</td>
<td>multiplicity</td>
<td>commitment</td>
<td>commitment</td>
</tr>
<tr>
<td>Belenky et al. (1986)</td>
<td>received knowledge</td>
<td>subjective knowledge</td>
<td>constructed knowledge</td>
<td>knowledge</td>
<td>constructions</td>
<td>subjective knowledge</td>
</tr>
<tr>
<td>Kuhn (1991)</td>
<td>absolutists</td>
<td>multiplists</td>
<td>evaluativists</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baxter-Magolda (1992)</td>
<td>absolute knowers</td>
<td>independent knowers</td>
<td>contextual knowers</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Cognitive Models**

| Schommer (1990)      | justification for knowing | justification for knowing | justification for knowing |
| Hofer and Pintrich (1997)| justification for knowing | justification for knowing | justification for knowing |

**Contextual Models**

<table>
<thead>
<tr>
<th>Ryder, Leach, Driver (1999)</th>
<th>data based reasoning</th>
<th>radical relativist reasoning</th>
<th>theory and data based reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linn and Bell (2002)</td>
<td>static views</td>
<td>dynamic views</td>
<td></td>
</tr>
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</table>

**Table 3. The distribution of epistemological belief types across personal epistemology models.**
Personal Epistemology as a Toolbox of Beliefs

The comparison of the results of this study with the developmental, cognitive, and contextual models of personal epistemology revealed that each of these families of models provide valuable information about personal epistemology. However, none of these models alone can explain personal epistemology as a whole. In this part of the discussion, epistemological belief types are presented as a framework that not only elaborates the existing models but also expands them.

The framework of epistemological belief types relies on the metaphor of a toolbox. In this metaphor, each person has a toolbox and a set of tools in it. The function of the tools is to help the person accomplish a variety of tasks. The kind of tool that is required for a task depends on the kind of the task. Some tasks can be accomplished by using a single tool. Other tasks may call for the use of multiple tools. Or a person may choose to use multiple tools for a task simply because he or she is able, or feels that using more than one tool would get the job done better. The whole point of using a tool at all though, is to accomplish a task.

The toolbox metaphor maps on to the conceptual framework of epistemological belief types in two points: task and tools. First, the task in the metaphor is to justify one’s knowledge or that of others. When a person is asked a question about knowledge, answering the question becomes a task. The person accomplishes to justify his or her answer to the question by expressing a variety of epistemological belief types. For example, in this study the participants treated the question of how confident they were in buoyancy principles and Newton’s laws as a task, which is justifying why they were
confident or not. Second, each tool in the toolbox represents an epistemological belief type that individuals utilize to explain why they believe the way they believe. For instance, in this study when the participants were asked about their confidence in buoyancy principles and Newton’s laws, some participants used authoritative belief type while others used modeling belief type to justify their confidence. Moreover, some participants used more than one epistemological belief type to justify their answers. For example, in addition to authoritative belief type some participants expressed experiential, rational, or empirical belief types to justify their confidence in buoyancy principles and Newton’s laws.

The framework of epistemological belief types fills the gaps in previous conceptualizations of personal epistemology. The framework of epistemological belief types is capable of explaining individuals’ beliefs about knowledge that the developmental, cognitive, and contextual models explain. The developmental and the cognitive models of personal epistemology cannot account for domain specificity and context sensitivity problems. The framework of epistemological belief types provides an account for both domain specificity and context specificity of personal epistemology. The contextual models of personal epistemology can account for domain specificity and context sensitivity but they are too broad in their definitions of the content of the repertoire of epistemological beliefs. The framework of epistemological belief types elaborates the content of the repertoire of beliefs about knowledge by specifying seven distinct epistemological belief types. The following two sections, the comparison of the
two problem contexts and the comparison of the expertise level groups, are examples for
the application of the framework of epistemological belief types.

Epistemological Belief Types and Task Context

By exploring epistemological belief types in the context of a well-structured
problem and an ill-structured problem separately, it became possible to compare beliefs
about knowledge across the two problem contexts. This study was, to the researcher’s
best knowledge, the first study that has included both a well-structured problem and an
ill-structured problem to explore epistemological beliefs. Ill-structured problems have
been recognized as useful to capture individuals’ beliefs about knowledge. In addition to
ill-structured problems, well-structured problems are also significant for studying
personal epistemology. Because most of the problems that physics students are required
to solve are well-structured, including a well-structured problem as a task context to
explore epistemological beliefs was important. In this section by using the framework of
epistemological belief types the two problem contexts are compared.

There were three findings of the comparison of epistemological beliefs in the
context of the well-structured and the ill-structured problem. First, authoritative and
experiential beliefs about knowledge were expressed only in the context of the well-
structured problem. Second, relativistic and religious belief types were only expressed in
the context of the ill-structured problem. Third, rational, empirical, and modeling belief
types were expressed in both problem contexts.

The first finding of the comparison was that authoritative and experiential belief
types were expressed only in the context of the well-structured problem. Why
authoritative belief type was expressed in the context of the well-structured problem and not in the ill-structured problem? One explanation might be that the participants recognized the well-structured problem as an established idea and the ill-structured problem as a controversial idea in physics. That is, on one hand, well-structured problems have correct answers that are accepted by scientific community, on the other hand, ill-structured problems have no single correct answer. Because in the ill-structured problem about the ultimate fate of the universe there are no accepted correct answers, there is no such authority as in the well-structured problem to rely on. Hence, the participants in this study might have expressed authoritative belief type in the context of established knowledge and not in the context of controversial conjectures.

In addition to authoritative belief type, experiential belief type was exclusively used in the context of well-structured problem. Why experiential belief type was expressed only in the context of the well-structured problem and not in the context of the ill-structured problem? One explanation for the presence of experiential belief type solely in the context of the well-structured problem might be that the well-structured problem was accessible to sensory experience, while the ill-structured problem was remote from sensory experience. Buoyancy of solids in liquids is a topic that is accessible to direct observation whereas the ultimate fate of the universe is not. Experiential beliefs were expressed by stating that everyday experience confirmed scientific knowledge. This suggests that undergraduate and graduate physics students and faculty believed that scientific explanations were consistent with their sensory experiences.
The second finding that resulted from the comparison of epistemological belief types in the two problem contexts was relativistic and religious belief types that expressed only in the context of the ill-structured problem. Again, this is another belief type that has to do with the nature of the problem context. Relativistic belief type is present when the problem is controversial and open ended as in the problem of the ultimate fate of the universe.

In addition to relativistic belief type, religious belief type was exclusively used in the context of ill-structured problem. Religious beliefs about knowledge are non-existent in any of the previous personal epistemology models. There are two possible explanations for the presence of religious belief type in the content of the ill-structured problem. First, religious belief type may be an artifact produced because of the particular topic of the ill-structured problem that the participants were asked to solve in this study. The ill-structured problem was about ultimate fate of the universe, which is a question that occupied humans’ since for thousands of years. Arguably, all religions have an explanation for the beginning and the end of the universe. The problem might have led some participants to associate the ultimate fate of the universe with religion. When Brickhouse, Dagher, Letts, Shipman (2000), investigated the interface between undergraduate students’ religious beliefs and views of science, they initiated the discussions by asking the students about their thoughts on the Big Bang theory and the theory of biological evolution. Brickhouse et al. (2000) reported that the Big Bang theory and the theory of biological evolution were fruitful topics in terms of understanding students’ views of science and religion. Therefore, in the current study, the ultimate fate
of the universe might have been a particularly stimulating topic for the participants to express their religious beliefs.

The second explanation for the presence of religious belief type in the ill-structured problem is that religious belief type is a part of personal epistemology. If this is the case, the prediction of the framework of epistemological belief types is that religious belief type would be found in other ill-structured problem contexts. To resolve this issue further research is needed.

The third finding that resulted from the comparison of epistemological belief types in the two problem contexts was rational, empirical, and modeling belief types were expressed in the context of both the well-structured and the ill-structured problem. This implies that rational, empirical, and modeling belief types are not context dependent. In other words, these three epistemological belief types can be found in any problem, well-structured or ill-structured, in the domain of physics.

The results of this study reinforce the idea that personal epistemology is more complex than that has been characterized by many of the existing models, which posit that personal epistemologies are made up of one-dimensional constructs in the form of developmental stages or multi-dimensional constructs in the form of beliefs. This study constrained the investigation within a single discipline and involved two different problem task contexts to investigate personal epistemologies of individuals with different expertise levels in physics. Even with the narrowed focus the results of the study implied that personal epistemology is sensitive to task context.
Epistemological Belief Types and Sophistication in Personal Epistemology

By exploring beliefs about knowledge across five expertise levels (freshmen, seniors, masters students, PhD students, and faculty), it was possible to compare beliefs about knowledge among the expertise level groups. The reason for comparing epistemological beliefs across different expertise levels was to provide a cross-sectional account of epistemological sophistication. The expertise levels were defined by years of engagement with physics beyond secondary education. It was anticipated that as expertise level increased sophistication in personal epistemology would also increase. Through the framework of epistemological belief types, the current study provided insights to epistemological development in a specific academic domain, physics. Throughout the comparison of expertise level groups, the epistemological belief types were used without considering the problem context. If a participant expressed a particular epistemological belief type in either context, that participant was counted to have held that epistemological belief type.

Comparison of epistemological belief types across the expertise levels revealed two important points. First, authoritative belief type was expressed by more undergraduate students than graduate students whereas authoritative belief type was not expressed by faculty at all. Second, more faculty members than graduate students expressed modeling belief type whereas modeling belief type was not expressed by undergraduate students at all.

It was anticipated that undergraduates would resort to authority in justifying knowledge in physics because previous research (e.g. Perry, 1970; Baxter-Magolda,
1992) repeatedly reported that undergraduates tended to believe that knowledge was in possession of authorities. As anticipated, the greatest number of participants who expressed authoritative belief type was in undergraduate groups. However, it was surprising that a greater number of seniors expressed authoritative beliefs than freshmen. Previous research reported that students in later years of undergraduate education appealed to authority less than students in early years. For example, King and Kitchener (1994) reported that juniors and seniors were at higher stages of epistemological development than freshmen, in other words, a lesser number of seniors than freshmen believed that knowledge is in possession of authorities. In the current study, the situation was reversed. Seniors expressed authoritative belief type more than freshmen. This may be interpreted as epistemological regression rather than sophistication for the undergraduate students. Further speculation, it might be the four years of undergraduate physics education that leads the seniors to be more rigid and to take knowledge for granted.

When grouped as undergraduates, graduates, and faculty the expertise levels did display a decreasing trend in expressing authoritative belief type. Some undergraduates and a lesser number of graduates believed that knowledge was in possession of authorities or experts. Faculty did not express that knowledge was in possession of authorities. Perhaps, faculty members considered themselves as the authorities in knowledge in physics and they believed that they generated and justified knowledge. That is why they did not need other authorities to do it for them. The same explanation also holds for why few graduate students expressed authoritative belief type. The
graduate students were on the track to become professional physicists, in other words, experts or authorities. Therefore, it is possible to say that epistemological sophistication is inversely related to authoritative belief type.

The second finding of the comparison of expertise level groups was that more faculty members than graduate students expressed modeling belief type while undergraduate students did not express modeling belief type at all. The only notable consistency in the data across expertise level groups was in the expression of modeling belief type by the faculty group. Most of the participants in the faculty group and some of the graduate students expressed modeling belief type in both well-structured and ill-structured problem contexts. This result implies that the expressing of modeling belief type is a sign of epistemological sophistication in physics because knowledge production in science involves producing and evaluating theoretical models.

Knowledge production and evaluation in science is heavily based on model construction and evaluation. Giere (1997) points out “most scientists can be said to be engaged in constructing models of some aspect of the world” (p. 20). According to Giere (1997), theoretical models are similar to geographical maps. Both maps and theoretical models involve social conventions that are used for constructing and interpreting reality. In this study most faculty members stated that their business involved constructing models, they articulated the use of mathematics and graphs to represent the fit between models and data, and they identified predictions of models among the criteria for judging the quality of models.
Model building and evaluation is a *specialized practice* in physics. In this study the participants in the faculty group were competent members of the physics community with a common understanding of the standards of constructing and evaluating theoretical models in physics. The graduate students were at different stages of the process of enculturation into the professional physics community, which explains why only some of them deployed modeling repertoire. The undergraduate students are only potential candidates of future professional physicists, which explain why so few of these students deployed modeling repertoire.

The explanation of the expression of modeling belief type by the different expertise levels with enculturation to the professional physics community is consistent with the results of research in social studies of science. For example, Traweek (1988) found that enculturation into the professional physics community is different for undergraduate, graduate, and post-doctoral levels. According to Traweek (1988), in the undergraduate level, students learn primarily from textbooks and lectures that attempt to transfer a large amount of information, which is consistent with the results of the current study. 40% of freshmen and 70% of seniors expressed authoritative belief type and none of them expressed modeling belief type. Also teaching at the undergraduate level is primarily aimed at transmission of knowledge and not model construction. According to Traweek (1988), in the graduate level of their education physics students gradually specialize and develop practical skills that they will need in conducting their research. This description is also consistent with the results of the current study. 30% of masters students and 50% of PhD students expressed modeling beliefs.
Furthermore, Campbell (2003) found that scientists in American universities engage in a variety of activities in managing students in their programs. According to Campbell (2003) the scientists recruit potential graduate students, teach and train both undergraduate and graduate students, supervise programs of study, select projects and research topics for their students, and influence career decisions of their students. Campbell reaches similar conclusion as Traweek (1988) about the enculturation of new scientists and the reproduction of the culture of the scientific community:

Through a long period of apprenticeship and the establishment of complex relationships with their sponsors, new scientists, and members of the broader scientific community, invest a great deal of time and other resources in maintaining the community (p. 923).

In addition to the enculturation process, another reason for the differences in the expression of the modeling belief type between the expertise level groups is related to the kinds of tasks that undergraduate, graduate, and professional scientists undertake in their physics education and practice. At undergraduate level students perform laboratory experiments that are on well-known phenomena. Until physics students are in graduate level and began working on their research projects, they do not experience truly ill-structured authentic scientific inquiry. In their investigation of professional socialization of doctoral students in laboratory and field science, Delamont and Atkinson (2001) found that undergraduate and graduate tasks were very different in quality. For undergraduate laboratories lecturers chose and stage-managed experiments that routinely produced correct results. The graduate students, on the other hand, experienced a reality shock
when they were faced with the contingencies of authentic scientific research. According to Delamont and Atkinson (2001),

In contrast to this stable and controlled world of the undergraduate curriculum, doctoral students discover that ‘real’ science is more complex, and that failure is a normal outcome of routine work. Successful doctoral students master the tacit, indeterminate skills and knowledge, produce usable results, and become professional scientists (p. 88).

Delamont and Atkinson (2001) conclude that most, perhaps all of the problems that undergraduate students solve and the experiments they perform are well structured, but ill-structured tasks that are inherent to authentic scientific research are not encountered before graduate level.

To sum up, authoritative belief type decreases as the expertise level increases. On the other hand, modeling belief type becomes predominant epistemological belief type as the expertise level increases. Modeling belief type is a sign of epistemological sophistication in physics. In the journey to sophistication, physics education introduces two challenges. Although enculturation is a natural social process through which individuals become physicists, undergraduate level of enculturation appears to be problematic. While undergraduates are learning scientific method, they are also learning to accept scientific knowledge at face value and to take it for granted. The second challenge that physics education present to undergraduate students is that they are not introduced to authentic scientific inquiry that is inherently ill-structured.

Summary

Personal epistemology can be conceptualized as a toolbox of epistemological belief types. The framework of epistemological belief types does no posit developmental
It does not map a path for epistemological development. This framework does not posit multiple independent dimensions for personal epistemology such as source of knowledge and structure of knowledge. It focuses on only one dimension, justification of one’s knowledge or that of others.

Epistemological beliefs are utilized in different combinations with respect to changing task contexts. Considering that there are two types of task contexts in physics, which are well-structured and ill-structured, the epistemological belief types utilized in each context is different. The context of well-structured tasks is open to justification through authority and personal experiences, while the context of ill-structured allows for justification through subjective terms.

The results of this study show that epistemological sophistication in physics as evidenced by expression of modeling belief type does not happen until the individuals are at the graduate level of their education. Studies from social studies of science (e.g. Delamont and Atkinson, 2001; Campbell, 2003; Traweek, 1988) report that there is more to learning science than learning the particular science. That is, there is considerable amount of tacit knowledge and skills that students learn as they are in the process of becoming members of the communities of their discipline. Undergraduate, graduate, and post-graduate levels of physics education have different characteristics in terms of the qualities of tasks that students engage in. Consistent with these studies the current study documented that epistemological competence is only evident beyond the undergraduate level.
Implications for Science Education

This investigation of personal epistemology has implications for preparing future scientists and for elementary and secondary science education. The recommendation of this study for undergraduate physics education is to make some of the tacit knowledge in physics explicit and accessible to students. Modeling appears to be part of this body of tacit knowledge. The results of this study imply that undergraduate students tend to view knowledge in absolutist terms. The social studies of science reported that until they are at graduate level, students do not engage in authentic scientific research or practice building theoretical models. In order to help undergraduate students learn the epistemological practices of physics community, engaging them in model building activities and discussing criteria for evaluating models would be such a step in transforming modeling from tacit to explicit.

In order to make modeling explicit part of instruction some degree of ill-structuredness should be included in the tasks that students engage in their undergraduate years. Delamont and Atkinson (2001) documented that undergraduate laboratory activities consist of stage-managed experiments that produce correct results, which fits to the definition of well-structured problems. Because students are used to experiments that produce usable results as undergraduates, when they are faced with real scientific inquiry they experience a reality shock. Having them engage in authentic research in their undergraduate years may help decrease this reality-shock. This engagement may be in the form of participating in an existing research group, which would help students learn the practices, standards, and norms of the physics community. Similarly, activities and
experiments in existing curricula of the physics laboratories could be modified to include some degree of ill-structuredness and model building.

The implications of this study for K-12 science education are different than the implications for undergraduate physics education due to differences between the goals of education. Clearly the goal of the undergraduate physics education is to prepare future scientists, which involves the students’ enculturation to the physics community. On the other hand, the most commonly stated goal for science education in the elementary and secondary levels is to promote scientific literacy. This study acknowledges the role of K-12 science education as promoting scientific literacy. The important question is then what level of competency do we expect from elementary and secondary students in terms of epistemological sophistication so that they would be scientifically literate.

The expected level of epistemological sophistication for students in terms of scientific literacy in standards documents is often stated as competency in nature of science. The National Science Education Standards [NSES] (NRC, 1996) emphasize that students should be able to evaluate scientific investigations and explanations. According to the NSES (NRC, 1996) this evaluation involves review of experimental procedures, examination of evidence, identification of faulty reasoning, detection of statements that go beyond the evidence, and suggestion of alternative explanations for the same observations. Students should understand that “Different scientists may publish conflicting experimental results or might draw different conclusions from the same data” (p. 171). This characterization overlaps with modeling belief type identified in the current study. A strict interpretation of this characterization could be rephrased as: students
should express modeling belief type and use it fluently and competently in evaluating scientific investigations and explanations. If this strict interpretation is intended as the level of sophistication expected from students, a serious reality check is required in the light of the results of this study. In this study the consistent and competent use of modeling belief type was only evident for the physics faculty, who have already completed their initiation to the professional physics community and spent at least 15 years of post secondary work in physics. Therefore, with this strict interpretation, only after completing graduate and perhaps post-graduate work scientists become competent in evaluating scientific investigations and explanations. To expect elementary and secondary students to achieve this level of epistemological sophistication is equivalent to ask them to perform a brain surgery as their science project. The results of this study resonate with Matthews’ (1998) caution about being modest in the expectations from students in terms of their understanding of scientific epistemology:

It is unrealistic to expect students or prospective teachers to become competent historians, sociologists, or philosophers of science. We should have limited aims in introducing epistemological and nature of science questions in the classroom: a more complex understanding of science, not a total or even a very complex understanding...There is no need to overwhelm students with cutting-edge questions. They have to crawl before they can walk, and walk before they can run. This is no more than commonsense pedagogical practice: Simple pendulums are dealt with before compound pendulums, addition and subtraction before multiplication and division, Euclidean geometry before non-Euclidean geometry, and so on. There are numerous low-level questions that students can be engaged by: What is a scientific explanation? What is a controlled experiment? What is a crucial experiment? How do models function in science? How much confirmation does a hypothesis require before it is established? (p. 168 - 169).
Hence, science educators should be realistic about their expectations for epistemological sophistication from K-12 students. Bearing in mind that the goals of science education in K-12 are not to prepare future scientists but to promote scientific literacy, the expectations from students should be defined in more realistic terms.

Similarly, the claims for explicitly teaching scientific epistemology to K-12 students should be reevaluated. For instance, Khisfe and Abd-el Khalick (2002) claimed that teaching nature of scientific epistemology with an explicit approach helped sixth grade students develop improved views of the nature of scientific epistemology than teaching with an implicit inquiry oriented approach. The results of this study show that competent understanding and use of scientific epistemology, i.e. model construction and evaluation, does not develop until students are well into a field, which casts doubts on the claims for explicitly teaching nature of scientific epistemology. Teaching model construction and evaluation by means of transmission appears to be counterintuitive. A better way to help K-12 students improve epistemologically could be engaging the students in model construction and evaluation related tasks. Chinn and Malhotra (2002) reported that few of the existing inquiry tasks contain features that resemble authentic scientific inquiry. Therefore, concentrating research efforts in developing inquiry activities that focus on model building and construction and engaging students in these activities appears to be a plausible step towards helping students’ epistemological development in science.
Recommendations for Future Research

The results of this study require extensive and highly diverse concrete research to investigate several issues that this study highlighted. The framework of this study, the seven epistemological belief types, should be tested with different problems in physics in order to elaborate the content and the use of this framework. Would the seven belief types be found with different problems in physics than the two specific problems that have been posed to the participants in the current study?

In addition, these seven epistemological belief types need to be investigated deeper with fewer individuals using more problems. Another recommendation is that this epistemological framework of seven epistemological belief types was investigated in specifically physics domain, but it would be significant to explore this framework in different domains such as chemistry and biology. Finally, the sophistication of personal epistemology in physics deserves closer attention in order for elaborating the process of becoming a physicist.
APPENDIX

INTERVIEW SESSION PROTOCOL
Problem 1.

When a cylindrical wooden block is placed in a container with water in it, two thirds of the wooden block stays immersed in water. Then the tap is turned on to slowly add vegetable oil to the container. Vegetable oil is a less dense liquid than water and the two liquids do not mix together. While vegetable oil is being added to the container which one of the pictures shows how the wooden block would look inside the container? Why do you think so?

Problem 1 Probe Questions:
- What leads you to reach that answer?
- On what do you base your answer?
- How confident are you with your answer?
- Can you ever know that your answer is correct? How or why not?
- How confident are you about the principles you have used to solve this problem?
Problem 2.

In cosmology one of the most important problems is the ultimate fate of the universe. There are two rival models explaining the ultimate fate of the universe: Big Crunch and Big Rip. Physicists who favor Big Crunch model say that the universe will stop expanding and start to collapse upon itself. Other physicists who favor Big Rip model say that the universe will continue expanding until all physical objects in the Universe will eventually be torn to pieces and then to elementary particles.
Problem 2 Probe Questions:

- What do you think about this problem?
- What leads you to hold that point of view?
- On what do you base that point of view?
- How confident are you about your point of view?
- Can you ever know that your point of view is correct? How or why not?
- Can one of the models be right? What do you mean by right?
- Can one of the models be better? What do you mean by better?
- How is it possible that experts in the field disagree about this subject?
LIST OF REFERENCES


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