CONCEPTUAL, STRUCTURAL AND EPISTEMIC ASPECTS OF SCIENCE TEACHERS' ARGUMENTATION PRACTICES IN THE CONTEXT OF EVOLUTIONARY THEORY

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ABSTRACT

CONCEPTUAL, STRUCTURAL AND EPISTEMIC ASPECTS OF SCIENCE TEACHERS' ARGUMENTATION PRACTICES IN THE CONTEXT OF EVOLUTIONARY THEORY

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The purpose of this study was to examine conceptual, structural and epistemic aspects of science teachers' argumentation practices and how they used conceptual knowledge to articulate their arguments at different epistemic levels in the context of evolutionary theory.

This study was conducted with qualitative multiple case study research. In this respect, data were collected from four separate cases. In particular, four science teachers who taught middle school science from 5^{th} to 8^{th} grade were selected as cases for this study. Science teachers were interviewed based on four evolutionary scenarios. Data was analyzed through using six different pre-established frameworks.

The results of this study illustrated that science teachers frequently used scientifically appropriate criteria to distinguish alternative explanations from each other. Among of these, science teachers with high conceptual knowledge appealed to theoretical criteria while others with low conceptual knowledge appealed to empirical criteria. Another result of this study was that some of them appealed to Lamarck's inheritance of acquired traits and use and disuse theories, and adaptation as cause of evolutionary change. In addition, teleological reasoning was prominence among teachers. Specifically, they perceived evolutionary process as a goal-driven process. The results also indicated that all supported their arguments with multiple justifications; however, they scarcely constructed counter-arguments, from which was concluded that they had confirmation bias. They also constructed more theoretical propositions than data propositions. This finding pointed to unfamiliarity with the use of data. Lastly, evolutionary concepts along with misconceptions and cognitive biases about evolution were articulated in their theoretical justifications.

Keywords: Argumentation, science teachers, evolutionary theory, conceptual understanding, epistemic level

ÖZ

EVRİM TEORİSİ BAĞLAMINDA FEN BİLİMLERİ ÖĞRETMENLERİNİN ARGÜMANTASYON UYGULAMALARININ KAVRAMSAL, YAPISAL VE EPİSTEMİK BOYUTLARI

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Bu çalışmanın amacı fen bilimleri öğretmenlerinin argümantasyon uygulamalarının kavramsal, yapısal ve epistemik boyutlarda incelenmesi ve kavramsal bilgilerini kullanarak argümanlarını farklı epistemik düzeylerde nasıl oluşturduklarının araştırılmasıdır.

Araştırma nitel bir çalışma olan çoklu-durum çalışması ile gerçekleştirilmiştir. Veriler 4 farklı uygulama ile toplanmıştır. Uygulamalar ilköğretim 5-8.sınıflarda fen bilimleri öğretmenliği yapan 4 öğretmen ile gerçekleştirilmiştir. Fen bilimleri öğretmenleri ile evrim teorisi senaryoları kullanarak görüşmeler yapılmıştır. Analizler 6 farklı değerlendirme aracı kullanılmıştır.

Çalışmanın sonuçları fen bilimleri öğretmenlerinin alternatif açıklamaları değerlendirmek için genellikle bilimsel olarak geçerli kriterler kullandıklarını göstermiştir. Bu kriterler arasında, kavramsal anlamaları yüksek olan öğretmenlerin genellikle teorik kriterler kullanması ve kavramsal anlamaları düşük olan öğretmenlerin ağırlıklı olarak ampirik kriterler kullanması örnek olarak verilebilir. Kavram yanılgıları konusunda, bazı öğretmenlerin Lamarck'ın sonradan kazanılan

özelliklerin kalıtımı ve kullanılan organların geliştiği, kullanılmayanların köreldiği teorilerini argümanlarında kullandıkları ve adaptasyonu evrimsel değişimin bir nedeni olarak algıladıkları ortaya çıkmıştır. Bilişsel önyargılar incelendiğinde, öğretmenlerin birçoğunun evrimsel olayları açıklarken teolojik açıklamalar kullandığı ortaya çıkmıştır. Yani, öğretmenlerin evrimsel süreci amaç yönlü olarak algıladıkları bulunmuştur. Bu çalışmanın bir başka sonucu öğretmenlerin çoğunlukla birçok gerekçe kullanarak iddialarını savundukları fakat alternatif düşünceleri göz önünde bulundurarak çok fazla karşı argümanlar oluşturmadıkları ortaya çıkmıştır. Bu sonuç fen bilimleri öğretmenlerinin onaylı önyargı yoluyla sadece kendi iddialarını desteklemeye eğilimli olduklarının göstergesidir. Bununla birlikte, öğretmenlerin ağırlıklı olarak teorik önermeler sunarken verilere dayalı önermeleri çoğunlukla ihmal ettikleri ortaya çıkmıştır. Bu sonuç öğretmenlerin iddialarını savunurken veri kullanımına yeterince aşina olmadıklarının bir göstergesi de olabilir. Son olarak, fen bilimleri öğretmenlerinin argüman kurarken evrimsel kavramların yanında kavram yanılgıları ve bilişsel önyargılar kullandıkları bulunan sonuçlar arasındadır.

Anahtar Kelimeler: Argümantasyon uygulamaları, fen bilimleri öğretmenleri, evrim teorisi, kavramsal anlama, epistemik düzeylendirme

I dedicate this study to my dearest parents

Nurten Yeşilyurt and Kemal Yeşilyurt

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AAAS	American Association for the Advancement of Science
NRC	National Research Council
MNE	Ministry of National Education
TAP	Toulmin's Argumentation Pattern

CHAPTER 1

INTRODUCTION

Argumentation is core of discourse practices that are fundamental of human thinking. It is not restricted to a particular discipline, studying in various disciplines such as philosophy, education, law, political science, discourse analysis. Many scholars attempted to define it in a unified way from different perspectives and approaches. However, two meanings of it come into prominence in the related literature, namely individual and social meanings (Jiménez-Aleixandre & Erduran, 2008). Individual meaning refers to argument as justification and evaluation of claims based on evidences and reasoning. However, individual meaning alone was restricted argumentation merely to justifying their claims. The development of argumentation skills, on the other hand, depends on practice of engaging in debate of opposing claims (Driver, Newton, & Osborne, 2000). Therefore, social meaning of argument gains value. Social meaning refers to argument as process of evaluation of alternative positions and convincing others. Van Eemeren and Grootendorst (2004) adopted only social meaning of argumentation in that they defined argumentation as "a verbal and social activity of reason aimed at increasing (or decreasing) the acceptability of a controversial standpoint for the listener by putting forward a constellation of propositions intended to justify (or refute) the standpoint before a rational judge" (p. 5). Kuhn (1993) suggested that individual and social aspects were linked together such that social argument is a kind of way to reflect internal thinking processes in argumentation practices. In this regard, Jiménez-Aleixandre and Erduran (2008) recommended that both meanings was associated if argument was considered as product which involves reasons proposed to justify a claim and argumentation is considered as a social process in which opposing claims are critiqued by an individual or a group as Kuhn and Udell (2003) proposed. Hence, the argumentation practices include generating argument through justification and discussion based on theoretical or empirical evidences, evaluation and critiquing the alternative theories, persuading others about the validity of claims.

In the field of argumentation theory, various theoretical contributions have been made throughout the centuries. The fundamentals of argumentation theory were established by Aristotle with his treatises on Analytical, Dialectical and Rhetoric. These three arguments differ in the purpose and in turn, application to different fields. The analytical argument is based on absolute truth and reality, dialectical argument deals with exchange of ideas by means of dialogue and rhetoric of argument deals with convincing opponents. However, Aristotle's arguments were subjected to criticisms in that his theory did not take into account of the influence of personal views and experiences (Puvirajah, 2007). In this regard, Crawshay-Williams (1957) stressed the subjectivity approach for argumentation in addition to objectivity approach. In the following, Toulmin (1958) made the great contribution to theory of argumentation through proposing a framework that provides argument structure developed in natural settings. Even though Toulmin's layout was used in wide range of contexts such as legal settings and science education, critiques of this framework have been voiced such that it was difficult to distinguish between components of arguments. In same year, Perelman and Olbrechts-Tyteca (1958) analyzed argumentation based on socially constructed truths and developed new rhetoric. Based on the new rhetoric, the focus of argumentation is on influencing the audience. On the other hand, neither Toulmin nor Perelman and Olbrechts-Tyteca considered contextual and situational aspects of argumentation (Van Eemeren, 2002). In this sense, informal logic movement was developed for addressing the problems that are associated with Toulmin's and Perelman and Olbrechts-Tyteca's approaches to argumentation. In this strand, Johnson and Blair (1994) focused on the relationship between premise and conclusion of arguments and Walton (1996) developed argumentation schema based on presumptive reasoning through analysis of fallacious arguments. Both frameworks were developed in order to analyze argumentation practices in the context of everyday language.

In the discipline of science, argumentation with regard to the interpretation of evidences and coordinating data with theoretical claims in the light of alternative theories is considered as a core element of science and scientists' discourses. As a striking example of this, Charles Darwin (1859, p. 459) presented On the Origin of Species as "one long argument". This statement emphasizes the value of argumentation in scientific practices. In his book, Darwin proposed the theory of evolution by natural selection through justifying his assertions by constructing multiple lines of reasoning based on theoretical and empirical evidences to persuasive scientific community and general public. He did not only justify his theory but also attempted to rebut alternative theories. For instance, he opposed Lamarck's theories through presenting evidences. Besides, he took into consideration of circumstances under which theory is not valid in "Difficulties on Theory" section. For instance, he argued as "If it could be demonstrated that any complex organ existed, which could not possibly have been formed by numerous, successive, slight modifications, my theory would absolutely break down. But I can find out no such case." (p. 189). After the publication of Darwin's book, the great debate among scientific community began and still continues among public and creationist. These practices are all considered essential components of generating scientific arguments (e.g., Erduran, Simon & Osborne, 2004; Kuhn, 1993; Toulmin, 1958). As Mayr (1991) stated, science itself can be described as one long argument. From this perspective, scientific argumentation is at the heart of science and central to the discourse of scientists (Kelly, Drucker, & Chen, 1998).

Researchers and reformers in science education have increasingly emphasized the importance of scientific argumentation in learning science and understanding of nature of scientific practices in terms of conceptual, epistemic and social aspects during the last several decades (Duschl, 2008; Erduran et al; 2004; Jiménez-Aleixandre, & Erduran, 2008; Kuhn, 2005; Sandoval & Millwood, 2005). Put it differently, engaging in argumentation enable students to comprehend science as a way of knowing where evidences are fundamental to the basis of beliefs. Besides, it provides an insight into epistemology of science; scientific practices and methods, and its nature as a social practice through persuading others about the validity of scientific claims (Duschl, 2008).

A growing body of research on argumentation in science education has analyzed students and teachers' argumentation practices in terms of their structure, content and justification (Erduran, 2008; Sampson & Clark, 2008). Researchers focused mostly on structural aspects of argumentation (e.g., Erduran et al., 2004; Schwarz, Neuman, Gil, & Ilya, 2003; Toulmin, 1958). In this strand, Toulmin's (1958) argumentation pattern (TAP) has been widely used among science education researchers as a methodological tool (e.g., Bell & Linn, 2000; Erduran et al., 2004; Jiménez-Aleixandre, Rodríguez, & Duschl, 2000). Toulmin's framework enables researcher to evaluate components of argumentation and the nature of justification. However, several researchers encountered methodological difficulty in distinguishing components of arguments. In order to handle this difficulty, several researchers developed framework by either collapsing components of reason into justification category or distinguishing justification and rebuttal (Erduran et al., 2004; Zohar & Nemet, 2002). Another framework was developed by Schwarz et al. (2003) to focus on structure of argument and acceptability of justification. Based on these frameworks, research on analysis of students' arguments indicated that students tended to construct one-sided arguments and their arguments were not sophisticated in terms of justifications.

On the other hand, above mentioned frameworks do not provide information about content of the argument. In this sense, several researchers attempted to analyze conceptual aspect of arguments. Zohar and Nemet (2002) and Lawson (2003) developed framework to examine how students used scientific ideas to construct arguments. Analysis with these frameworks, researchers found that students rarely applied relevant scientific knowledge in their arguments. Although these frameworks enable researchers to analyze accuracy of justifications, they did not assess the use of evidence in arguments. In order to address this issue, several researchers turned their attention to epistemic aspect of argumentation (e.g., Kelly & Takao, 2002; Maloney, 2007; Sandoval, 2003). In this strand, Kelly and Takao (2002) developed analytical framework to analyze relative epistemic status of students' propositions. Regarding this aspect of argumentation, researchers found that students did not sufficiently support theoretical claims by data statements. In another study, Tavares, Jiménez-Aleixandre and Mortimer (2010) adapted Kelly and Takao's framework for evolutionary theory context and they reached the similar findings with Kelly and Takao.

In another strand of the research, several researchers attempted to provide additional insight into argumentation practices through integrating structural, epistemic and conceptual aspects of argumentation (e.g., Clark & Sampson, 2007; Sandoval, 2003). On the one hand, Jiménez-Aleixandre et al. (2000) and Clark and Sampson (2007) examined students' argumentation in terms of structural and epistemic aspects. These studies indicated that students did not mostly attempted to generate counter-arguments and their arguments were limited in terms of epistemic operations. In addition, Sandoval (2003) developed a framework to provide insight into conceptual and epistemic aspect of argument. Findings showed that although students used scientifically accurate knowledge in their arguments, they struggled to coordinate data with claim. On the other hand, researchers attempted to use three aspects for their analysis of argumentation practices, namely conceptual, structural and epistemic aspects (Clark & Sampson, 2008; Sampson, Grooms & Walker, 2011). In these studies, while Clark and Sampson's (2008) findings indicated students appealed to accurate and relevant conceptual knowledge, Sampson et al.'s (2011) findings illustrated that students tended to use everyday explanations rather than scientific one. Another difference between findings of these studies was the use of evidence in arguments. In particular, Clark and Sampson's results illustrated that students attempted to justify their claims by using single piece of evidences rather than multiple evidences. However, Sampson et al.'s results indicated that students' epistemic qualities were high. In both studies, students attempted to justify their claims, however, they did not provide strong rebuttals. These researchers analyzed structural, epistemic and conceptual aspects of argumentation separately. However, Tavares et al. (2010) attempted to develop a coding schema to integrate structure of argument with epistemic status and also analyze how students apply conceptual knowledge in their arguments. Therefore, this schema not only provides information about integration of structural and epistemic aspects of argument but also enables researchers to make judgment about articulation of conceptual knowledge. In the present study, based on literature, Erduran et al.'s (2004) framework was employed to analyze science teachers’ structural aspect of argumentation and Tavares et al. adapted version of framework was used to analyze science teachers’ epistemic aspects of argumentation practices. In addition, this study investigated how science teachers articulated conceptual knowledge to construct argument at different epistemic levels.

In related literature, another factor to be considered was the criteria used to evaluate validity of alternative explanations or arguments. In this sense, Hogan and Maglienti (2001) stressed the importance of epistemological criteria such that they have an impact on one’s reasoning structure. In their study, the difference between reasoning skills of students and scientists was found. More specifically, while scientists took into consideration of coherence between conclusion and the range of evidence, students appealed to their personal views and experiences. Similar results were reached by Sampson et al. (2011). They found that students mostly tended to used informal criteria (e.g., plausibility, appeals to analogies) that are not accordance with scientific standards. Sampson and Blanchard (2012) studying with teachers found that teachers’ criteria used to distinguish between alternative theories were limited to previous knowledge and coherence between the claim and evidence. In the present study, science teachers were provided alternative explanations related to phenomena to analyze their criteria when evaluating acceptability of explanations.

Above mentioned research on argumentation in science education indicated that most of the studies focused mostly on students’ argumentation practices. However, there are several studies on teachers’ argumentation practices. After some researchers revealed that teachers who have inadequate knowledge about nature of argumentation did not provide any opportunity to their students to generate arguments (Newton, 1999; Yalçınoğlu, 2007) and teachers who have adequate knowledge enable students to take part in construction of arguments (e.g., Simon, Erduran & Osborne, 2006; Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2002), several researchers turned their attention to nature of teachers’ argumentation practices. These studies indicated that teachers struggled to sufficiently justify their arguments through coordinating claims with data. In addition, they generated their arguments based mostly on their previous knowledge and experiences rather than data statements (e.g., Sampson & Blanchard, 2012; Zembal-Saul et al., 2002) Therefore, in reference to existing literature, science teachers' argumentation practices from different perspectives were analyzed in the present study.

Evolutionary theory was chosen as a theme of the present study. Although science education reform efforts have acknowledged the importance of evolutionary theory by stressing the need for students and teachers to develop comprehensive understanding of evolution (National Academy of Science [NAS], 1998), studies indicated that students' and even teachers' conceptual knowledge about evolutionary theory did not correspond with the evolutionary biologists' knowledge. They explained the mechanism of evolution via Lamarck's theory of use and disuse and inheritance of acquired traits (e.g., Bishop & Anderson, 1990; Jensen & Finley, 1996), they perceived fitness as a mean of strongest or healthiest (Bishop & Anderson, 1990; Gregory, 2009), they considered nature as a selective agent (Gregory, 2009). In addition, they also had inadequate knowledge regarding genetics. Put more specifically, they struggled to integrate genetics and natural selection (Bishop & Anderson, 1990; Gregory, 2009). In this strand, several researchers underlined the cognitive bias or cognitive constraints as a reason for difficulty in understanding of evolutionary theory and as a source of misconceptions (Moore et al., 2002; Sinatra, Brem & Evans, 2008). Cognitive biases affect individual's reasoning about evolution (Opfer, Nehm & Ha, 2012). These cognitive biases encompass essentialism, teleology and intentionality. Research on alternative conceptions regarding evolutionary theory revealed that both teachers and students perceived evolutionary process as a goal- or need-driven process (teleology) (e.g., Jensen & Finley, 1996; Southerland, Abrams, Cummins, & Anzelmo, 2001), they tended to consider that species have an essential that allows for them to be classified into "natural" categories (essentialism) (e.g., Sinatra et al., 2008; Shtulman, 2006) and they perceived the process of evolution as a phenomena directed by mental agent (intentionality) (Gregory, 2009). In another strand of the research, several researchers attempted to make analysis of argumentation practices in the context of evolutionary theory. While findings of some studies revealed that students and teachers used the evolutionary concepts regarding natural selection, speciation, and adaptation in order to justify their claims (e.g., Sandoval, 2003; Tavares et al., 2010; Yalçınoğlu, 2007), the results of others studies indicated that their arguments included misconceptions such as Lamarck's theory of use disuse and ancestral relationship between current species (Tavares et al., 2010; Zembal-Saul et al., 2002). In addition, while Tavares et al. (2010) found that students rejected to some cognitive biases such as intentionality and teleology, Zembal-Saul et al. (2002) found that teachers utilized teleological reasoning for their arguments. In the present study, science teachers' conceptual aspects of argumentation in the context of evolutionary theory were analyzed since as some researchers revealed, science teachers continue to hold misconceptions about evolution (Alters & Nelson; Rutledge & Warden, 2000) and they who hold misunderstanding about evolutionary theory have potential to influence students' learning of evolution negatively (Smith, 2010). Hence, they have significant role in teaching and learning evolutionary theory. For that reason, this study focused on science teachers' conceptual understanding.

1.1. The Purpose of Study

The present study was situated in the intersection between studies on conceptual understanding of evolutionary theory and argumentation practices in science education. Therefore, the purpose of this study was to examine science teachers' structural, epistemic and conceptual aspects of argumentation practices in the context of evolutionary theory and how they use evolutionary conceptions to articulate argumentation at different epistemic levels.

1.2. Research Questions

The present study seeks to explore the following questions;

RQ1. What are the criteria science teachers used to evaluate the validity or acceptability of alternative explanations for evolutionary phenomenon?

This question focused on whether science teachers use scientifically appropriate criteria or not to distinguish alternative explanations from each other. For this research question, Sampson et al.'s (2011) framework that underlines rigorous and informal criteria was used. Investigation of this research question provides a better understanding of science teachers' reasoning structure.

RQ2. What are levels of science teachers' conceptual understanding regarding evolutionary theory?

This question examined the conceptual aspects of science teachers' argumentation practices. In particular, science teachers' conceptual knowledge in their arguments was explored by using Nehm et al.'s (2010) framework. By using Abraham, Grzybowski, Renner and Marek's (1992) schema, levels of science teachers' conceptual understanding with regard to evolutionary theory were further analyzed. This research question underlined two important points. First, this question could enable to reveal science teachers' evolutionary and alternative conceptions. It could provide valuable information because related literature indicated that science teachers have an impact on students' perceptions and understanding about evolutionary theory (e.g., Rutledge & Warden, 2000; Smith, 2010). Second, it has potential in providing comprehensive understanding of the use of conceptual knowledge in their arguments. It is also essential since previous studies indicated that argumentation practices and conceptual knowledge are related (Sampson & Clark, 2008; Tavares et al., 2010).

RQ3. What are the quality levels of science teachers' argumentations regarding each evolutionary theory scenarios?

This question investigated structural aspects of science teachers' argumentation practices. More specifically, this research question seeks to explore components of argumentation practices such as data, warrant or rebuttals. Although integration of argumentation into science lessons required some knowledge and skills, there is limited research focusing on science teachers' argumentation practices to inform educators and program developers (e.g., Sampson & Blanchard, 2012; Simon et al., 2006). Therefore, in this study, structural aspects of science teachers' argumentation practices were analyzed by using Erduran et al.'s (2004) framework.

RQ4. What are the science teachers' epistemic levels relevant to evolutionary theory?

This question explored the epistemic aspects of science teachers' argumentation practices. The use of evidence is considered as a one of the scientific competencies (OECD, 2006). Therefore, it is essential to provide information about the use of evidence at different epistemic levels. In this study, science teachers' relative epistemic status of knowledge claims were examined by using Tavares et al.'s (2010) framework.

RQ5. What is the variation of science teachers' criteria, conceptual understanding, argumentation and epistemic levels across four evolutionary scenarios?

This question investigated variation among criteria that science teachers' use when evaluating validity of alternative explanations. Related literature indicated that criteria and argumentation practices vary across the different contexts (Hogan & Maglienti, 2001). In scenarios related evolutionary theory, alternative explanations were crafted purposefully so that their content and structure would vary across the scenarios. Therefore, the present study explored whether science teachers' criteria vary across the four scenarios. In addition, related literature also illustrated that individuals' explanations regarding evolutionary problems did not show coherence across the contexts (Kampourakis & Zogza, 2009). This coherence across the contexts is important since this can be act as an indicator of sound understanding (Tavares et al., 2010). In the present study, scenarios were related to four different evolutionary phenomena. Therefore, in the present study, how science teachers' conceptual understanding varies across the scenarios was analyzed. Further, epistemic and structural aspects of argumentation were expected to vary because those aspects are closely related to conceptual aspect (Sampson & Clark, 2008). Hence, this research question has potential in enabling to explore the context effect, if any.

RQ6. How do science teachers use conceptual knowledge with respect to evolutionary theory to articulate their arguments at different epistemic levels?

This question examined the integration of three aspects of argumentation practices, namely conceptual, structural and epistemic aspects. This investigation could extend the understanding of justification process (Tavares et al., 2010). In addition, this research question has potential in providing information about how these three aspects of argumentation practices were linked together. For that reason, in the present study, the articulation of conceptual knowledge regarding evolutionary theory and argumentation practices at different epistemic levels was analyzed by using Tavares et al.'s (2010) rubric.

1.3. Definitions of Important Terms

1.3.1. Argumentation

In the present study, argumentation was defined as generating argument through using the connection between data and claim, evaluation the alternative theories based on evidences, critiquing the scientific argument and persuading others about the validity of claim (Jiménez-Aleixandre & Erduran, 2008). In the present study, conceptual, structural and epistemic aspects of argumentation practices were examined.

1.3.2. Evolution Theory

Evolutionary theory asserts that all species including humans have been evolved (and continues to evolve) from a common ancestor by the mechanism of natural selection that have taken place over a long periods of time. In the present study, argumentation practices were analyzed in the context of evolutionary theory. Specifically, science teachers engage in argumentation practices on the basis of four scenarios related to evolutionary theory.

1.3.3. Conceptual Understanding

Conceptual understanding is defined as the individual's ability to apply the scientific concepts to scientific phenomenon in everyday life contexts. In the present study, science teachers' conceptual understandings with respect to evolutionary theory were analyzed.

1.3.4. Misconception

Misconception refers to beliefs or ideas about concept or phenomena which are not consistent with current scientific knowledge. In this study, science teachers' misconceptions regarding evolutionary theory were sought to explore.

1.3.5. Cognitive Bias

Cognitive bias was described as rules of thumbs that influence human thinking (Sinatra et al., 2008). Three cognitive biases were identified in biological reasoning, namely teleological, essentialist and intentionality biases: (1) teleological bias refers to the tendency to perceive evolutionary process as a goal- or need- driven process; (2) essentialist bias refers to tendency to believe that things have an essential nature; (3) intentionality bias refers to tendency to perceive that evolutionary change was directed by mental agent. In the present study, science teachers' cognitive biases were examined through using four evolution problems.

1.3.6. Epistemic Status

Epistemic status refers to degree of abstractness or generalizability of knowledge claims. Kelly and Chen (1999) sorted epistemic status of claims into multiple epistemic levels. Epistemic levels make distinction between lower level of data statements and epistemologically higher levels of theoretical statements. In the present study, science teachers' propositions in their arguments were analyzed based on relative epistemic status of them.

1.4. Significance of the Study

Available literature indicated that engaging in scientific argumentation is considered as an essential component for science education since argumentation practices enable students to develop meaningful science concepts and understand the process by which scientists construct knowledge about natural phenomena (Driver et al., 2000). For this reason, the analysis of argumentation practices in science education has received growing attention among scholars (Sampson & Clark, 2008). Many of the researchers analyzed argumentation practices in terms of structural aspect. This aspect enables researcher to reveal students' components of argumentation and the lines of justifications (Simon, 2008). However, analysis based merely on structure of arguments leads to miss some parts of the big picture and therefore, limits our understanding about the nature of scientific argumentation. In this sense, Simon (2008) voiced this limitation such that focusing only on process of argumentation limits understanding of the content of argument and the use of evidence. In particular, the related literature has highlighted the need for epistemological focus in the analysis of argumentation practices in order to develop the understanding how knowledge claims are justified and what counts as evidence as well as how theoretical knowledge claims and evidence are connected (Kelly & Takao, 2002). However, the available literature indicated that there have been insufficient studies investigating how participants construct their justifications (Kelly, 2005). Therefore, the present study adopted epistemological approach to argumentation to analyze epistemic aspect of science teachers' argumentation practices.

In addition to epistemic aspect, conceptual knowledge should be taken into consideration for the ability to generate justification (Kelly, Druker, & Chen, 1998). In this sense, the analysis of conceptual aspect of argumentation was one of the concerns of this study. On the other hand, perspective of this study was different from previous works (e.g., Sadler & Donnelly, 2006; von Aufschnaiter, Erduran, Osborne, & Simon, 2008) in that rather than examining the effects of conceptual knowledge on argumentation practices, this study investigated how individuals use conceptual knowledge to articulate their arguments. In this sense, the theme of scientific argumentation determined to focus on is evolutionary theory. Evolutionary theory is considered to lie at the heart of science education since it is a major unifying concept in science. It explains three fundamental features of the natural world: the similarities among species, the diversity of life and physical features of the world. For that reason, it underlines all the life sciences. This means that it integrates concepts from biology, geology, chemistry, ecology, genetics and archeology (NAS, 1998). In addition to importance of this theory in science education, Tavares et al. (2010) stressed that to examine the articulation of conceptual knowledge with argumentation skills in detail, evolutionary theory was adequate theme in that applying evolutionary theory in arguments at different epistemic levels requires the integration of different scientific principles which in turn, needs to master essential skills. Specifically, it requires critically examining the range of evidences, criticizing and rejecting alternative explanations that do not fit the facts and evidences and connected evidences to scientific theories related biology, geology, ecology and genetics. Therefore, in the present study, analysis of science teachers’ scientific argumentation practices and the articulation was employed in the context of evolutionary theory. Hence, to provide broad range of approaches for argumentation practices, science teachers’ argumentation practices were analyzed in terms of structural, epistemic and conceptual aspects in the present study. In addition, to enlarge our view and deepen our understanding about justification process, how science teachers’ conceptual knowledge with respect to evolutionary theory and argumentation practices were articulated at different epistemic levels were identified in this study. These detailed investigations about argumentation could provide information about desired knowledge and skills for argumentation practices and in turn, this information could be used to develop curricular materials and instructional approaches to foster more effective scientific argumentation in science lessons.

Further, the analysis of conceptual aspects of argumentation practices could have potential to enable to analyze conceptual understanding since argument generation process requires the application of knowledge and understanding to contexts. In this respect, science teachers’ conceptual understanding regarding evolutionary theory was also examined in the present study. Although teachers should have comprehensive understanding of evolutionary theory to teach it effectively (Smith, 2010; Tekkaya, Cakiroglu & Ozkan 2004), available literature showed that understanding evolutionary theory is very problematic among them and varying conceptions that teachers brought to context are inconsistent with evolutionary biologists’ understandings (e.g., Nehm & Schonfeld, 2007; Taskın, 2011). Specifically, teachers hold misconceptions and cognitive biases that make understanding about evolutionary theory very challenging. Still, there has been limited research on this area in Turkey. Therefore, it is essential to reveal science teachers’ conceptual understanding regarding evolutionary theory and to examine how they apply their conceptual knowledge to their arguments. This investigation could provide valuable information for researchers and science teacher educators.

In the available literature, it was apparently realized that studies on argumentation practices gave scant attention to teachers' knowledge about scientific argumentation. On the other hand, there are relatively few studies focusing on science teachers' scientific argumentation patterns showed that science teachers have struggled to generate sophisticated arguments (e.g., Sampson & Blanchard, 2012; Zembal-Saul et al., 2002). However, teacher is the key person that orchestrates the argumentation practices in order to identify different lines of thought and encourage students to construct arguments. In this sense, new Turkish science curriculum gave emphasis for argumentation based science learning as "scientific inquiry process includes not only exploring and making experiments but also explaining and generating arguments" and in parallel of this approach, to enable students to engage in scientific argumentation practices, curriculum stressed the role of teachers in argumentation practices such that "teachers should provide students opportunity to engage in discourses in which they reflect their thoughts, justify their claims with multiple reasons and generate counter-arguments to oppose others' claims." and during those discourse activities, "teachers should serve as a guide and mediator (Ministry of National Education [MNE], 2013, p. III). Although the importance of argumentation was highlighted in science curriculum, teachers' lack of knowledge and skills to support students engage in argumentation practices was identified as a major barrier to integrate argumentation in science classrooms (Zeidler, 1997). Therefore, as Zohar (2007) stressed, teachers need to have required knowledge about nature of argumentation in order to carry out argumentative activities in science classrooms. On the other hand, we have limited understanding on teachers' knowledge about how they constructed scientific argumentation (Sampson & Blanchard, 2012; Zembal-Saul et al., 2002).

Regarding above mentioned issue, it is important to inform researchers and science educators about the knowledge and skills of science teachers who are expected to integrate argumentation into teaching and learning science. Hence, the findings of this study could provide science educators an insight into science teachers' strengths and weaknesses in skills about scientific argumentation practices to take action on this issue. Besides, as Sampson and Blanchard (2012) emphasized, engaging teachers in argumentation activities can be one way to help them learn more about the scientific argumentation. Hence, the present study also tried to provide science teachers to opportunity to have practice on argumentation which in turn, contributes to development of their knowledge about scientific argumentation.

CHAPTER 2

LITERATURE REVIEW

This chapter comprises an analysis of the related literature on the argumentation theory, argumentation in science education and evolution education. In the first part, literature on argumentation theory, four main argumentation theory were described, namely Aristotle's argumentation theory, Toulmin's (1958) argumentation patterns, Johnson and Blair's (1994) non-formal argumentation and Walton's (1996) presumptive reasoning. In the second part, literature on argumentation in science education was examined under three main titles which are research on the analyses of argumentation in science education, science teachers' argumentation practices and the relation of aspects of argumentation. In the last part, literature on evolution education were reviewed under two main headings, namely research on analyzing alternative conceptions about evolution and research on argumentation in the context of evolutionary theory in science education.

2.1. Argumentation Theory

Argumentation theory from Aristotle to today has been developed. Argumentation can be associated with rationalism and interpretivism paradigm. In rationalistic argumentation, there is a single path to reach knowledge and arguments are based on facts and universal rules. On the other hand, in interpretivist argumentation, there are multiple realities shaped by individual perceptions and experiences (Puvirajah, 2007).

2.1.1. Aristotle's Argumentation Theory

Aristotle identified three forms of argument based on his treatises; namely, analytical, dialectical and rhetoric.

The analytical argument is related rationalistic paradigm and associated with the notion of absolute truth or reality. That's why; this type of argument encompasses absolutely objective rather than subjective interpretations. Based on the application of this approach, well-trained individual will find same conclusions for given problem. Mathematical proofs are, for instance, placed in this type of arguments (Van Eemeren et al., 1996)

The dialectical argument is related to exchange and evaluating opposing ideas through dialogue. This type of argument is based on the works of Hegel on triadic approach including thesis, antithesis and synthesis. According to this approach, two opposing parties put forward their claims (thesis & antithesis) and then, they arrive at a common ground through negotiation (synthesis of new thesis) (Puvirajah, 2007).

Aristotle made distinction between analytical and dialectical reasoning such that former one is related to truth and the latter related to justifiable opinions. Then, he further proposed rhetoric to dialectic. The rhetorical argument is concerned with persuasion of opponents to agree with the validity of the assertion. In this type of argumentation, it is important that the speaker use evidences and be trustworthy to convince others. Rhetorical arguments mostly used in judicial and parliamentary debates (Van Eemeren et al., 1996).

Aristotle's treatises provided different kinds of arguments applying in multiple fields in preceding centuries. However, his arguments were criticized in terms of objectivity and absolute truth. Crawshay-Williams (1957) voiced controversial and unsolved problem of Aristotle's arguments. According to Crawshay-Williams, this problem arose because the criteria used when evaluating validity of argument based on individual views and experiences, that is, intersubjectivitiy. Therefore, author introduced the subjectivity approach other than objectivity to argumentation (Van Eemeren & Grootendorst, 2004). Hence, author emphasized the both subjective and objective approach for argumentation. On the other hand, the nature of argumentation was still limited to formal logic.

2.1.2. Toulmin's Argumentation Pattern

In his book titled *The Use of Argument*, Toulmin (1958) proposed a model to make distinction between formal argument as used in mathematics and logic and informal argument as used in natural settings. Toulmin criticized the deductivist view and emphasized that rationality of justifying claims depends on the specific context rather than on universal principles. Toulmin's model describes the constitutive components of argument and functional relationships between these components of argument (Driver et al., 2000). Put more specifically, Toulmin's argumentation pattern identifies four major components, namely claim, data, warrant and backing. Based on this model, claim is conclusion or point of argument put forward for general acceptance; data refers to facts or evidences which provides a support for given claim; warrant includes reasons (rules, principles, etc.) which provide justification of link between data and claim; and backing refers to generalizations which provide justification for the particular warrants. According to this model, claim is the purpose of an argument. Soundness of argument based on degree to which the claim is justified through data, warrants and backings. Besides, Toulmin proposed two more components for more complex arguments, namely qualifiers and rebuttals. Qualifiers are phrases that specify conditions under which claim can be taken as reliable and rebuttal refers to extraordinary or exceptional circumstances that undermine or refute the supporting claim (Figure 2.1).

Toulmin suggested that procedural form of argumentation, no matter what the subject is, same for all fields. However, types of justification of argument vary field to field. Hence, the evaluation of quality of arguments is field-dependent. Although many studies of science educators were inspired by the Toulmin's works, critics have been raised against Toulmin's layout. In practice, some components of argument are hard to distinguish (Van Eemeren, 2002). According to Van Eemeren (2002), Toulmin's layout is not an alternative to formal logic since it is field-independent and that's why pragmatic, situational and contextual factors are not taken into account.

In the same year, Perelman and Olbrechts-Tyteca's (1958) theory of new rhetoric contributed to development of argumentation theory.

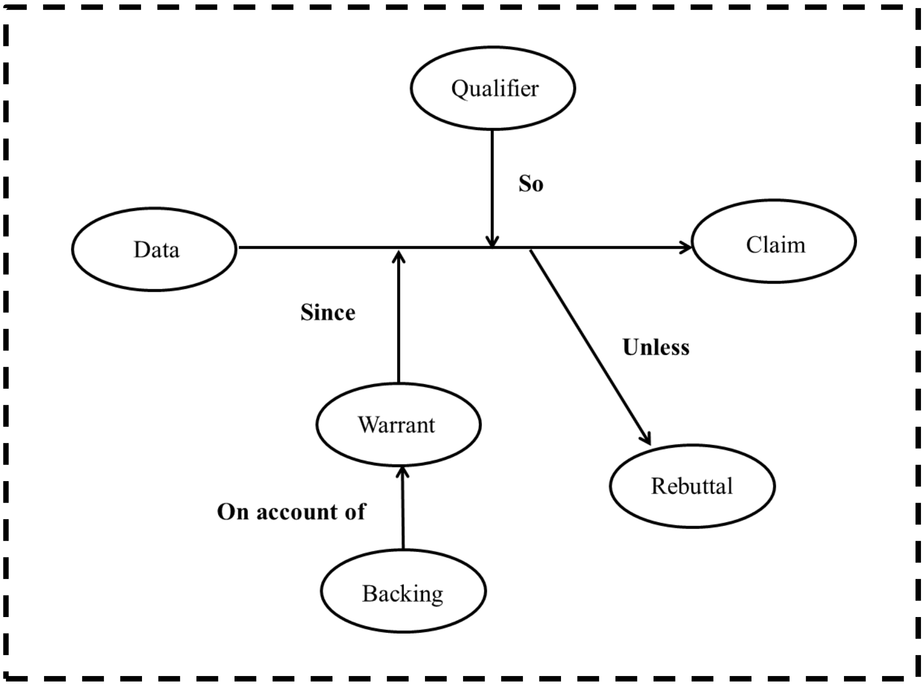

Figure 2.1 Toulmin’s Argumentation Pattern (1958). Adapted from “Using Toulmin’s Argument Pattern in the evaluation of argumentation in school science by S. Simon, 2008, *International journal of Research & Method in Education*, *31*(3), 277-289, p. 279.

2.1.3. Perelman and Olbrechts-Tyteca's Theory

Perelman and Olbrechts-Tyteca (1958) identified theory of New Rhetoric in their book, *The new rhetoric: A treatise on argumentation*. The new rhetoric deals with “the study of the discursive techniques allowing us to induce or increase the mind’s adherence to the theses presented for its assent” (cited in Van Eemeren & Grootendorst, 1995, p. 122). Based on the new rhetoric, the good argument should provide more evidence consistent with claim that is justified among audience. Therefore, the soundness of arguments is assessed based on its effects on the target audiences (Van Eemeren, 2002). Perelman and Olbrechts-Tyteca approach to argumentation, like Toulmin’s (1958), was not based on application of formal rules. In particular, they avoided from absolutes philosophy which states that in order to persuade audiences to accept particular standpoint, arguments should be based on absolute and universal truths. Rather than this approach, they adopted such an approach that arguments should be based on socially constructed truths (Puvirajah, 2007). Therefore, new rhetoric is different from classic rhetoric of Aristotle, in that the new one emphasized the social dimension of argumentation. According to theory, all arguments should be started in common ground between audience and arguer and arguments should be based on claims which audiences agree upon. Only if common ground is provided, then argumentation proceeds to debate and it is called point of departure. Arguer should provide the credibility of arguments to persuade audiences and according to authors, this credibility was provided in two ways. These techniques are that argument should be logically valid and be based on reality.

Van Eemeren (2002) argued that Perelman and Olbrechts-Tyteca's (1958) approach, like Toulmin's (1958), does not offer an alternative to formal logic because it does not also consider the contextual factors. Besides, this approach also does not take into account of functional form of language of argumentation.

In response to aforementioned critiques of Perelman and Olbrechts-Tyteca's (1958) theory and Toulmin (1958)'s argumentation theory, the studies on informal logic were initiated in 1970s. Informal logic is an attempt to develop criteria of analysis of argumentation within ordinary language (Johnson & Blair, 2002). Studies of informal logical underlined the reasoning and argumentation and argumentation practices in the context of everyday language. In line with this, two frameworks were developed based on informal logic, namely Johnson and Blair's (1994) non-formal argumentation and Walton's (1996) presumptive reasoning.

2.1.4. Johnson and Blair's Non-formal Argumentation

Johnson and Blair (1994) emphasized the relationship between premise and conclusion of arguments. In this respect, authors proposed three analysis methods for premises (propositions or claims) of the argument, namely relevance, sufficiency and acceptability. Relevance criterion deals with the appropriate relationship between premise and conclusion of arguments. Sufficiency criterion is related to sufficient evidence provided for conclusion. Acceptability criterion deals with truthiness of premise, that is, inaccurate premises of argument are not acceptable.

2.1.5. Walton’s Presumptive Reasoning

According to Walton (1996), argumentation takes place in goal-directed and interactive dialogue in which two or more people are reasoning together. Quality of argument, good or fallacious, is based on whether it supports or hinders the goal of dialogue. Based on this analysis, each argumentation constitutes discrete argumentation schemes which enable it to “function as a way of shifting a burden proof” in dialogues (Walton, 1996, p. 1).

Informal logicians considered arguments which are neither deductive nor inductive as invalid arguments or fallacious arguments. However, when Walton (1996) analyzed these fallacious arguments, he realized that some of them were actually reasonable rather than fallacious and he considered these types of arguments as presumptive arguments (Puvirajah, 2007). Therefore, Walton’s presumptive arguments consist of various forms of everyday talk which are neither deductive nor inductive. Walton, in his book *Argumentation Schemas for Presumptive Reasoning,* proposed 25 argumentation schemes. Some of schemes are basic and others are composites generated from basic ones. Each argumentation scheme is associated with set of critical questions provided. The presumptions can be shifted back and forth within dialogue based on whether critical questions could be properly asked and sufficiently replied to. Walton called this sequence of questions and answers as argumentation theme.

In short, research on formal and informal logic provided frameworks and various theoretical approaches for argumentation which in turn, enable researchers to analyze argumentation in various fields. Hence, in the following section, argumentation in science education was analyzed.

2.2. Argumentation Research in Science Education

The main goal of the science education is to enhance student’s ability to think scientifically. As Sagan (1996, p. 28) stated, “Science is a way of thinking much more than it is a body of knowledge.” In this perspective, argumentation practices offer a way to enable students to comprehend science as a way of knowing (Driver et al., 2000). Scientists use arguments to build the explanations, theories and models about the natural world and they accept or reject theories according to criteria, so one can say that science itself is based on argument. For that reason, argumentation is the integral part of the learning about science. In line with this, during the last several decades, science education researchers and international science standards have increasingly stressed the importance of argumentation in science education (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996; Driver et al., 2000; Duschl, 2008; Jiménez-Aleixandre, & Erduran, 2008; Kuhn, 2005; MNE, 2013). In Turkey, science curriculum recommended integration of argumentation into teaching and learning science. In particular, science curriculum emphasized that teachers should enable students to take part in argumentation practices in which they propose their claims, justify them through using various warrants and data and generate counter-arguments in order to rebut opposing views (MNE, 2013).

In the following part, literature related to argumentation in science education was examined into three sections. In the first section, research on assessment of argumentation practices in science education was discussed. In the next section, the studies on science teachers' argumentation practices were examined. In the last section, research on the relation among conceptual, epistemic and structural aspects of argumentation was reviewed.

2.2.1. Research on Analysis of Argumentation in Science Education

Recent works on the use of methodologies in argumentation have focused heavily on qualitative analyses of argumentation in science education. In this regard, several analytical frameworks used and developed by science educators to analyze the students' argumentation practices regarding their structure, content and justification (Erduran, 2008; Sampson & Clark, 2008).

Several researchers attempted to analyze students' argumentation in terms of its structure (e.g., Bell & Linn; Kelly et al., 1998; Tavares et al., 2010). In this regard, for a significant body of studies on argumentation in science education, Toulmin's

(1958) framework has been a major analysis method to assess structural quality of arguments (e.g., Erduran et al., 2004; Jiménez-Aleixandre et al., 2000; Kelly, Drucker, & Chen, 1998; Osborne, Erduran, & Simon, 2004). Toulmin's layout is domain-general framework which can be applied to analyze quality of arguments within or outside of scientific context. As noted earlier, this framework includes six constitutive elements of argumentation which are data, claims, warrants, backings, rebuttals, and qualifiers. According to this framework, a scientific argument is generated by using data, warrants and backings to convince the others about the validity of asserted claim. In addition to these elements, more complex arguments include rebuttals and qualifiers as well. From this perspective, the soundness of argument is assessed depend on the absence or presence of these different structural elements. Bell and Linn (2000), for instance, used Toulmin's argumentation pattern to assess middle school students' arguments in the science context. In their study, students were asked to generate arguments about the topic of light through using computer-based program called Sense Maker. It was found that students mostly utilized data to justify their claims. On the other hand, students rarely provided warrant and backings for their argument. Besides, they did not attempt to evaluate and criticize other alternative theories in spite of two alternative explanations given. More fundamentally, they did not challenge the other alternative hypothesis and they solely aligned with the one alternative. These findings led them to conclude that students were unable to appreciate the counter-arguments. Authors also interested in the source of backings and reported that students constructed distinctive backings based on their personal experiences.

In another study, Kelly et al. (1998) examined high school students' arguments through analysis of their discourse while studying on hands-on performance task with respect to electricity. In this study, students' argument structure varied in terms of the use of warrants. In some cases, claims generated based on scientific knowledge were not justified. In another cases, claims were justified with faulty warrants and in others, numerous warrants were provided with poorly structured claims. Besides, Kelly et al. voiced methodological difficulty encountered when identifying data, claim and warrant based on Toulmin's framework. They stated that some statements that are generally classified in claim serve as warrants. Therefore, authors had to make careful analysis through taking into account of contextual factors in order to distinguish components of argument.

Methodological difficulties of Toulmin's (1958) layout was also acknowledged by Sampson and Clark (2008) arguing that analysis of argument structure is influenced by researchers' personal experiences that leads to low inter-rater reliability and that's why researchers questioned the applicability of Toulmin's framework. In this regard, in order to minimize above mentioned methodological difficulty with Toulmin's argumentation patterns, several researchers modified this framework. For example, Erduran et al. (2004) attempted to extend the applicability of this framework by developing five levels argumentation framework. In their study, qualitative and quantitative analyses were employed. For qualitative analysis, the distribution and clusters of the components of Toulmin's argument pattern (TAP) was examined. For instance, they classified arguments as CD indicating argument consists of claim and data or CDWBR indicating argument includes claim, data, warrant, backing and rebuttal. Through using this categorization, authors sought to the effectiveness of materials and strategies for developing 8^{th} grade students' argumentation practices. They reported that at the beginning of the study, students' arguments frequently consisted of two or more components such as CD (claim-data) and CDW (claim-data-warrant) but after the intervention, students' arguments developed and comprised four or five components such as CDWB (claim-data-warrant-backing) and CDWBR (claim-data-warrant- backing-rebuttal). For qualitative part, authors developed a five levels scale in order to analyze the quality of arguments. The structure of framework was mainly based on competing theories strategy in which students discussed alternative theories using appropriate evidences. They analyzed argument quality based on presence or absence of reasons (data, warrants and backings) and rebuttals. Authors argued that presence of reasons in arguments provide a strong support for a claim and the presence of rebuttals are considered as better quality arguments since offering reasons for claim alone is not sufficient for convincing others, which in turn, does not change others' opinions. Based on the five levels framework, they found that students' argument quality positively developed after intervention. Hence, this modified model of argumentation provided useful information about students' reasoning and quality of argumentation practices and opportunity to compare group performances (Erduran et al., 2004).

In another study, in order to examine structural aspect of argumentation, Schwarz, Neumann, Gil and Ilya (2003) developed domain general framework to analyze arguments students provided in structured interview or essays in the context of science in terms of their structures and acceptability of justification. The quality of argument was assessed based on five criteria: (1) argument type, (2) soundness of arguments, (3) overall number of reasons, (4) number of reasons supporting counter-arguments, (5) quality of reasons. According to this framework, arguments are hierarchically ranged from simple assertions to compound arguments. Authors classified students' assertions into four argumentation structure. In particular, simple assertions include merely conclusions are not supported by any reason. One-sided arguments consist of one conclusion supported by one or more reasons. Two-sided arguments consist of more than one reason to both support and oppose the conclusion. On the other hand, this does not mean that this type of argument includes explicit analysis of pros and cons (Schwarz et al., 2003) and compound arguments consist of this explicit analysis for both claim and counter-claim. Although this framework does not analyze conceptual quality as Toulmin's framework, it provides additional aspect to analysis of arguments with respect to evaluation of acceptability and coherence among justifications. The findings of Schwarz et al.'s findings indicated that students mostly generated one-sided arguments including an assertion that justified with weak justification. On the other hand, following to intervention regarding argumentation practices, students tended to construct more compound arguments that include acceptable and relevant reasons for both their claims and counter-claims. However, authors emphasized that students who have inadequate conceptual knowledge did not utilized their previous scientific knowledge to support their claim. This finding indicated that conceptual knowledge and argumentation practices are linked together.

The methodological difficulty with Toulmin's layout and Schwarz et al.'s (2003) framework was also stated by Sampson and Clark (2008) stating that the Toulmin's and Schwarz et al.'s frameworks focused solely on structure of an argument, not the content. More fundamentally, these frameworks do not enable to make judgments about whether warrants and backings are valid and appropriate to support the claim since their framework are based on a general structure that is field-invariant. In this regard, Lawson (2003) suggested that researchers help students learn how to construct scientifically valid arguments rather than focusing on general structure of arguments. In this respect, Lawson identified the aim of developing an argument as “to determine which of two or more proposed alternative explanations (claims) for a puzzling observation is correct and which of the alternatives are incorrect” (p. 1389). Lawson called this type of argument as hypothetico-predictive argument. According to Lawson, persuasive arguments should consist of evaluation of alternative hypothesis other than justifying claims by means of hypothetico-deductive reasoning. Based on this type of argument, students start with observations that bring about causal questions, which in turn, lead to construct tentative hypothesis. These hypotheses must be tested so as to provide their validity. The “If/and/Then” words are used to connect the explanations and predictions regarding results of test. After conducting experiment, test results should be compared with the hypothesis to assess validity of hypothesis. It has to be noted that quality of argument is assessed through deductive validity rather than presence or absence of constitute elements of argument. Sampson and Clark argued that this type of assessment is appropriate for specific scientific issues rather than general scientific concepts. However, this framework enables students to learn criteria used by scientists to assess the quality of argument within specific scientific concepts. Besides, Lawson argued that ability to hypothetico-predictive arguments brings about the development of conceptual knowledge.

In a similar vein, Zohar and Nemet (2002) developed a domain-specific framework to address the issue of content of arguments and also other methodological issue associated with Toulmin’s framework, that is, the issue of distinguishing the components of arguments. In order to overcome these issues, authors examine both content and structure of argumentation patterns through two separate coding schemes based on Toulmin’s framework. They modified Toulmin’s argumentation pattern in such a way that they combined Toulmin’s data, warrants and backings within a justification category in order to handle methodological difficulties of Toulmin’s arguments as Erduran et al. (2004) did. According to model, stronger argument consists of more than one justification that should be scientifically correct. Weak arguments include scientifically inaccurate and non-relevant justifications. Therefore, they classified justifications into four categories: (1) no consideration of scientific knowledge, (b) inaccurate scientific knowledge, (c) non-specific scientific knowledge and (d) correct scientific knowledge. On the one hand, this framework provides insight into how students appealed to conceptual knowledge in justifications. On the other hand, it does not attempt to assess the accuracy of claims. Therefore, their study found that most of students did not generate sophisticated arguments. In particular, their arguments included merely a claim and weak justification and few brought to bear accurate biological knowledge for their arguments. After students were explicitly taught about both biological knowledge and argumentation structure, authors identified development in both argument quality and their justifications. Sampson and Clark (2008) emphasized that arguments should be generated on the basis of accurate claims. In this regard, this framework is more appropriate for socio-scientific issues rather than scientific concepts since in the context of socio-scientific issues, valid counter-claims can be generated from many different perspectives while in the context of scientific issues, it is necessary that claim be valid and backed up by multiple scientific evidences. In addition, Sampson and Clark showed another constraint of this framework in that this framework does not assess the use of all available data to support the claim. Authors argued that the use of all available data and coordinating them to claims is significant for strong justifications.

In this regard, research on scientific argumentation has drawn attention to importance of the evaluation of knowledge claims to justify argument (Jiménez-Aleixandre, 2008). The process of knowledge evaluation including presenting and transforming data and connecting data to theoretical knowledge is considered as epistemic practices (Jiménez-Aleixandre & Reigosa, 2006). In addition, the use of evidence for either justifying claim or challenging opponents' views has been taken into account by Programme for International Student Assessment (PISA) as an essential part of scientific literacy (OECD, 2006). Besides, Jiménez-Aleixandre (2008) argued that the evaluation of evidence should consist of assessing how theoretical knowledge is coordinated with data. In addition, Kelly, Chen and Prothero (2000) also stressed epistemological aspects of arguments such that arguments comprise justification processes depend on articulation of discipline specific knowledge and epistemologically grounded terms. Takao and Kelly (2003) also stressed that the process of constructing evidence-based arguments enable students to comprehend scientific concepts more deeply rather than rote memorization of science concepts. In this sense, Kelly and Takao (2002) developed a domain-specific model to analyze how students justify their theoretical assertions through multiple data statements. This framework focused on the analysis of relative epistemic status of propositions and how these propositions are connected to generate convincing argument. Authors argued that Toulmin's framework does not enable to make judgments about epistemic status of propositions. In this regard, Kelly and Takao developed six epistemic levels model based on the works of Latour's (1987) and Kelly and Chen (1999). Put it differently, Kelly and Chen constructed set of epistemic levels specific to physic concept in order to extend Toulmin's framework. Kelly and Chen developed these levels based on Latour's study. According to Latour, "scientists typically argue from the particular contingencies of their actual experiments and try to construct facts at a more generalized level. In this way, they stack the facts, moving from low induction facts using the pictures, figures, and numbers to progressively higher induction, more abstract facts." (as cited in Kelly and Chen, 1999, p. 902). Therefore, Kelly and Takao sorted students' propositions from the most specific assertions (epistemic level I) to progressively more general theoretical assertions (epistemic level VI). They identified three criteria to analyze quality of arguments: The first one is integration of claims across the epistemic levels. Authors pointed out that the epistemic levels do not represent a hierarchy. Instead, a strong argument should consist of evidences from different epistemic levels. The second one is the ratio of data statements to theoretical assertions. Authors argued that strong arguments should consist of theoretical claims sufficiently supported by data statements. The last one is related to distribution of observation/interpretation statements across the levels. They stated that strong arguments should include more interpretation statements than those of observations since they assessed the degree of inference made by students. Their framework is highly specific with the particular domain regarding geology. In this sense, they argued that scientific arguments need consideration of relevant scientific knowledge. Kelly and Takao also reported the major limitations of their own analysis. Several discrepancies between raters' analysis of arguments were found. More specifically, they did not sufficiently take into consideration of appropriateness of links between propositions. Sampson and Clark (2008) added that the reason of discrepancy between rater might be that authors did not assess the accuracy of propositions. Although this framework has some methodological difficulties, it enables to make judgments about the types of justification in terms of epistemic status. Based on this framework, Kelly and Takao found that students mostly appealed to theoretical claims in their justifications without coordinate with data.

In parallel with the findings of Kelly and Takao (2002), several studies examining the use of evidence in students' argumentation indicated the difficulties in coordinating data with claim. For instance, Maloney (2007) studied with group of children in order to analyze the use of evidences in their arguments. The results showed that students generated many arguments but many of them were not supported by evidences. Therefore, author concluded that the use of more evidence brings about different viewpoints but the use of same evidence causes repeating arguments. In another example, Jiménez-Aleixandre and Bravo (2009) also investigated articulation of conceptual knowledge regarding ecological model of energy flow and the use of evidence at different epistemic levels. In their study, they studied with 12th grade students in Spain. Students were provided a task regarding trophic levels and four questions. Based on students' explanations, authors developed six epistemic level models specific to ecology concept based on Kelly and Takao's framework. In particular, model includes lower level of descriptions of data (provided and retrieved data), relationships specific for the task context, and higher level of theoretical conclusions (specific theoretical claims in terms of concrete and abstract concepts and general theoretical claims). It was found that students most frequently generated propositions regarding theoretical claims in terms of abstract ecological concepts and rules and principles with respect to energy flow and less frequently utilized provided and retrieved data. Authors also analyzed the quality of arguments through investigating how many different epistemic levels are combined in a single explanation. The result of this analysis confirmed their first analysis in that students mostly combined theoretical claims and they scarcely combined theoretical claims with data statements in a single explanation. Authors explained the possible reason of this ratio such that students were not familiar with the coordination of evidence and theoretical assertions.

In another strand of the research, several researchers assessed in interaction of epistemic and argumentation practices to deepen understanding of justification process. Jiménez-Aleixandre et al. (2000), for instance, argued that analysis based merely on Toulmin's argumentation pattern does not enable to interpret some exchanges and in order to capture these exchanges. In this sense, they also took into consideration of epistemic aspect in addition to structural aspect. Authors investigated structural and epistemic analysis of high school biology students' arguments on the topic of genetics. Researchers distinguished engagement in scientific dialogue or argumentation from engagement in specified class tasks. Authors analyzed students' discourses in terms of two aspects: argumentative and epistemic operations. Argumentative operations including components of students' arguments were analyzed by revised Toulmin's (1958) model. Epistemic operations were defined as students' construction of different kinds of knowledge. Epistemic operations were classified as induction, deduction, causal relations, definition, classification, consistency, and plausibility. The findings of this study showed that students generated naive arguments and did not use data or backings to justify for their claims. Put more specifically, most of the students' arguments were restricted in that their argumentative operations consisted of only claims and no rebuttals were presented. Besides, students' epistemic operations were also limited and they mostly focused on causality and appeal to analogies. Researchers also reported that when analyzing arguments, the difficulties with Toulmin's framework they faced were related to distinguishing explanation, data and warrant. In another study, Clark and Sampson (2007) also offered a framework in order to examine 8th grade students' nature of the argumentation within personally-seeded discussions in terms of structural and epistemic aspects. This schema includes three codes from Erduran et al.'s (2004) framework, namely claim, ground and rebuttal and authors added four more codes in order to characterize students' epistemic operations, namely support, query, emotive appeal and off-task comments. These operations focused on the epistemic moves when students generated arguments. The quality of arguments was assessed by using these codes based on Erduran et al.'s five levels framework. Based on this framework, authors found that most of the students did not attempt to provide counter-arguments and the arguments without oppositions were not supported by grounds. The arguments including oppositions were mostly placed in level 4 and level 5. In particular, students' arguments with oppositions include one or more strong rebuttals. In addition, in terms of epistemic aspect, off-task behavior, emotive appeals were appeared in students' argumentation practices. Therefore, this framework enables to focus on the structure of arguments and epistemic aspect of argumentation. However, it provides less information regarding content of the arguments. In particular, author reported that students provided sophisticated arguments within personally seeded discussions based on this schema but high quality arguments were not always constructed with accurate scientific concepts in this study.

In parallel of the above mentioned issue regarding conceptual aspect, Sandoval (2003) and Sandoval and Millwood (2005) developed coding schema in order to analyze conceptual and epistemic quality rather than the structural quality of arguments based on field-independent components. Based on this framework, the first dimension is conceptual quality that measures (a) the degree of articulation of the causal claim within a specific theoretical framework (e.g., natural selection); (b) how well the claims are warranted using available data. The second dimension is epistemological quality which analyzes (a) how well sufficient data is cited; (b) writing a coherent causal explanation for a given phenomenon; (c) whether appropriate references is incorporated when referring to data. This analysis of students' arguments provides information about how well students generate arguments through using relevant scientific theories and this analysis also helps to reveal students' implicit epistemic criteria used when constructing argument. In this study, authors analyzed high school students' argumentation practices. According to authors, students should be coordinate data with scientific theory in order to convince opponents. As for epistemic dimension, authors found that although students understood the importance of linking evidence to claim, they mostly supported their claim through referencing single piece of data. In particular, they did not attempt to compare multiple data for their claims. This means that students often failed to interpret the articulation of specific data and particular claims. In addition, authors also reported that students rarely interpreted data, that is, they represented data directly in their explanations (e.g., “it is shown on the graph”) rather than interpret how this data supported their claims. Therefore, authors argued that students tended to perceive data as self-evident. In particular, they might believe that evidence has only one possible meaning. As for conceptual dimension, students brought to bear scientifically accurate conceptual knowledge to their arguments. Sampson and Clark (2008) emphasized some methodological boundaries of this framework such that this framework provides less information about the structure of arguments.

In order to address above mentioned constraints of frameworks, several researchers turned their effort to analyze argumentation in terms of structural, epistemic and conceptual quality. Clark and Sampson (2008) emphasized the importance of assessment of arguments in terms of scientific correctness. In line with this, Clark and Sampson extended their framework developed in previous study (Clark & Sampson, 2007) by adding an assessment of conceptual quality. Therefore, they investigated students’ arguments in terms of structural, grounds, and conceptual quality. As for conceptual quality, their schema included four levels: “(1) non-normative comments (conceptual quality level 0); (2) transitional comments (conceptual quality 1); (3) normative comments (conceptual quality 2) and (4) nuanced comments or more than one normative comments (conceptual quality 3)” (p. 299-301). Overall conceptual quality was based on the frequency of non-normative, transitional and normative explanations in students’ arguments. In this study, researchers also extended their coding schema by adding two categories for rebuttal, namely rebuttal against grounds and rebuttal against thesis. In addition, authors also assessed the ground quality of arguments by developing four levels schema: “(1) no grounds (grounds quality 0); (2) explanation without evidence (grounds quality 1); (3) using evidence as grounds (grounds quality 2) and (4) coordinating multiple pieces of evidence as grounds (grounds quality 3)” (p. 298). Then, overall quality of arguments was assessed based on five oppositional levels based on Erduran et al.’s (2004) framework model. Based on their framework, they illustrated that students mostly provided rebuttal against the thesis rather than against the grounds. In terms of conceptual quality, students' arguments included non-normative, transitional and normative comments but students scarcely used nuanced comments. In addition, they found that students who have higher conceptual level including normative or nuanced comments generally provided high quality of arguments including at least one rebuttal. Regarding the use of evidence, they did not sufficiently support their claim with evidences. This framework includes three aspects of argumentation that provides great deal information.

In a similar vein, Sampson et al. (2011) focused on multiple aspects of argumentation. Authors developed a framework in order to analyze the components of written scientific arguments in terms of four aspects; (1) adequacy of the explanation; (2) conceptual quality; (3) quality of evidence and (4) sufficiency of the reasoning. According to this model, argumentation starts with a claim (prediction and accurate explanation or conclusion), the claim should fit the evidence (observations that indicate trends over time, explain appropriate relationships between variables and differences between groups) and the evidence should be justified through using reasoning (explains how the evidence support explanation and why the evidence should count as evidence). In addition to this framework, authors also developed three more coding schemes in order to investigate how students participate in argumentation practices. First coding scheme was developed to examine how students react to ideas and that's why scheme consists of four categories of responses, namely accept, discuss, reject and ignore. Second coding scheme was developed to analyze how students question or challenge the alternative ideas, so this scheme includes four comments, namely information seeking, expositional, oppositional, and supportive. The last one was developed so as to investigate criteria students used when evaluating alternative ideas. This scheme consists of two criteria, in particular rigorous and informal. They examined nineteen 10^{th} grade students' argumentation practices and written arguments within a scientific context based on these schemes. The results of this study illustrated that after intervention including 15 ADI (Argument-Driven Inquiry) activities, students tended to generate high quality arguments especially in terms of sufficiency of reasoning and quality of evidence. However, students did not sufficiently refer to relevant theories and laws and they mostly generated arguments based on their everyday reasoning rather than scientific one. Besides, students mostly tended to justify their claims rather than to rebut the other alternatives.

In another study, Tavares et al. (2010) focused on the articulation of conceptual knowledge and argumentation practices in evidence claims. In particular, they analyzed how students appeal their conceptual knowledge in their arguments and they also attempted to integrate argumentation practices with epistemic status of propositions. In their study, authors examined 12th grade Brazilian students' oral arguments generated in the context of scientific debates. In their study, results were documented in the use of evidenced claims at different epistemic levels on the basis of Kelly and Takao's (2002) framework. Author adapted this framework to evolutionary theory concept. Their framework consists of five epistemic levels moving from lower level of data representations (provided and recalled from previous knowledge) and higher level theoretical claims (specific theoretical claims either illustrated with data or not and general theoretical claim). Results of this study illustrated that students mostly generated specific theoretical claims specific to issue discussed. Besides, students applied diverse conceptual knowledge to justify their claim and rebut the alternatives. In addition, authors presented a coding schema indicating interaction between components of Toulmin's argumentation patterns and evidenced claims as: "(a) claims: stating a claim (drawn from the problem); transforming one of the alternative claims; offering a new claim; (b) data: appealing to data provided in the problem; appealing to data recalled from previous knowledge; (c) justifications (or warrants): supporting a claim in theoretical justifications; supporting a claim in theoretical justifications illustrated with data; (d) rebuttals: challenging the evidence of the opposing claim; (e) modal qualifiers: qualifying a claim through the use of modal qualifiers" (p. 580). Hence, they could illustrate justification process in depth through analyzing types of justifications across the levels.

Aforementioned studies on analysis of argumentation focused on or developed framework from Toulmin's (1958) layout (e.g., Erduran et al., 2004; Kelly et al., 1998). However, Duschl, Ellenbogen and Erduran (1999) claimed that for argumentation discourses, Walton’s argumentation schemes based on presumptive reasoning was more appropriate. Therefore, in their study, Duschl et al. investigated middle school science students’ nature of argumentations through Walton’s argumentation schemes for presumptive reasoning. Researchers examined argumentation discourse through using dialog logic. Firstly, they attempted to analyze arguments based on Toulmin’s argumentation pattern but they stated that analysis did not provide useful information. Thereupon, researchers tried to use Walton’s (1996) argumentations schema and they put forward that Walton’s schemes was more appropriate for dialectical context and evidences and premises students constructed. Therefore, eight of 25 schemes were used for this study. Researchers found that students employed almost all argumentation schemes and they initially generated arguments in the form of dialectical structure and then, developed in the forms of analytical structure as scientists do. Besides, researchers argued that more arguments were identified based on Walton’s scheme in comparison with other schemes.

Taken as a whole, each argumentation framework has been designed to examine quality of argumentation based on the purposes of the study in terms of examining structural, conceptual and epistemological quality in different contexts such as domain-general or domain-specific. These distinct methodological perspectives have provided great deal information regarding students’ argumentation practices. For instance, studies examining structure of arguments in terms of justification indicated that students often generated one-sided arguments (Schwarz et al., 2003), they did not justify their claims with multiple reasons (Sandoval & Millwood, 2003; Zohar & Nemet, 2002) and did not attempted to challenge other viewpoints (Bell & Linn, 2000; Sampson et al., 2011). In addition, other studies investigating argumentation in terms of content and epistemic aspects showed that students struggled to articulate their relevant scientific knowledge (Clark & Sampson, 2008; Sampson et al., 2011; Zohar & Nemet, 2002) and they tended to justify their claims based on single piece of evidence (Kelly & Takao, 2002; Sandoval, 2003). Therefore, each analytical framework has its own contributions and limitations regarding methodology.

As a result, among these frameworks discussed above, two analytical frameworks are consistent with the purposes of the current study, namely modified version of Toulmin's argumentation framework (Erduran et al., 2004) and Tavares et al.'s (2010) framework.

Structural analysis of arguments provides information about how individuals assimilate the argumentation practices and the types of reasoning used when generating arguments (Driver et al., 2000). In this sense, Toulmin's (1958) framework enables researchers to analyze quality of argumentation in terms of components and complexity of arguments (Simon, 2008). However, as noted earlier, some methodological difficulties were associated with this framework. In the present study, in order to overcome these difficulties, structural analysis of science teachers' argumentation was employed based on Erduran et al.'s (2004) schema. As mentioned before, Erduran et al. modified the Toulmin's framework to handle the difficulties encountered when distinguishing claims, warrants, backings and rebuttals and to assess students' argumentation patterns in which competing theories were presented in order to enable students to examine and evaluate the alternative or opposing explanations and in the light of this, construct their arguments. That is, this framework provides to seek rebuttals in arguments (see method section for details). Kuhn (1991) stressed the use of rebuttal is "the most complex skill" and thus, students must ''integrate an original and alternative theory, arguing that the original theory is more correct'' (p. 145). From this perspective, their assessment framework focused on the presence and nature of rebuttals in arguments rather than presence or absence of all components. Put more specifically, their framework distinguishes the three levels of argument with rebuttals: arguments with weak or incomplete rebuttals; arguments with clear rebuttals; and arguments with multiple rebuttals. Hence, this framework was appropriate for the present study since teachers' argumentation practices were examined through scenarios including alternative explanations. Besides, it should be noted that as Erduran et al. (2004) used, in the current study, I used rebuttal in Kuhn's sense of presenting counter-arguments that challenge the alternative views rather than in Toulmin's sense of presenting extraordinary or exceptional circumstances under which the claim cannot be supported.

In addition to structural analysis of argumentation, research on argumentation in science education put forward the need for analyzing arguments in terms of conceptual and epistemic aspects (Sampson & Clark, 2008). In this regard, in the present study, to deepen understanding of justification process, science teachers' argumentation practices were also analyzed in terms of conceptual and epistemic aspect. In parallel with these purposes, Tavares et al.'s (2010) framework was used as basis of analysis to classify science teachers' propositions into different epistemic status. As mentioned before, Tavares et al. adapted Kelly and Takao's (2002) framework into context of evolutionary theory (see method section for details). Kelly and Takao developed their scheme in order to identify how evidence is used to support a theory or model in terms of epistemic levels focusing on general distinctions between lower level grounded claims about data and epistemically higher level appeals to theory specific to the disciplinary context of the argument described. The examination of epistemic levels of the various evidenced claims provides a way to characterize types of evidenced claims use to support their conclusion and to describe how specific scientific knowledge is articulated in epistemologically evidenced claims.

Besides, to examine how theoretical knowledge regarding evolutionary theory connect with data statements at different epistemic levels, Tavares et al.'s (2010) rubric was also employed. As mentioned before, this frame provided information with respect to integration of argumentation patterns with epistemic status.

Taken as a whole, Toulmin's argumentation model focuses on the structure of argumentation that provides insight about components of arguments (e.g., data, claim, warrant) but this model does not take into account of relative epistemic status relevant to specific domain embedded in arguments which in turn, neglects the critical aspects of arguments and interpretations of some exchanges (Jiménez-Aleixandre et al. 2000; Sampson & Clark, 2008). That is why I also examined the epistemic status of science teachers in terms of their ability to articulate knowledge and theories about evolution in their evidenced claims.

Hence, in the current study, science teachers' argumentation practices were assessed in terms of structural aspect following Erduran et al.'s (2004) framework in order to identify the components of argumentation they used and their epistemic aspects of argumentation relevant to evolutionary theory were also investigated in terms of relative epistemic levels on the basis of Tavares et al.'s (2010) framework in order to identify how science teachers appeal to evolution knowledge in their justifications. Besides, another Tavares et al.'s rubric was also employed in order to explore integration of epistemic, structural and conceptual aspects of argumentation practices.

In argumentation studies, several researchers investigated students' criteria when evaluating alternative explanations in order to represent the holistic picture of argumentation practices. For instance, Hogan and Maglienti (2001) examined the criteria that middle school students, non-scientists adults, technicians and scientists used to evaluate the validity or acceptability of alternative ideas provided by hypothetical students. Authors analyzed criteria through using epistemological criteria coding scheme. This scheme focused on to what extent explanation includes judgments about strengths and weaknesses of conclusion. It was found that scientists and technicians predominantly utilized the criterion of coherence between conclusion and the range of evidence. Students and adult non-scientist also utilized this criterion but they also used three more criterions, namely plausibility of conclusion based on inferences drawn from evidence, plausibility of conclusion based on adherence with evidence and previous knowledge, plausibility of conclusion based merely on previous knowledge. Therefore, the difference between scientists and non-scientists is the emphasis on coherence of empirical evidence versus plausibility of conclusion. Authors reached a conclusion such that empirical criteria students used were limited in terms of empirical support for causal claims. In philosophy of science, positivist perspectives emphasized the interaction between theory and methodology. Therefore, it is also expected students to coordinate evidence and theories. Researcher also stressed that non-scientists generally think based on their theories and they do not evaluate conclusions in the light of alternative explanations. Besides, they also stated that epistemological criteria non-scientists used vary from context to context. In line with this, Kuhn et al. (1995) claimed that the reason of inadequate of scientific reasoning is that lay people generally tend to consider their beliefs and experiences as hypothesis and they consider only with their hypothesis. Thus, they do not sufficiently take into consideration of alternative theories. This is closely related to lack of skills to generate arguments.

In another study, Yalçınoğlu (2007) examined teachers' criteria when they evaluate about alternative explanations. In this regard, teachers were provided three hypothetical conclusions constructed by students for each scenario. Author analyzed criteria based on Toulmin's argumentation pattern. It was found that teachers mostly used the criterion of the use of scientific evidence (data), reference to theory behind the concept (backing), scientifically accurate knowledge (data), reference to topic behind the scenario (warrant), addressing the question (claim) and reference to evidence provided in the scenario (data). Based on the study's findings, Yalçınoğu concluded that teachers generally took into consideration of consistency between evidence and conclusion that is similar to Hogan and Maglienti's (2001) findings for scientists. Besides, authors argued that when teachers were asked explicitly about the validity of conclusion rather than personal agreement, they tended to use more scientific criteria.

Sampson and Blanchard (2012) also attempted to analyze teachers' criteria when evaluating the validity or acceptability of provided explanations. Authors provided three alternative explanations for each scenario. Alternative explanations were purposefully crafted such that one includes sufficient and accurate explanation, one consists of sufficient but inaccurate explanation and other includes insufficient but accurate explanation. They identified an argumentation framework that includes empirical, theoretical and analytical criteria to analyze both teachers' criteria and quality of arguments. Specifically, empirical criteria include criterion of how claim fits with available evidence, of the adequacy of evidence and of relevance of evidence. Theoretical criteria comprise judgments about sufficiency of the claim, its usefulness and consistency of claim with theories and laws. Analytical criteria consist of evaluation for line of reasoning, for logic underlying data analysis and adequacy of its rationale. Based on this, several filters that teachers used to choose explanation were emerged. In particular, teachers utilized three criterions, namely fit with their existing understanding, examining explanation in the light of other explanations but this is based on their existing understandings and fit with the provided data. Besides, teachers also considered some aspects of explanation such as plausibility and sufficiency of them. Authors concluded that teachers utilized appropriate but limited criteria in comparison with those that scientists used.

In addition, as noted earlier, Sampson et al.'s (2011) developed a coding scheme in order to find out how often students used rigorous criteria valued in science to justify or challenge an idea. Researchers used two categories of criteria, namely rigorous and informal. While rigorous criteria are in accordance with scientific standards, informal criteria deal mostly with everyday explanations that are insufficient to justify or challenge ideas. Rigorous criteria include "fit with data, sufficiency of data, coherence of an explanation, adequacy of an explanation and consistency with scientific theories and laws". Informal criteria consist of "appeals to authority, discrediting speaker, plausibility, appeals to analogies, judgments about the importance of an idea and consistency with personal" (p. 233). After intervention, authors found that students tended to use rigorous data than those are used before intervention.

In the light of available literature, scenarios include three or two alternative explanations and these were purposefully constructed to include accurate and inaccurate explanations. Hence, science teachers' criteria when evaluating alternative explanations were analyzed based on Sampson et al.'s (2011) framework in the present study.

2.2.2. Research on Argumentation in Science Teacher Education

In the past decades, science education researchers have placed strong emphasis on how students' engagement in argumentation practices (e.g., Bell and Linn, 2002; Clark & Sampson, 2007; Jiménez-Aleixandre et al., 2000; Osborne et al., 2004), evaluate explanations (e.g., Clark & Sampson, 2008; Sandoval, 2003), and generate arguments (e.g., Sandoval & Millwood, 2005). On the other hand, there have been relatively few studies that investigated teachers' knowledge and skills regarding argumentation (e.g., Erduran et al., 2004; Yalçınoğlu, 2007). However, the available literature illustrated that teachers' knowledge have an impact on the integration of argumentation into science classrooms which in turn affects students' science learning.

For instance, in their study, Newton et al. (1999) questioned whether science teachers provide students opportunities to foster argumentation skills in science classes. Based on classroom observations, authors found that science teaching and learning was heavily based on teachers' practices. In particular, activities were mostly based on teacher-led questions and students' answers. Teachers did not sufficiently support student-centered practices such as knowledge construction and argumentation. Although teachers perceived discussion as an important tool for students' learning, they voiced concerns regarding lack of pedagogical knowledge, covering curriculum and difficulties with managing discussions. In a similar vein, Yalçınoğlu (2007) investigated high school biology teachers' argumentation and attention to reasoning and argumentation within their instructional practices. Author found that none of the participant teachers craft well structure arguments. Besides, findings based on classroom observations indicated that although some elements of argument were identified throughout their instruction period, teachers did not explicitly integrate argumentation into teaching science. That's why, classroom activities were mostly based on teachers' talks. Therefore, students scarcely got opportunities to construct arguments and that's why their reasoning and argumentation skills were poor based on the findings of students' assessments.

Several researchers attempted to examine development of students' argumentation practices following teacher training programs. Zohar and Nemet (2002) examined the students' argumentation skills in the context of dilemmas in genetics. Teacher guided students who participated in argumentation activities. Before instruction, students tended not to justify their opinions and take into consideration of alternative points of views. However, after integration of explicit teaching argumentation to activities, a dramatic change was observed in students' practices. In particular, after intervention, students started to generate more sophisticated arguments including justifications of claims and counter-arguments. Hence, authors emphasized the value of explicit teaching argumentation for students reasoning and argumentation skills. Besides, McNeill and Krajcik (2008) illustrated that when teacher provided explicit information about the importance of argumentation practices in science and structural components of arguments, students' argumentation skills improved. In line with this, Zohar (2007) suggested that in order to teach argumentation, teachers should comprehend the argumentation itself and its strategies to integrate evidence based argumentation practices into science teaching.

In another study, Erduran et al. (2004) examined the distribution of Toulmin’s argumentation pattern (TAP) in classroom discussion among students and teachers across two years. Throughout the school year, teachers were trained in workshop including recommendations to promote students’ argumentation classrooms. Authors analyzed teachers’ talk during argumentation phases. They reported that at the beginning of the study, students’ arguments frequently consisted of two or more components such as CD (claim-data) and CDW (claim-data-warrant) but after the intervention, students’ arguments developed and comprised four or five components such as CDWB (claim-data-warrant-backing) and CDWBR (claim-data-warrant-backing-rebuttal). Based on the findings, authors argued that argumentation practices in classrooms are probably teacher-dependent. Put more specifically, the reason of this improvement of students’ argumentation practices was more likely related to improvement in teachers’ argumentation skills since students were relatively most frequently guided and encouraged to engage in practices. Likewise, Simon et al. (2006) investigated pedagogical strategies that promote teachers’ practices and how these strategies enhance students’ practices. Quality of argumentation in classroom was assessed by TAP. The workshop series was conducted for training teachers across one year. Authors observed the development in teachers’ practices which in turn, influence students’ practices. These results led authors to conclude that science teachers need to understand more about the nature of scientific argumentation and how to evaluate scientific argumentation practices to promote students’ knowledge and skills. Besides, authors revealed that teachers gave emphasis on different aspects of argumentation (e.g., reasoning, generating counter-argument, the use of evidence) depend on their views about argumentation and their goals for students’ science learning. Similarly, Kelly and Chen (1999) recommended that teachers’ knowledge and strategies used during students’ engagement in argumentation influence students’ argumentation quality. In Turkey, Erduran, Ardac, and Yakmaci-Guzel (2006) conducted a case study with two Turkish pre-service science teachers to investigate developments of teachers’ instruction practices in secondary science classrooms after training. Workshops included training with respect to how to structure and approach the teaching of argument in science. Besides, training regarding "(1) how to introduce argument; (2) how to manage small group discussions; (3) how to teach argument; (4) what resources can be used to support argumentation by students; (5) how to evaluate arguments; and (6) how to model them for pupils" was also included (p. 6). Subsequent to training, teachers were required to implement their lessons based on argumentation. Results showed that the coordination argumentation practices with curriculum objectives were difficult for teachers. Authors reached some encouraging results such that development in teachers' knowledge and skills improved their instructional decisions and practices.

As Zeidler (1997) discussed, if teachers do not have sophisticated understanding of argumentation, it is not expected them to integrate argumentation in their science lessons. Therefore, several researchers turned their attention to teachers' knowledge and skills. Zembal-Saul et al. (2002), for instance, attempted to examine pre-service science teachers' knowledge about the scientific argumentation. In particular, authors developed a rubric in order to analyze teachers' argumentation practices in terms of causal structure, evidence, data justifications and evaluating their explanations. The researchers found that although teachers sufficiently coordinated evidence and claims, their arguments were still limited in terms of the nature and the use of evidence. More specifically, most of them ignored the alternative explanations and did not provide any counter-arguments. Besides, they supported their claims by utilizing single piece of evidence rather than multiple pieces of evidences; that is, they referenced same data more than once in their arguments. In addition, authors found that teachers scarcely provided justifications and the reason of this may be that they thought the relationship between evidence and explanation to be evident.

More recently, Sampson and Blanchard (2012) analyzed how science teachers evaluate the validity of alternative explanations, construct written argument to support a particular explanation within different science contexts and also explored their views about implementation of argumentation in science lessons. In their study, researchers used cognitive appraisal interview during which science teachers were asked to describe their strategies and reasoning used so as to complete the tasks. Each task related to specific science concept and consists of three alternatives explanations crafted by the researchers so that one provides sufficient and correct, other provides insufficient but accurate and another provides sufficient but inaccurate answers. The results of this study indicated that science teachers evaluated the validity of explanations based on their previous knowledge and past experiences rather than data presented in the context. Most of the teachers did not use reasoning and evidences to justify particular explanation. Authors also noted that although teachers view argumentation as a way to promote students' scientific thinking and develop their understanding of the concept, they discussed concerns about the implementation of argumentation such as students' capacity level, the amount of time and lack of resources. These findings led them to conclude that teachers need to learn more about the nature of scientific argumentation and develop strategies to integrate argumentation in science lessons. In line with this, Sampson and Blanchard (2012) recommended that one way to develop teachers' argumentation knowledge is to engage them in task activities as used in their studies since these experiences help them to comprehend the aspects of argumentation.

Overall, available literature indicated that teachers' instructional practices had direct influence on students' practices related to argumentation and instructional practices were shaped by teachers' knowledge and skills regarding scientific argumentation. However, we have limited understanding on teachers' knowledge and practices about scientific argumentation. Therefore, there is a need to investigate teachers' existing knowledge as Simon et al. (2006) voiced "the focus of professional development should be on teachers' existing understanding of the importance of evidence and argument in science'' (p. 256). However, research on teachers' argumentation practices has been apparently insufficient. From this point of view, the focus of the present study was on science teachers' scientific argumentation practices. For this reason, evolutionary theory was chosen as a context of the current study since as a unifying theme, theory of evolution is heart of the science. In particular, many broad topics in science are held and threaded together by evolutionary theory.

Therefore, this context provided valuable way to analyze science teachers' scientific argumentation practices.

2.2.3. Research on the Relation among Conceptual, Epistemic and Structural Aspects of Argumentation

Several researchers attempted to examine effects of conceptual understanding on argumentation practices. For example, von Aufschnaiter et al. (2008) investigated junior high school students' argumentation practices and cognitive development in the context of science and socio-scientific issues. Authors examined small group and classroom discussions in order to analyze students' argumentation quality based on Toulmin's (1958) framework. The development of students' scientific knowledge was also analyzed through tracing the usage of scientific knowledge in their arguments. Then, two analyses were utilized to explore their effect on each other. Authors worked with 12 teachers who were given instruction about skills of developing argumentation in science education. The findings of study indicated that students participated into argumentation practices only when they had some basic understanding of particular science concepts. Even if tasks included additional information, students did not attempt to use this information for arguments. Instead, they generated arguments on the basis of previous knowledge. Besides, high quality arguments consisted of grounded scientific knowledge. These findings led them to conclude that familiarity and understanding of the particular subject matter enable students to engage in and generate more sophisticated arguments.

In another study, Acar (2008) studied with pre-service science teachers in order to examine relationship between argumentation skills and conceptual knowledge. A total of 125 pre-service science teachers attended in inquiry-based physics course. This course covered two argumentation activities. Throughout the course, author analyzed pre-service science teachers' argumentation based on two criteria, namely whether or not students use evidence in their arguments, counter-arguments and rebuttals, whether or not students provide appropriate evidence and whether or not students generate appropriate counter-arguments and rebuttals. Students' conceptual understandings of balancing, sinking and floating concepts were evaluated through conceptual test. The results of this study illustrated that following instruction, pre-service science teachers' argumentation skills developed, that is, teachers provided justifications of their claims and counter-argument and rebuttals for counter-claims more frequently. However, there are also several contradictory findings in available literature. Means and Voss (1996), for instance, examined how reasoning skills are related to knowledge levels. For this study, they worked with 60 students whose ages ranged from 5 to 11 and 90 students whose ages ranged from 8 to 12 in the United States. Their results revealed that although content knowledge provided for the development of some patterns of argumentation such as constructing more claims, data and warrants, content knowledge did not always related to higher reasoning skills. Specifically, basic components of arguments were frequently generated; however, challenging alternative points of views and generating rebuttals were less frequently. This means that most of the argumentation patterns students constructed were limited to lower levels. They found that reasoning skills were related to ability level. Likewise, Sadler and Donnelly (2006) investigated the effects of content knowledge on quality of argumentation in the context of socio-scientific issues. In particular, authors examined how genetics content knowledge relates to argumentation quality in the context of genetic engineering issues. In their study, eight grade students were interviewed through asking questions based on scenarios. Authors analyzed students' argumentation quality in terms of three components, namely position and rationale, multiple perspective-taking and rebuttal. The findings of this study showed that basic understanding of the particular subject matter was needed to understand the task and make interpretation about it. However, strong background scientific knowledge was rarely associated with high quality arguments.

The effects of argumentation practices on conceptual understanding were analyzed by several researchers. In this line, Asterhan and Schwarz (2007) investigated the effects of monological and dialogical argumentation on conceptual understanding in the context of evolutionary theory. For this purpose, they studied with 86 Israeli undergraduate students. To analyze this effect, if any, they employed two experimental designs. In the first experiment, experimental group worked in collaborative learning tasks in which they engaged in dialogical argumentation while control group worked in ordinary collaborative tasks. In the second experiment, experimental group engaged in monological argumentation while control group discussed their solutions. In addition, conceptual understanding regarding evolutionary theory was evaluated by two schemas. First schema focused on the classification of students' evolutionary explanations and the use of Darwinian principles. The results of this study illustrated that conceptual understanding of students who engaged in both monological and dialogical argumentation developed. However, author also found that increase in the use of explanation related to evolutionary theory were not always accompanied by increase in the use of correct Darwinian principles. Another study was employed by Nussbaum and Sinatra (2003), who examined the effects of argumentation on conceptual change. 41 undergraduate students were participated in this study. They were asked to physic problem with respect to path of falling object and provided alternative explanations. In experimental group, students were asked to generate arguments for the correct explanations. Although control and experimental groups did not differ in terms of the accuracy of explanations, they differed in the quality of explanations. Therefore, author concluded that argumentation practices have potential to improve concept learning and in turn, conceptual change.

In another strand, Jiménez-Aleixandre and Bravo (2009) examined the relationship between the quality of students' conceptual understanding and the quality of their evidenced claims. Authors assessed students' conceptual understanding about ecology by developing a framework and assessed their quality of evidenced claims by adapted version of Kelly and Takao's (2002) framework. In particular, they examined the quality of evidenced claims based on whether students combine evidenced claims at different epistemic levels. The results of this study indicated that majority of students applied their conceptual knowledge regarding energy flow to articulate in evidenced claims. They also found that threshold conceptual knowledge was needed to generate evidenced claims but comprehensive understanding did not contribute to the use of evidenced claims at various epistemic levels. These results were consistent with those of Sadler and Donnelly (2006). In the present study, the relationship between conceptual knowledge and practices was not examined. Instead, the purpose of this study was to examine the process of articulation of conceptual knowledge and argumentation practices in evidenced claims. The present study also attempted to reveal science teachers' misconceptions and cognitive biases other than evolutionary notions in their arguments and evidenced claims.

A notable investigation was conducted by Sampson and Clark (2011) comparing high and low achievers according to their conceptual understanding levels in a particular knowledge domain to analyze the effect of content knowledge on argumentation practices. Authors analyzed interactions among groups while they engaged in collaborative scientific argumentation. 168 high school students' argumentation generations were examined in terms of sufficiency of the explanation, conceptual quality of explanation, evidence quality and adequacy of reasoning. It was found that high performing students generally constructed sophisticated arguments compared to low performing students. More specifically, low achieving groups did not usually take into consideration of opposite view and discussed alternative explanations compared to high achieving groups. Besides, low performing groups used fewer supplied data to support their arguments than higher performing groups did. Low achieving groups also appealed to rigorous criteria whereas, high achieving groups used informal criteria. Therefore, content knowledge was required to construct high quality arguments. In addition, these differences between high and low achieving students led them to conclude that the use of evidence, reasoning and conceptual understanding were interrelated.

2.3. Research on Evolutionary Theory in Science Education

Evolutionary theory is the unifying theme and cornerstone of biology and other life sciences. Science education reform efforts have stressed its importance in biology and science education. NAS (1998, p. 3) argues that "to teach biology without explaining evolution deprives students of a powerful concept that brings great order and coherence to our understanding of life." The importance of understanding evolution is also emphasized by the Benchmarks for Science Literacy that states, "The educational goal should be for all children to understand the concept of evolution by natural selection, the evidence and arguments that support it, and its importance in history" (as cited in NAS, p. 47).

In this section, studies on evolutionary theory in science education were reviewed under two sections. In the first section, research on analyzing alternative conceptions about evolutionary theory was examined. In the next section, research on argumentation in the context of evolutionary theory in science education was discussed.

2.3.1. Research on Analyzing Conceptions about Evolutionary Theory

Evolutionary theory was along before Charles Darwin. However, Darwin was the first to generate scientific argument regarding evolution by means of natural selection in 1859 in his book, *On the Origin of Species*. Later, Darwin's theory was combined with Mendel's studies on inheritance which leads to emergence of theory of modern evolutionary synthesis (Mayr, 1982). The modern evolutionary synthesis encompasses series of concepts. In this sense, Mayr (1982) identified five facts and three inferences (as cited in Anderson, Fisher, & Norman, 2002, p. 956).

> Fact 1: All populations have the potential to grow at an exponential rate.
> Fact 2: Most populations reach a certain size, then remain fairly stable over time.
> Fact 3: Natural resources are limited.
> Inference 1: Not all offspring survive to reproductive age in part because of competition for natural resources.
> Fact 4: Individuals in a population are not identical, but vary in many characteristics.
> Fact 5: Many of the characteristics are inherited.
> Inference 2: Survival is not random. Those individuals with characteristics that provide them with some advantage over others in that particular environmental situation will survive to reproduce, whereas others will die.
> Inference 3: Populations change over time as the frequency of advantageous alleles increase. These could accumulate over time to result in speciation.

Based on above mentioned conceptions, many studies attempted to investigate whether students' and teachers' conceptual understanding regarding evolutionary theory is compatible with scientists' explanations. However, studies have underlined the students' and even teachers' difficulties with understanding of evolution concepts and with transferring their evolution knowledge to other biology concepts (Tavares et al., 2010). Southerland et al. (2001), for instance, studied with second-, fifth-, eight- and twelfth-grade students from different regions of United States to investigate the conceptual knowledge about evolutionary theory. Students were asked to explain biological phenomena with respect to a bean plant growing toward a sunny window, a ptarmigan in summer brown pelage and winter white pelage, a group of birds in a flying V formation, and a cactus with very thick, dense, thorny leaves. Based on the responses, students' biological explanations were sorted into several reasoning categories: (1) anthropomorphic: causal agent for change; (2) teleological: need-driven process; (3) mechanistic proximate: actions at individual level rather than population level; (4) mechanistic ultimate: actions at entire population of organisms; (5) predetermined: process driven by god, nature or an agent. Based on those categories, authors reported that teleological reasoning was commonly used by fourth grade students and less frequently by twelfth grade students. For example, one student attempted to explain the reason of color change in feathers as "it needs to be camouflaged". Mechanistic ultimate explanations were prominently applied by twelfth grade students. For example, a twelfth grade student said "over the years developed that and part of the like their genes would know to do that" as the reason of leaning of plant toward light. Therefore, authors concluded that as grade levels increased, students' scientific reasoning abilities developed.

In a similar vein, students' preconceptions about evolution were examined by Kampourakis and Zogza (2007) through using five problem solving based scenarios regarding morphological similarities, the lengthening of the giraffe's neck, prey-predator relationship, color change, similarities in DNA. Authors studied with 100 lower secondary students in Greece. Prior to analyze students' preconceptions, authors stressed the difference between Lamarck's evolutionary theory and other misconceptions. Put more specifically, they defined Lamarck's theory of evolution in terms of his two central theories: theory of use and disuse and inheritance of acquired traits. They also identified other misconceptions commonly used among students and teachers as change due to a final cause (teleology) and change imposed by need in the light of literature. Based on this categorization, they found that although students rarely appeal to Lamarck's theories in their explanations, their explanations mostly involved need-driven adaptive processes. For example, one of the students explained the reason of lengthening of the giraffe's neck as "the need to feed and satisfy its needs". In addition, students' conceptions were different from Lamarck's views in that Lamarck explained evolution through physiological mechanism whereas students explained the process via intentional view or supernatural force. Besides, students rarely utilized the evolutionary notions, in particular differential survival. Authors also recommended the researchers to focus on students' conceptions with respect to teleology and the role of chance.

After two years, Kampourakis and Zogza (2009) sought to change in secondary students' conceptions following instruction. Instruction included biological concepts, levels of biological organization, mechanism of heredity and of the origin of genetic variation as well. Subsequently, these concepts were utilized to explain microevolution and macroevolution. Authors collected data from open-ended written questionnaire and open-ended questionnaire based on evolutionary scenarios regarding the origin of homologies and adaptations that was used in interviews. In order to analyze students' conceptions about evolutionary theory, authors used three categories: evolutionary, proximate and teleological explanations. Proximate explanations include naturalistic explanations but those are insufficient to explain evolutionary process. The results of this study indicated that specific evolution instruction brought about conceptual conflict regarding unpredictability and chance. Besides, students applied more evolutionary and proximate explanations after instruction regarding evolutionary theory. For instance, one student stated "These animals were influenced by their environment and the respective climate and thus they acquired these features" so as to explain the coloration of the body. This was an example of proximate explanation since it was based on individual level and deals with developmental and physiological traits. In addition, there was no coherence among students' explanation in different context even regarding same phenomena.

In several studies, researchers have attempted to explore undergraduate students' conceptual understandings in the context of evolutionary theory (e.g., Bishop & Anderson, 1990; Jensen & Finley, 1996). Bishop and Anderson (1990), for instance, studying with 176 undergraduate non-science majors in biology course examined the conceptions with respect to natural selection and factors responsible for evolutionary change. Authors collected data through Evolution Concept Test that encompasses essay questions regarding cheetahs' speed and blindness in cave salamander and multiple choice tests. In their study, it was found that three major misconceptions regarding evolutionary theory were prominent among students. The first one is that students struggled to explain the mechanisms underlying origin and survival of new traits in population. In particular, they hold inadequate understanding about random changes in genetics and differential survival. Instead, they thought that environmental pressure leads to change of traits. They explained the mechanism of this process with need, adaptation and theory of use and disuse. For example, they utilized such phrase as "cheetahs need to", "species change due to use or fail to use organs or abilities". The next one is that students did not take into account of variation among population. Instead they perceived evolutionary process as a change in whole species. The last one deals with the evolution as the changing proportion of individual with different traits. More specifically, they perceived evolution process as gradual change in the traits themselves. In addition to those misconceptions, students also utilized two terms, adaptation and fitness, in an unscientific manner. For instance, students considered adaptation as a change in response to environmental influences. They also used fitness to mean strong, health or strength rather than ability to produce fertile offspring.

In another study, in order to develop and increase undergraduates' Darwinian conceptions, Jensen and Finley (1996) assessed students' learning of evolution by natural selection through instructional materials and techniques. In their study, prior to interventions, Darwinian conceptions such as survival of the fittest, variation within population, inheritance or changing proportions of traits within population were utilized by the students and also they held some misconceptions regarding teleology and Lamarck's theory of use and disuse and inheritance of acquired traits and intentionality as well. For instance, they explained adaptation process through intentional reasoning such that they used the phrase like "learns to adapt in a given situation" or speed was taught". Among them, students most frequently utilized teleological explanations. For example, students utilized key phrases in their explanations such as “in order to balance nature” and “have always needed”. Following intervention covered instruction regarding students’ preconceptions, traditional content and paired problem solving, the use of misconceptions substantially decreased. However, authors found that although it was easy to improve students’ Darwinian conceptions except for inheritance, change in students’ misconceptions as to Lamarckian conceptions was more difficult than change in teleological conceptions. In addition, authors illustrated the benefits of problem solving approach in changing and developing students’ conceptions related to evolutionary changes. In another study, Shtulman (2006) studied with high school students and undergraduates in United States in order to examine their understanding of six evolutionary phenomena, namely variation, inheritance, adaptation domestication, speciation and extinction. Based on these concepts, author developed a 30-question test. In this study, it was found that majority of participants considered evolution as transformation of the essence of species. In addition, students tended to explain evolutionary phenomena through teleological reasoning rather than mechanistic one and utilized the phrase like “in order to”, have to” or “need to”. Author concluded that the tendency to essentialize species developed in early ages hinder them to understand differential survival.

Several researchers voiced the importance of cognitive bias or cognitive constraints for students’ conceptions concerning evolutionary theory. For example, Moore et al. (2002) studied with 126 undergraduate students who did not take any course on evolution in South Africa in order to examine their conceptions about evolutionary theory through using scenarios, namely About Peppered Moths, More about Peppered Moths and Tuberculosis. Moore et al. (2002) argued that students tend to ascribe agency when explaining an evolutionary phenomenon which in turn leads to misconceptions. They utilized the term of agency as a category to identify students’ responses including purposive adaptation and change due to need. The result of the study illustrated that students held unscientific notions regarding evolution through goal-and conscious-driven that influence the use of language in their explanations, in particular, students used language such as “in order to fit”, happened with a purpose”, equip itself” and “learning”. Authors argued that agency concepts may prevent the understanding of mechanism of natural selection in two ways: agency notions might lead to perceiving natural selection concepts hard to understand and learners who struggle to understand this concept appeal to agency concepts to explain evolutionary phenomena easily. In a similar vein, Sinatra et al. (2008) also voiced the cognitive constraints, namely teleological, essentialist and intentionality constraints that precluded understanding of evolutionary theory. Authors argued that students and even adults have “rules of thumb” that influence thinking process and render evolutionary theory difficult to learn since the mechanism of evolutionary theory is not compatible with these rules. In line with this, Bloom and Weisberg (2007) tried to explain the reason behind employing these constraints such that natural cognitive disposition brings about developing teleological view since everything is operated by mental agent and purpose in everyday life. Another study focused on aforementioned constraints or biases conducted by Evans (2008). Author compared conceptions of children in different ages and adults in United States. Based on the analysis of results, it was concluded that both children and adults hold cognitive biases. There was difference in the age groups in terms of essentialist explanations. Younger children tended more to explain evolutionary phenomena through essentialist reasoning than older children and adults did. As age level increases, appreciation of variation within population developed and common descent developed. In addition, it has to note that regardless of age, both children and adults explained the evolution of butterflies and frogs with common descent but they did not for evolution of human and other mammals.

In another strand of research, several researchers turned their efforts to analyze teachers’ conceptions about evolutionary theory. The major reason of these efforts was that science teachers are considered as “missing link” between students’ misunderstanding of evolutionary theory and scientists’ understandings (Nehm & Schonfeld, 2007). Nehm and Schonfeld attempted to examine 44 biology teachers’ conceptual knowledge regarding evolutionary theory in the United States. In this study, Bishop and Anderson’s (1990) questionnaire was employed. The findings indicated that teachers had diverse and abundant misconceptions and non-normative ideas about evolution. In particular, theory of use and disuse, teleology and inheritance of acquired traits were utilized in their explanations. In addition, several teachers mentioned about the co-existence of human and dinosaurs, harmful mutations and lack of transitional forms. However, following intervention covered misconceptions identified by pre-tests, although the usage of these misconceptions decreased, many teachers continued to bring misconceptions to course. In addition, authors reported that teachers applied more frequently to key concepts of natural selection following to intervention. They appealed to competition, limited resources, variation, selective survival and overproduction of offspring. Another study on Canadian pre-service elementary school teachers' conceptual understanding about biological evolution was conducted by Asghar et al. (2007). The results of the study showed that teachers did not have adequate understanding of mechanisms of evolutionary theory and their understanding was limited to human evolution. In another study, Rutledge and Warden (2000) studied with 989 biology teachers in Indiana's public high schools to analyze their understanding of evolutionary theory. They used evolution content knowledge test consisting of items related to the concepts of natural selection, extinction processes, homologous structures, coevolution, analogous structures, convergent evolution, intermediate forms, adaptive radiation, speciation, evolutionary rates, the fossil record, biogeography, environmental change, genetic variability, and reproductive success. The results showed that biology teachers held low level of understanding about environmental change, reproductive success, the process of evolution and variation.

In Turkey, Taskın (2011) investigated pre-service science teachers' conceptual understanding through administering essay questions after intervention encompassing the hands-on and minds-on activity called "A toilet paper timeline of evolution: 5 E cycle on the concept of scale" regarding age of Earth and fossil record. Author found that they had inadequate understating of evolution. In particular, they utilized the terms of adaptation, population, speciation, mutation, common ancestor, transition form and variation in an unscientific manner. The predominant misconception among teachers is about the geological time scale. In particular, they did not know about the first appearance and disappearance of any organisms. Apart from this, teachers explained evolution at individual level rather than population, adaptation as a consequence of environmental pressure and they did not mention about population genetics. Another study conducted in Turkey by Tekkaya and Kılıç (2012) also investigated the 7 Turkish biology teachers' pedagogical content knowledge regarding evolution. Data were collected through interview transcripts, lesson plans and concept maps. The findings of this study showed that although they were aware of difference between Lamarck's and Darwin's theories, they utilized Lamarck's theory to explain the natural phenomena regarding evolution of blind cave salamander and cheetahs' running speed. For instance, some of the teachers applied Lamarck's theory to explain changes in traits within a population. In addition, they also held inadequate understanding about common ancestry. However, results also indicated that biology teacher used the concept of differential survival as a reason of extinction of dinosaurs.

A comprehensive review about the conceptions regarding evolution was conducted by Gregory (2009). In this review, author identified commonly used misconceptions among students and teachers by examining previous studies. The first misconception is teleology or function compunction. Author argued that as human experiences include purposes and needs, it is expected to perceive evolution as a goal- or need-driven process. Therefore, this bias could be appeared in especially the concepts of ecological balance or species survival. The next common misconception is anthropomorphism and intentionality. This conceptual bias deals with perception of evolution through intentional action. Author stressed that intentional reasoning brings about misconception regarding evolution at individual level since students who hold this bias tend to ascribe conscious intent to single individual (e.g., it learns or tries). The next two misconceptions are Lamarck's theories, namely theory of use and disuse and inheritance of acquired traits or soft inheritance. Author argued that students and teachers appealed to Lamarck's theory of use and disuse especially in explanations for why useless organs or structures become vestigial. Author stated that misconception about change due to inheritance of acquired traits is arisen especially in youth since they have inadequate understanding about genetic. Another misconception is nature as a selective agent. Individuals perceived the mechanism of natural selection as a driving force that "choose" or "prefer" genetic variants. Hence, one can simply attribute that natural selection has purpose or goals and it can be associated with teleology. Another misconception is source versus sorting of variation. It deals with the dependence of variation on natural selection. In particular, individuals considered that mutations arise due to environmental challenges and that's why all mutations are beneficial rather than neutral or harmful. The next one is related to typological, essentialist, and transformationist thinking. Author described this cognitive bias such that individuals tend to underestimate the variation between individuals within a population and thus, consider species as sharing a common "essence". This bias could be associated with transformationist thinking, that is, populations transform as a whole. The last one consists of misconception about events and absolutes versus processes and probabilities. More specifically, individuals could consider natural selection as an event rather than a process. Natural selection takes place continually and simultaneously whereas events follow a particular order and it has a start and end point. Besides, natural selection is also considered as being "all or nothing" rather than a probabilistic process. Gregory (2009) also voiced that cognitive biases held by individuals influence their perceptions of evolutionary theory and most of misconceptions are derived from cognitive biases.

Based on the literature on misconceptions and cognitive biases regarding evolutionary theory and the findings of survey with more than 10.000 students who were administered to two evolutionary scenarios, Nehm et al. (2010) attempted to develop a framework that includes not only misconceptions but also key concepts of evolutionary theory. The scoring rubric was developed through sorting students' conceptions into three major categories related to biological evolution as key concepts, misconceptions and cognitive biases. More recently, Ha and Nehm (2014) assessed explanations of naïve and experts from USA and Korea for two problems regarding trait gain and loss based on Nehm et al.'s (2010) rubric. It was found that students and teachers had more difficulty in explaining process of trait loss with normative scientific ideas than in explaining process of trait gain. Besides, findings indicated that participants utilized three types of naïve ideas, namely theory of use and disuse gradual accumulation and purpose-driven (teleology) and they most commonly explained evolutionary phenomena through teleological reasoning. Authors also reported that biological thinking and reasoning is context-dependent, that is, students' and teachers' explanations varied biological phenomena to another. In another study, Opfer et al. (2012) studied with 320 undergraduate biology students to examine their use of natural selection to explain evolutionary change by using Nehm et al.'s (2010) framework. The results indicated majority of students used key concepts of evolution (normative concepts) including variation, heritability of variation and differential survival; however, they also used cognitive biases consisting of teleological and essentialist biases as a cause of evolutionary change. They found that especially those who had low achievement in biology course used both normative and non-normative concepts. These results leaded authors to conclude that overcoming the use of cognitive bias and appealing to key concept of evolutionary change are not independent events.

Overall, misconceptions and cognitive biases have been held by both teachers and students. They have inadequate understanding of evolutionary theory. They still appealed to pre-Darwinian concepts (e.g., Lamarck's theory) (Gregory, 2009; Jensen & Finley, 1996). In addition, even after intervention or education in biology, students' and teachers' misconceptions were robust to change (Ferrari & Chi, 1998; Jensen & Finley, 1996; Nehm & Schonfeld, 2007). In this regard, several researchers emphasized the importance of cognitive biases for understanding evolutionary theory (Evans, 2008; Sinatra et al. 2008).

Taken as a whole, in the present study, science teachers' conceptual understanding with respect to evolutionary theory and what types of evolutionary notions were used by teachers to articulate their arguments was analyzed. In this regard, Nehm et al.'s (2010) rubric was used since this assessment tool provides comprehensive assessment for conceptual knowledge in terms of key concepts, misconceptions and cognitive biases.

2.3.2. Research on Argumentation in the Context of Evolutionary Theory in Science Education

Several researchers have attempted to examine students' epistemic and argumentation practices in the context of evolutionary theory. As noted earlier, Zembal-Saul et al. (2002) investigated teachers' nature of scientific argumentation in terms of four dimensions. Among these dimensions, authors examined the causal structure of argumentations in terms of domain specific principles, in this case, natural selection for evolution of Galapagos Finches. It was found that pre-service science teachers' knowledge about natural selection was limited. In particular, although data regarding age, sex and mortality was provided in software program, teachers had difficulty in using the concept of differential survival and variation to articulate their arguments. In addition, teachers tended to explain the evolutionary process at individual level rather than population level. Besides, they also utilized teleological reasoning and Lamarckian conceptions in their arguments. In another study, Sandoval (2003) developed a rubric in order to examine students' conceptual and epistemic quality. As for conceptual quality, authors developed a framework including four causal elements of natural selection: environmental pressure; individual effect; differential trait and selective advantage. Based on the framework, good explanation includes articulation of four causal components and a good argument consists of articulation of four causal components warranted by appropriate data. Author found that students applied components of theory of natural selection to their arguments. Author explained phenomena through generating claims regarding variation, differential traits and selective advantage of these traits. Sandoval (2003) argued that explicit guide prompts embedded in software program enabled students to focus on the components of natural selection. However, author did not mention about students' misconceptions or cognitive biases. In another study, Yalçınoğlu (2007) examined teachers' argumentation based on Toulmin's framework within context of evolution. Author used two scenarios regarding microevolution and macroevolution. Although the analysis of teachers' conceptions was not the scope of this study, conceptions used to articulate their arguments were emerged throughout the study. Teachers mostly applied evolutionary explanations for their arguments. In particular, author reported that teachers most frequently used theory of evolution as backing. Justifications included genetic mutation, environmental pressure, variation and natural selection. As discussed earlier, Tavares et al. (2010) adapted Kelly and Takao's (2002) framework to evolution context in order to examine how 12th grade students articulate conceptual knowledge and argumentation practices in evidence claims. Authors utilized three scenarios regarding theory of evolution, namely feathered dinosaurs (exaptation), gaps in the fossil record (Cambrian explosion) and Lake Nabugabo cichlids (speciation through geographic isolation). Authors sorted students' explanations into three types of justifications, namely empirical evidence, theoretical notions illustrated with empirical evidence and theoretical backings. According to findings, students mostly appealed to evolutionary notions of common ancestry, speciation, mutation, adaptation, chance and pre-existing variation. The analysis of students' non-normative ideas was not the purpose of this study. However, authors also reported common misconceptions used by students. A few provided proximate cause explanations on the basis of individual-level events and of present developmental characteristics due to immediate causes. It is also notable that students did not use any teleological explanations based on the final causes or purposes. In fact, they rejected the intentional and teleological explanations. Besides, it was found that conceptual knowledge about evolution was critical for constructing a good argument and supporting claims with evidences at different levels of epistemic levels.

Many science education researchers emphasized the articulation of conceptual knowledge with argumentation practices. Tavares et al. (2010) stressed that arguments should consist of the articulation of conceptual knowledge with argumentation practices as claims coordinated with evidence. Jiménez-Aleixandre and Bravo (2009) also stated that conceptual knowledge is required to use relevant evidence and generate argument and use of evidence is also required to coordinate it with theory. Authors also recommended that argumentation studies should investigate how conceptual knowledge and the use of evidence articulate in arguments. From this perspective, one of the purposes of the present study was to analyze the articulation of science teachers' conceptual knowledge and argumentation practices in evidenced claims based on four scenarios regarding evolutionary theory. For the present study, evolutionary theory was chosen as a theme since this theory provides diverse epistemic and argumentation practices. In particular, as Mayr (1988) underlined that from epistemological perspective, evolutionary theory differs from other scientific fields in that this theory is heavily based on construction of historical explanations and causal explanations for how or why things occur through observations rather than empirical data. Therefore, it was expected that science teachers applied diverse theoretical, historical and causal explanations regarding evolutionary theory to articulate in their arguments.

2.4. Summary of Review of Literature

Past studies related to argumentation in science education illustrated that structural aspects of argumentation practices provided individual's line of reasoning. However, there have been several studies on additional aspects of argument generation such as epistemic and structural aspects. That these aspects were closely linked together has been established several studies (e.g. Bravo & Jiménez-Aleixandre, 2009; Sampson & Clark, 2011; Sandoval, 2003). Sampson and Clark (2008) voiced, there is need to analyze integration of these aspects of argumentation. Besides, among research on argumentation, there are few studies focusing on teachers' argumentation practices although teachers' argumentation skills are considered important determinants for development of those of students (e.g., Erduran et al., 2004 & McNeill & Krajcik, 2008).

In addition, there has been scant attention to teachers' conceptual understanding regarding evolutionary theory especially in Turkey although past research revealed that misconceptions were prevalent among teachers (e.g., Nehm & Schonfeld, 2007; Taskın, 2011). Along with misconceptions, students' cognitive biases regarding evolutionary theory have gain attention among scholars since several studies found that cognitive biases such as teleology, essentialist and internationalist biases affected students' biological reasoning which in turn, caused misunderstandings about evolutionary change (e.g., Opfer et al., 2012; Sinatra et al., 2008).

CHAPTER 3

METHOD

In this chapter, research design and procedures are discussed. Qualitative case study approach guides the methodological framework of the current study. The overall design of the study, participants of the study, procedure of data collection and data analysis, trustworthiness of the qualitative study, and assumptions and limitations are all presented in detail.

3.1. The Research Design of the Study

In the present study, structural, epistemic and conceptual aspects of science teachers' argumentation practices in the context of evolutionary theory as well as how they use conceptual knowledge to articulate their arguments at different epistemic levels were investigated. In line with this aim, the present study was designed based on the qualitative research methodology.

3.1.1. Qualitative Research Methodology

Qualitative method, as described by Van Maanen (1979) (as cited in Merriam, 2009, p. 13) is "an umbrella term covering an array of interpretive techniques which seek to describe, decode, translate, and otherwise come to terms with the meaning, not the frequency, of certain more or less naturally occurring phenomena in the social world." The main focus of the current study is on the interpreting and describing participants' practices and coming to understand what meaning they attribute to their experiences. In particular, analysis of data provided qualitative indication of the nature of science teachers' argumentation practices and conceptual understandings as well.

Several characteristics of qualitative research pertinent to the current study have been described by Creswell (2007):

i. Focus on meaning and understanding: The main interest of the present study was the science teachers' meanings about argumentation, epistemic and evolution by utilizing their self-generated data sets.
ii. Researcher as primary instrument: For the present study researcher gathered data by interviewing with science teachers and analyzed data by examining transcribed documents.
iii. Multiple sources of data: In the present study, researcher collected two forms of data, namely interview transcripts and field notes.
iv. Interpretive inquiry: researcher made interpretations about interactions among data sets.
v. Theoretical lens: In the present study, argumentation and evolution theory was used to understand how science teachers articulate their conceptual knowledge and argumentation practices.
vi. Holistic account: Researcher tried to sketch larger picture of nature of science teachers' argumentation practices and conceptual understandings through analysis of each case independently and cross-case analysis in the context of evolutionary theory.

Merriam (2009) proposed five types of qualitative research, namely basic qualitative research, ethnography, phenomenology, grounded theory and case study. In the present study, case study design was employed in order to gain a deep understanding of the science teachers' argumentation practices and conceptual understanding and meaning for those involved.

3.1.2. Case Study

Case study research is different from other qualitative research types in that the main focus of case study is on in-depth analysis through one or more cases within a bounded system (Creswell, 2007).

Stake (1995) defined case or bounded system as "a specific, a complex, functioning thing" (p. 2) and a case could be a teacher, a group of teacher, an institution and a program/ an innovation. Merriam (2009) stated that one particular program or one particular people in a bounded context could be unit of analysis. In the present study, the cases are science teachers who worked in two different private schools and two distinct public schools in Ankara and each science teacher was considered as a primary unit of analysis because data was gathered from each science teacher and then, the findings were compared among them.

Yin (2003) described the case study as “an empirical inquiry that investigates contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident.” (p. 13). In line with this statement, the case study guided the present study because evolutionary scenarios in this study were considered as a context in which science teachers experienced argumentation practices. Besides, evolutionary scenarios, science teachers and their practices were taken as a whole.

Merriam (2009) identified three characteristics of case study research; particularistic, descriptive and heuristic. Firstly, particularistic means that phenomena studied by focusing on specific instances (cases). In this study, each case was investigated in-depth so as to understand experiences of participants within the context. Secondly, descriptive means that case study provides rich description of the phenomena studied. In the present study, researcher described the each case, themes of the cases and compared themes of cases in their totality and thus, drew holistic picture of them. Lastly, heuristic means that case study research enables readers to rethink about the particular phenomena through emerging relationships and meanings. In the present study, researcher tried to reflect emerging interaction between patterns and interpretation of them.

Stake (1995) proposed three types of case study research; intrinsic, instrumental and collective study, also known as multiple case study. This study was designed based on the multiple cases research. Multiple case study was used to examine more than one case. Besides, multiple case study is a technique for increasing trustworthiness rather than single case study (Merriam, 2009). Multiple case study can be selected for the purpose of either predicting similar findings (a literal replication) or contrasting findings (a theoretical replication) through handling different cases. In the present study, each case has common and distinct characteristics such as their background which will be explained in detail in the participant section. Yin (2003) stated that cross-case analysis is the most important part of the multiple case studies. Hence, the present study was guided by multiple case design in which each case was analyzed separately and then, cross-case analysis was employed.

Case studies are also distinguished based on the purpose; exploratory, descriptive and explanatory studies (Yin, 2003). Among these studies, the purpose of descriptive case study is to describe the phenomena according to pre-established theories and the focus of this study is on describing science teachers' argumentation practices and conceptual understandings through utilizing already existing argumentation and evolution theory. Hence, this study is the example of descriptive multiple case study.

3.2. Selection of Cases

In qualitative research, sampling method is purposive in nature (Merriam, 2009) since the purpose of the qualitative research is to provide in-depth understanding rather than to make generalizations. In this respect, Patton (1990) proposed several techniques for purposefully selecting information-rich cases. Of these strategies, convenience, criterion and maximum variation strategies were used based on the purpose of the research. Convenience sampling was utilized in the present study since the researcher could select the available sample (Fraenkel & Wallen, 2006). When ease to access and time issues was taken into consideration, the participants of this study selected graduated from the same university where the researcher studies at. Hence, science teachers were examined according to their availability for data collection procedure. They were also selected for their willingness and well communication with the researcher.

Criterion sampling was described as selecting cases that fulfill the criteria. Merriam also emphasized that the selection of case should be guided by some criteria established first. Stake (1995) stressed that the first criterion for selection of cases is choosing information-rich case in order to provide insight and in-depth understanding.

In parallel with this approach, for the present study, the participants were selected purposefully as specific cases by the researcher. First of all, to understand the meaning of phenomena from their perspectives, science teachers who took evolution course during undergraduate program were selected. Since context was related to evolutionary theory, it was essential to have some basic understanding of evolution concepts. Second, researcher talked with teachers about their demographic and background knowledge. After explaining the purpose of the study and data collection procedure, participants were asked how much they contribute to this study. Based on the responses, the researcher determined four teachers who were able to provide rich description of their thinking process.

Before conducting a multiple case study, each case should be selected purposefully to acquire either similar or contrasting results (Yin, 2003). In line with this purpose, maximum variation sampling was employed. Therefore, another reason behind the selecting cases (teachers) who differ in teaching experiences and achievement in evolution course was to provide variation. In particular, two of them had teaching experience on evolutionary theory and the rest of them did not. Besides, two of them had high achievement in evolution course in undergraduate program and the other had low achievement. These differences among cases might lead to variation in conceptual understandings and in turn, their practices that could enable researcher to investigate common and distinctive patterns or themes through employing cross-case analysis. In this sense, each case was analyzed both separately and as a whole.

When it comes to the issue of sample size, Creswell (2007) declared that the purpose of the multiple case studies is not to make generalizability, so there is no rule for number of cases. However, it is important that researcher studied a small number of cases in order to investigate phenomena or people in-depth. Besides, Creswell (2007) recommended selecting 3 to 5 cases for multiple case studies. Therefore, four cases were selected purposefully for the current study and each case was covered in detail in the following part.

3.3. Participants

The science teachers were taken as case for this study. Participants in the present study were four science teachers of grade 5 to 8 (Table 3.1). Even though quotes presented in the result section are verbatim, teachers were referred throughout this study with pseudonym names in order to ensure confidentiality. The participants' pseudonym names are Burcu, Leyla, Selin and Beste. All participants interviewed were female. Their ages ranged between 26 and 27. All of them graduated from Department of Elementary Science Education, Middle East Technical University (METU). They all took took biology courses; general biology I and II, physiology and evolution courses and science methods courses including instructional planning and principles and methods of teaching science courses in which argumentation was introduced. All worked in either public or private schools as an elementary science teachers. Their achievements in *Evolution* course and teaching experiences were different from each other in that Leyla and Burcu did not have any experience on teaching of evolutionary theory and their achievements of evolution course were relatively low. On the other hand, Selin and Beste had experiences on teaching of evolutionary theory and their achievements of evolution course were relatively high.

Participants were not instructed about the argumentation and evolutionary theory prior to the study, so the purpose of this study was to examine phenomena without intervention. On the other hand, several question prompts were utilized in order to implicitly facilitate argument generation process although there was no explicit training on argumentation pattern.

Table 3.1 Demographic characteristics of participant teachers

Participants	School Types	Teaching Experiences	Graduation Level & Department
Burcu	Public	2 years	METU B.S. Elementary Science Education MS Human Resources Development in Education
Leyla	Private	1 year	METU B.S. Elementary Science Education Hacettepe University M.S. Elementary Science Education
Selin	Private	4 years	METU B.S. Elementary Science Education M.S. Elementary Science and Mathematics Education
Beste	Public	2 years	METU B.S. Elementary Science Education M.S. Elementary Science and Mathematics Education

**All names are pseudonyms*

3.4. Data Collection Procedure

Data collection procedures include process of the development of data sources, pilot study and interview with science teachers. The time schedule for the present study is shown in Table 3.2.

Table 3.2 Time schedule for the present study

Stage of Thesis Writing Process	Start Date	End Date
Pilot Study and Analyses	April, 2013	June, 2013
Interviews	November, 2013	January, 2014
Data Analysis	February, 2014	April, 2014
Writing and Completing Thesis	May, 2014	September, 2014

Before conducting the current study, evolutionary scenarios were modified and translated into Turkish by the researcher. The contents of the scenarios were confirmed by three experts in department of Biology in METU and the framework of them was examined by two experts in department of Elementary Science Education in METU. Prior to collecting data, pilot study of scenarios was also carried out with 5 pre-service elementary science teachers who were in the senior year, 3 elementary science teachers and 3 biology students who were in the senior year in order to examine whether scenarios and interview questions were appropriate for the current study or not. Then, several interview questions were reviewed and other questions were developed based on the results of pilot study. *Among six* evolutionary scenarios, *Feathered Dinosaurs and Antibiotics* were removed from the study. The reason behind of this was that scenarios were not appropriate and useful for the argumentation practices, that is, they did not lead to discussion. After that official permission from the Ministry of National Education and Ethical Commission in Middle East Technical University was taken in order to conduct research with human subjects. The data collection procedure of the current study began in October. The main data for this study was collected by means of cognitive appraisal interview. Interviews with four science teachers were conducted in one-on-one settings and are audio-recorded. While collecting data, firstly, brief information about topic, purpose, process and duration of the study was given. All interviews operated in private office to last between 45 minutes and 1 hour and audio-recorded.

3.5. Data Collection Instruments

In the present study, data were collected through interview protocols regarding four evolutionary scenarios; namely, *Venezuelan Guppies* (Sampson & Blanchard, 2012), *Whales* (Yalcinoglu, 2007), *Lactose Intolerance*, and *Cambrian Explosion* (Tavares et al., 2010). In the following parts, their contents and process of development were described.

3.5.1. Evolutionary Scenarios

Firstly, relevant literature was reviewed in order to find out evolutionary scenarios and then, these were analyzed according to the purpose of the study. After evolutionary scenarios were decided to use for the present study, three scenarios (*Venezuelan Guppies, Whales and Cambrian Explosion)* were modified and translated into Turkish, and one scenario (*Lactose Intolerance*) was developed by the researcher (Appendix A). Scenarios were designed based on problem solving approach. Each scenario includes short paragraph of information about particular evolutionary phenomena. The paragraphs are followed by a question asking participants to solve the problem based on the information embedded in the paragraph and data set. Each also includes two or three alternative explanations. Different strategies were used to form alternative explanations in order to analyze how science teachers' criteria for assessing alternatives vary within different contexts.

Scenario I: Venezuelan Guppies

Venezuelan Guppies scenario deals with sexual selection/predator avoidance (microevolution): It was modified from Sampson and Blanchard's (2012) study. In this scenario, there are three alternatives crafted purposefully so that the first alternative explanation would provide an accurate and insufficient answer; the second one would provide an accurate (evolutionary theory) and sufficient answer; and third one would provide a sufficient but inaccurate answer which has commonly used misconceptions such as Lamarck's theory of evolution. Science teachers' were required to evaluate these alternatives to explain the reason of the observed variation in the coloration within male guppies.

Scenario II: Whales

This scenario is about macroevolution in whales, modified from Yalcinoglu's (2007) study. There are three alternatives crafted purposefully so that one would provide an accurate (evolutionary theory) and sufficient answer; two would provide inaccurate explanations: first one consists of commonly used misconception, in particular Lamarck's theory of evolution and the other one included cognitive bias regarding evolution driven by need and purposes. Science teachers were asked to assess these alternatives to explain the possible relationships among an extinct land mammal, an aquatic whale ancestor and modern whales.

Scenario III: Lactose Intolerance

This scenario deals with gene-culture coevolution in humans (microevolution), developed by the researcher of the present study. Burger, Kirchner, Bramanti, Haak, and Thomas's (2007) and Tishkoff et al.'s (2009) findings were used to developed this scenario. There are three alternatives crafted purposefully so that the first alternative explanation would provide an accurate (evolutionary theory) and sufficient answer; the second one would provide hypothesis regarding existence of lactose tolerance allele in humans, however, this theory collapsed after analyzing lactose tolerance allele of early Europeans. The third one would provide a sufficient but inaccurate answer which has commonly used misconceptions such as Lamarck's theory of evolution Therefore, science teachers were required to evaluate three alternatives to answer the question how lactose tolerance developed in humans.

Scenario IV: Cambrian Explosion

This scenario deals with debate about transition forms, modified from Tavares et al.'s (2010) study. There are two alternative explanations which have been subjected to debate among evolutionists; one alternative is related to gradualism and the other is related to punctuated equilibrium theory. Science teachers were required to discuss two alternative explanations to explain gaps in the fossil records.

3.5.2. Interview Protocol

The purpose of the development of interview protocol on the basis of evolution scenarios was to investigate science teachers' structural, epistemic and conceptual aspects of argumentation practices.

The cognitive appraisal interview (CAI, Silverman, 2010) was used to examine how science teachers engage in argumentation practices and how they articulate conceptual knowledge and argumentation practices. CAI enables participants an opportunity to reflect on and provide rationale what he or she just did. From this perspective, CAI provides more useful information about how participants think than a test or a survey (Henderson, Podd, Smith, and Varela-Alvarez, 1995). Sampson and Blanchard (2012) argued that CAI encourages participants to provide an appraisal of their rationale after they complete the task. Interview was conducted with four science teachers. Before conducting interview, it was pilot tested 5 pre-service elementary science teachers, 3 elementary science teachers and 3 biology students to ensure that questions posed were appropriate to collect meaningful data and answer the research questions. Interview questions were presented in Appendix B.

For this study, interview was designed in three distinct stages. Details were shown in Table 3.3.

***First Stage*:** The focus of first stage was to examine how science teachers evaluate the alternative explanations. In this stage, science teachers were provided time to complete the tasks. After science teachers finished reading the scenario, they were asked to decide which explanation was the most acceptable and then, asked to explain the reason behind their choice.

***Second Stage*:** The intent of this stage was to examine how science teachers craft or construct argument. In this stage, science teachers were asked to generate an argument. The available literature suggested that the use of argument prompts encourage participants to craft well-reasoned arguments (McNeil, Lizotte, Krajcik, & Marx, 2006; Osborne et al., 2004). From this perspective, in order to facilitate the process of constructing an argument, question prompts were used during the interview. Therefore, science teachers were asked to support their arguments with appropriate evidence and reasons, explain why the other alternative explanations are not sufficient to support their argument and create an argument for persuading other people who have different opinions, respectively.

Third Stage: after constructing their arguments, science teachers were also asked to explain what makes scientific arguments more persuasive than others and asked to explain what evolutionary theory is and why it is valid.

Table 3.3 The stages of the cognitive appraisal interview (CAI)

Stage	Purpose	Description of the Task
I	Identify the criteria used by science teachers for assessing alternatives	Science teachers were provided with evolutionary scenarios including evolution phenomena, a focus question and two or three alternative explanations and data Science teachers were required to determine which explanation is the most acceptable and then, generate reasons for their choice
II	Determine argumentation practices	Science teachers were asked to construct an argument for explanation they chose Science teachers were provided with question prompts to guide the process of argumentation: (1) what is your reasons and data to support your argument; (2) Why the other alternatives is insufficient (3) Create an argument to persuade others who have different opinions
III	Identify science teachers' thoughts about the contents of argument and perspectives of evolutionary theory	Science teachers were asked to reflect on their thoughts about what makes an argument more persuasive Science teachers were asked to reflect on their thoughts about what evolutionary theory is and why it is valid

3.5.3. Field Notes

Yin (2003) stated that taking notes during data collection is useful to detail data set. Researcher kept informal conversation about study during interview sessions. For example, some of them gave examples and some of them declared that they forget mentioning the some key concepts of evolution during off the record conversations. These notes were used as supplement to the main data set.

3.6. Data Analysis Procedure

Qualitative data analysis is the process of making meaning of data (Merriam, 2009). Analyzing data consists of transcription of all data, reading through data set in order to make sense of them, reducing data through the process of coding in order to establish themes or patterns as well as explaining and interpreting each through presenting examples from data set, tables and figures. For multiple case studies, two stages of analysis are conducted; within-case analysis and cross-case analysis (Creswell, 2007). Within-case analysis involves analyzing each case separately and four cases were then compared to each other through cross-case analysis in order to build general explanations (Merriam, 2009).

The transcriptions of the interview comprised the main data source for the current study. Firstly, audio-recorded interview data were transcribed in verbatim. Transcriptions were read to get general meaning of them. After reading, codes and themes were emerged and categorized based on pre-established frameworks. In order to provide reliability, transcriptions were read for several times and also data were analyzed by two experts.

Five analyses were performed relating to: science teachers' (1) criteria to evaluating alternative explanations; (2) conceptual aspects of argumentation practices; (3) structural aspects of argumentation practices; (4) epistemic aspects of argumentation practices; and (5) how science teachers used conceptual knowledge regarding evolutionary theory to articulate their arguments at different epistemic levels. Science teachers' practices were analyzed through using constant comparative method developed by Glaser and Strauss (1967).

Science teachers' conceptual understanding with regard to evolution was analyzed by the Nehm et al.'s (2010) rubric and Abraham et al.'s (1992) schema. Science teachers' structural, epistemic and conceptual aspects of argumentation were analyzed based on pre-established frameworks: Erduran et al.'s (2004), Tavares et al.'s (2010) and Nehm et al.'s (2010) analytical frameworks. Besides, criteria that science teachers used when evaluating alternatives were analyzed and categorized based on the content and themes in responses to interview questions. The descriptive statistics were also used in this study in order to describe the frequency counts of argumentation and epistemic levels, and how conceptual, argumentation and epistemic levels, and criteria for assessing alternatives vary by four different evolution scenarios.

Sampson et al.'s (2011) Rubric The criteria that science teachers utilized in order to distinguish between alternative explanations were analyzed based on two criteria namely, rigorous and informal criteria identified by Sampson et al. (2011). Rigorous criteria consist of reasons that are used by scientists to examine what count as scientific knowledge. These criteria include fit with data, sufficiency of data, coherence of an explanation, adequacy of an explanation and consistency with scientific theories or laws. Informal criteria deal mostly with everyday explanations that are insufficient to justify or challenge ideas. These criteria consist of appeals to analogies, plausibility, judgments about the importance of an idea and consistency with personal inferences.

Nehm et al.'s (2010) Rubric and Abraham et al.'s (1992) Schema Science teachers' conceptual aspects of argumentation practices were analyzed by using Nehm et al.'s (2010) rubric (see in Appendix C) and Abraham et al.'s (1992) schema. Nehm et al. (2010, p. 15-35) proposed a detailed concept evaluation rubric. In this rubric, seven key concepts, misconceptions and cognitive biases that were commonly held by students listed below:

Key concepts:
(1) The presence and/or causes of variation among individuals;
(2) The heritability of variation
(3) Competition
(4) The overproduction of offspring
(5) Resource limitation
(6) Differential survival of individuals
(7) Generational changes in the distribution or frequency of variation

Misconceptions:
(1) Pressure - a compelling force causing changes of an organism
(2) Adapt - one adjusts or acclimates oneself to new or changed circumstances
(3) Need - an organism needs to change in order to survive
(4) Must - an organism must change in order to survive
(5) Use and disuse - an organism acquires or loses a certain trait depending on how often a trait is used
(6) Energy - energy should be allocated in a trait that is helpful for survival

Cognitive Biases:

(1) Essentialism - tendency to consider that evolution consists of simultaneous changes in all members of species
(2) Intentionality - tendency to believe that events are directed by a mental agent
(3) Teleology - tendency believe that evolutionary changes are driven by purposeful change and need

Based on this rubric, science teachers' conceptions were categorized as key concept, misconception and cognitive bias. After categorizing participants' conceptions, their understanding levels were determined by Abraham et al.'s framework. Abraham et al. developed a concept-evaluation framework in order to evaluate understanding level. According to this framework, responses are classified into levels from 1 to 6 (see Table 3.4). This classification was made based on whether there are misconceptions, key concepts or cognitive biases in arguments.

Table 3.4 Scoring scheme for teachers' understandings on the open-ended evaluation on evolutionary theory

Degree of understanding	**Criteria for scoring**
No Response	Response left blank. Response that states or indicates, "I don't know" or "I do not understand"
No understanding	Response that repeats the question. Irrelevant or unclear responses
Specific misunderstanding or alternative conception	Response that includes illogical or incorrect information
Partial understanding with specific misunderstanding or alternative conception	Response that shows understanding of the concept but also makes statements that demonstrate a misunderstanding
Partial understanding	Response that includes at least one of the components of the validated response, but not all the components
Sound understanding	Response that includes all components of the validated response

Note. Adapted from "Understandings and misunderstandings of eighth graders of five chemistry concepts found in textbooks" by M.R. Abraham, E.B. Grzybowski, J. W. Renner, and E. A. Marek, 1992, Journal of Research in Science Teaching, 29, 106.

Erduran et al.'s (2004) Framework Science teachers' structural aspects of argumentation practices were analyzed in terms of levels of argumentation through utilizing Erduran et al.'s (2004) framework shown in Table 3.5. Erduran et al. developed a framework to minimize the methodological difficulties with distinguishing Toulmin's core elements of argumentation such as claims, warrants and rebuttals. Put more specifically, Erduran et al. made two distinctions: (1) whether an argument includes reason (i.e. data, warrant or backing) to support claim and (2) whether an argument includes rebuttal. Rebuttal was defined as the central component of argumentation practices since without any rebuttal, arguments might be less persuasive. That is, arguments consisting of only justifications of his/her own claim remain unchallenged that not enable to change the ideas or views. In this respect, Erduran et al. proposed a five level argumentation analysis framework. Additionally, Erduran et al. distinguished the weak and strong rebuttal according to whether rebuttal is justified by evidence or not.

Table 3.5 Analytical framework used for assessing the quality of argumentation practices

Level 1	Level 1 argumentation consists of arguments that are a simple claim vs. a counter-claim or a claim vs. claim
Level 2	Level 2 argumentation has arguments consisting of claims with either data, warrants or backings but do not contain any rebuttals
Level 3	Level 3 argumentation has arguments with a series of claims or Counter-claims with either data, warrants or backings with the occasional weak rebuttal
Level 4	Level 4 argumentation shows arguments with a claim with a clearly identifiable rebuttal. Such an argument may have several claims and counter-claims as well but this is not necessary
Level 5	Level 5 argumentation displays an extended argument with more than one rebuttal.

Note: Adapted from "Tapping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse", by S. Erduran, S. Simon, and J. Osborne, 2004, *Science Education, 88*, 915-933, p. 928.

Tavares et al.'s (2010) Framework Science teachers' epistemic aspects of argumentation practices were assessed by analysis of epistemic status in terms of relative epistemic levels based on the Tavares et al.'s (2010) framework. Researchers adapted Kelly and Takao's (2002) framework into biological evolution context to examine how evolution knowledge articulate argumentation practices at different epistemic status. This model consists of five epistemic levels from more specific claims to more general, theoretical claims regarding evolutionary theory seen in Table 3.6. As Kelly and Takao (2002) pointed out, sophisticated argument consists of evidences at variety of epistemic levels. Therefore, ordinal progression does not provide judgments for evidence quality. Instead, epistemic aspects of argumentation in terms of quality were analyzed based on two criteria, namely, integration of claims across the levels and the ratio of data statements to theory statements. Hence, for this study, science teachers' relative epistemic statuses were assessed within the evolution context.

Tavares et al.'s (2010) Coding Schema The articulation of conceptual knowledge regarding evolutionary theory and argumentation practices at different epistemic levels was analyzed by Tavares et al.'s (2010) coding schema to deepen understanding of argumentation practices. Schema represented the integration argumentation patterns with evidenced claims. (a) claims: stating a claim (drawn from the problem); transforming one of the alternative claims; offering a new claim; (b) data: appealing to data provided in the problem; appealing to data recalled from previous knowledge; (c) justifications (or warrants): supporting a claim in theoretical justifications; supporting a claim in theoretical justifications illustrated with data; (d) rebuttals: challenging the evidence of the opposing claim; (e) modal qualifiers: qualifying a claim through the use of model qualifiers. However, model qualifiers were not analyzed in the present study since Erduran et al.'s (2004) framework did not include model qualifiers.

Table 3.6 Categories of evidenced claims by levels of abstraction about evolutionary theory

Epistemic Levels Definitions		Examples from science teachers
Level 5	General theoretical propositions describing evolutionary processes, not specific to the issue discussed	**Selin:** It was mentioned genetic drift; Darwin's evidences that support evolution, it (genetic drift) leads to variation because it (variation) occurred completely randomly.
Level 4	Propositions in the form of theoretical claims specific to the evolutionary issue discussed	**Selin:** Here, species which have small and weak legs suit to their environment because they are common as a consequence of natural selection.
Level 3	Propositions in the form of theoretical claims or processes illustrated with data specific to the issue discussed	**Leyla:** When the number of predators decreases, the number of bright males increases since threat is gone.
Level 2	Propositions using empirical data recalled from experience or previous knowledge	**Beste:** like rat experiment, I don't think that habits of drinking milk are directly related to genes.
Level 1	Propositions making explicit reference to empirical data from the tasks	**Burcu:** There is a map related to Europeans in 8000-9000 years ago and data from Africans, that is, dairy farming has been done since at that time and people have been exposed to consumption of milk.

Note: Adapted from "Articulation of conceptual knowledge and argumentation practices by high school students in evolution problems" by M. L. Tavares, M. P. Jiménez-Aleixandre, and E. F. Mortimer, 2010, *Science Education*, *19*, 573–598, p. 583.

3.7. Trustworthiness of the Study

Validity and reliability issues are considered from different perspectives for quantitative and qualitative research because of distinctive characteristics of qualitative research. Therefore, the term of trustworthiness is used for the qualitative research as a substitute for validity and reliability. Lincoln and Guba (1985) identified four strategies in order to prove the trustworthiness of the qualitative study; credibility, transferability, dependability and conformability as counterparts of internal validity, external validity, reliability and objectivity, respectively.

3.7.1. Credibility (Internal Validity)

Credibility refers to the congruence of the research results with reality (Merriam, 2009). Creswell and Miller (2000) (as cited in Creswell 2007) proposed eight validation strategies for qualitative studies; triangulation, peer review, a prolonged engagement and persistent observation , negative case analysis, clarifying researcher bias from the outset of the study, member checking, rich, thick description, and external audits, and it is suggested that at least two strategies be considered to provide credibility. The following four of them were presented in this part: (1) triangulation; (2) member checking; (3) rich, thick description and (4) clarifying researcher bias.

3.7.1.1. Triangulation

Four types of triangulation were proposed, namely multiple methods, multiple sources of data, multiple investigators and multiple theories (Merriam, 2009). For the present study, multiple investigators method was used. Two persons, researcher of the present study and colleague analyzed same data set and compared their results independently. Besides, interviews were triangulated with field notes in the present study.

3.7.1.2. Member Checking

Member checking strategy refers to discussion with participants provided data about the findings and interpretation (Merriam, 2009). In the present study, after completion of analyzing data, each participant's views and feedbacks about the interpretations, categories and results generated by the researcher were received in order to assess the accuracy of findings.

3.7.1.3 Rich, Thick Description

Creswell (2007) suggested that researcher should provide rich and thick description for the participants, context and findings in order to enable readers to transfer findings to their own settings. In the current study, researcher provided detailed information about inquiry process, settings and participants for transferability issue.

3.7.1.4 Clarifying Researcher Bias

Researcher bias is a critical issue for validity since the researcher is the key instrument in qualitative studies. Researcher's expectations and values might affect the selection of relevant data from interview and this leads to misinterpretations and misunderstandings. In order to overcome this issue, interview transcripts were also analyzed by colleague independently. Besides, as a researcher, I searched articles and dissertations about argumentation and evolution theory in order to improve my knowledge about them. In addition, as a researcher of this study, I also took evolution and argumentation courses during undergraduate and master's program. However, question prompts used during interview and my attitude towards participants might influence their efforts.

3.7.2 Dependability (Reliability)

The reliability of qualitative study refers to the stability of the findings of the study confirmed by multiple coders (Creswell, 2007). Besides, validity can be used as a criterion for assessing reliability of the study (Fraenkel & Wallen, 2006). There are several strategies to provide reliability (Creswell, 2007). One of them is the inter-rater agreement.

After coding and analyzing data, argumentation and epistemic levels were analyzed by two researchers who have experience on argumentation and qualitative research. Besides, conceptual understanding regarding evolution theory was analyzed by a researcher who has experience on evolution. After independently analyzing data, the formula proposed by Miles and Huberman (1994) was used to calculate inter-rater reliability;

$$\text{Reliability} = \frac{\text{Number of agreements}}{\text{Total number of agreements} + \text{disgreements}}$$

The inter-rater reliability was established as 80% for argumentation levels, 85% for epistemic levels and 90% for evolution conceptions.

3.8. Researcher Role

Merriam (2009) described researcher role as a key instrument for data collection and analyses in qualitative research. Therefore, there should include information about researcher. I, as a researcher, am a Master's student in Elementary Science and Mathematics Education at Middle East Technical University (METU). I received my undergraduate degree from the Elementary Science Education at the same university. Throughout the study, I was the designer and interviewer. Before conducting study, three different evolutionary scenarios were adapted and one scenario was developed by the researcher. I conducted Interviews with four science teachers. The participants were expected to analyze each scenario on their own but if needed, I clarified some parts in scenarios. In addition, data obtained through interview were analyzed by the researcher. I did not direct the participants and I also took field notes including informal conversations during interview sessions.

3.9. Ethics

Regarding ethics, several issues were taken into consideration in the present study. Researcher got the permission from ethics committee so as to conduct this study. Before beginning the study, teachers were informed the purposes, content and procedure of this study. At the every stage of the data, the researcher was honest with the participants and thus, deception was not used in this study. In addition, participants' identity and privacy were kept confidential and pseudonyms were used for all participants while presenting the results. It is also stated that this was a voluntary participating study, that is, any one of them refusing or unwilling to participate into the study could withdraw from participating at any time. Besides, the present study did not include any danger or harm.

3.10. Assumptions of the Study

The study was based on the following assumptions:

- The data collection instruments developed and adapted for the present study was qualified enough to serve the purpose of this study.
- Teachers were information rich cases.
- The sample of this study was selected through purposeful sampling since they were familiar with the biological evolution concepts. Hence, it was assumed that they were good representatives regarding understanding and evaluating evolution scenarios.
- The characteristics of sample in pilot study and sample in actual study was similar.
- The interviews with teachers were conducted in standard conditions.

3.11. Limitations of the Study

The limitations of the present study are followings:

- The analysis was limited to one type of data source; interview protocol regarding evolution concept. There could include lesson plans regarding evolution and observation sessions conducted for argumentation practices.
- This study was limited to context and design of the study. In this study, four evolutionary scenarios were used to examine science teachers' structural, epistemic and conceptual aspects of argumentation practices.

CHAPTER 4

FINDINGS

This study was a qualitative multiple case study investigating conceptual, structural and epistemic aspects of science teachers' argumentation practices as well as the articulation of conceptual knowledge and argumentation practices in the context of evolutionary theory. In this sense, four case studies were conducted. The data were gathered from each case (teacher) through individual interviews. In this chapter, the findings obtained from each case in terms of their criteria for evaluating validity of explanation, conceptual, structural and epistemic aspects of argumentation as well as the articulation of conceptual knowledge and argumentation practices at different epistemic levels were presented in detail. After that, cross-case analysis was provided in order to uncover similarities and difference among cases. Representative excerpts from the interview transcripts produced by teachers were used to support assertions developed by the researcher.

4.1. Burcu's Case

She was 26 years old and graduated from Department of Elementary Science Education, METU in 2011. She took biology courses including general biology I and II, physiology and evolution courses and also science methods courses including instructional planning and principles and methods of teaching science courses in which argumentation was introduced. She completed *Evolution* course with a grade of CC (2/4). She was also doing her M.S. in Human Resources Development at METU. She was working at public school. She was in the second year of teaching profession when the data collection and she taught to 6^{th} and 7^{th} grades. She did not have any experience on teaching evolutionary theory.

In the following sections, the results of Burcu were presented under the five dimensions including criteria for evaluating validity of explanation, argumentation practices in terms of conceptual, structural and epistemic aspects as well as the articulation of conceptual knowledge regarding evolutionary theory and argumentation practices at different epistemic levels. The results of these analyses were represented for each scenario separately.

4.1.1. Scenario I: Venezuelan Guppies

Venezuelan Guppies scenario deals with natural and sexual selection (microevolution) (see Appendix A). Burcu was provided with this scenario in which she was asked to several questions about the reason of observed variation in the coloration within male guppies. Following subsections described the results on each phase.

4.1.1.1. Criteria for Evaluating Validity of Explanation for *Venezuelan Guppies* Scenario

After reading scenario, Burcu was asked to determine which of three alternative explanations was the most valid to explain the reason of coloration in *Venezuelan Guppies*. The following dialogue took place after she decided:

> Burcu: Explanation 2 and 3 are acceptable. (Explanation 2: Female guppies prefer to mate with brightly colored males. As a result, bright males tend to attract more mates and produce more offspring. When there are lots of predators in a habitat, however, brightly colored males do not survive long enough to reproduce. Explanation 3: The species of guppy try to appear very flashy like many other types of fish. However, when individual migrate into different pools, they need to adjust their coloration in order to avoid predators. As a result, some become drab in order to better fit in with a new habitat. This new trait is then passed down to their offspring because it is useful).
>
> Researcher: Why did you say that?
>
> Burcu: Because when examining the table (given in scenario), while the number of predators increases, the number of bright males decreases. However, we know that bright-colored males, this took place in other species, are primarily preferred by females in nature. On the other hand, being bright

> colored is not good because it is noticeable and this leads to attract predator's attention. Therefore, being bright decreases chance of survival of bright males.

Burcu evaluated the acceptability of alternative explanations of *Venezuelan Guppies* scenario based on both rigorous and informal criterion. She took into consideration of how data fit with claim. Specifically, she generated a counter-claim based on her previous knowledge by referencing data provided in scenario. This is in line with rigorous criterion valued in science. In addition, she seemed to consider the criterion of how well claims, in this case the second and third explanations, fit with her existing understanding of scientific concepts regarding sexual selection and prey/predator relationship. However, even though her previous knowledge corresponded with scientific explanations to some degree, she did not explicitly reference any scientific theory to explain her previous knowledge, so this seemed to be more personal explanation and for that reason, this is in line with informal criterion.

In the following, Burcu was asked to construct argument for *Venezuelan Guppies* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.1.1. Conceptual Aspect of Argumentation Practices for *Venezuelan Guppies* Scenario

For *Venezuelan Guppies*, Burcu chose the second and third explanations for this scenario. While, former one includes evolutionary explanations, latter consists of misconceptions regarding inheritance of acquired traits and cognitive biases with respect to intentionality and teleology. However, she used mostly evolutionary conceptions in her argument for both alternatives. Representative examples for her evolutionary explanations were:

> We know that bright-colored males, this took place in other species, are primarily *preferred* by females in nature. Therefore, being bright colored was considered by females as an indicator of ability to produce more fertile offspring.

> If a trait found in sex cells is favorable, it will be *passed to next generation*.

According to Nehm et al.'s (2010) framework, in the first example, she explained existing of bright-colored males in pools by differential survival, in particular, sexual selection. In the second example, she explained the heritability of genes. This notion is not consistent with the third explanation including inheritance of acquired traits. She might not have understood the third explanation comprehensively.

However, she used intentional reasoning in her arguments: "they (bright males) *learn* to adjust their colors in long periods of time". She seemed to perceive the process of coloration as a phenomena directed by mental agent.

Overall, although Burcu used mostly evolutionary notions concerning differential survival, heritability of genes and resource limitation, in particular prey/predator relationship in her arguments, she had a cognitive bias regarding intentionality and teleology. Hence, her conceptual understanding level was classified as partial understanding with specific misunderstanding (PU/MU) according to Abraham et al.'s (1992) framework.

4.1.1.3. Structural Aspect of Argumentation Practices for Venezuelan Guppies Scenario

She generated eight arguments at level 2 and level 4 so as to support and criticize the alternative explanation.

For the Level 2, she constructed seven arguments for the second and third explanations. One of the example quotations was presented in Table 4.1. In this example, she offered a new claim regarding being bright. In order to support her claim, she used data that is noticeable feature and linked data and claim through constructing prey/predator relationship and she reached conclusion from data regarding prey/predator relationship. However, she did not attempt to provide rebuttal. Therefore, her argument was classified as level 2.

For the Level 4, she generated an argument for the first explanation. Example quotation was illustrated in Table 4.1. In this example, explanation 1 was considered as a claim and she offered a counter-claim. Then, she justified her counter-claim by presenting data and reason. This rebuttal was considered as a strong one since it includes sufficient data and warrant and thus, placed in level 4.

Table 4.1 Burcu's excerpts at argumentation levels in *Venezuelan Guppies* scenario

Argumentation Level	Burcu's excerpts
Level 2	*Being bright colored is not good because it is noticeable and this leads to attract predator's attention. Therefore, being bright decreases chance of survival of bright males.*
Level 4	*The first explanation mentioned that they are created to either be drab or bright. This explanation seems to state that bright males should die and drab males should live, this does not make sense. Because being bright or drab change depends on condition and this trait is acquired not created in that way.*

4.1.1.4. Epistemic Aspect of Argumentation Practices for *Venezuelan Guppies* Scenario

Figure 4.1 illustrates Burcu's propositions across the epistemic levels. In this figure, each sentence was labeled with numbers and sentences served as a propositions. Each of propositions was categorized by epistemic levels and mapped in order to indicate ties across the epistemic levels. Lines connecting propositions represents explicit links between propositions and dashed lines represents the propositions including statements at two epistemic levels.

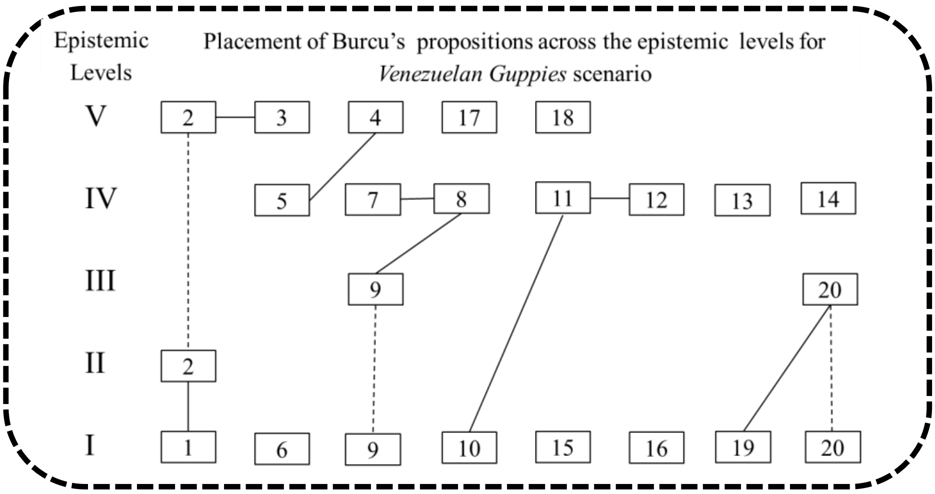

Figure 4.1 Burcu's argumentation structure by epistemic levels for *Venezuelan Guppies* scenario

Based on the five epistemic levels framework, she explicitly referenced provided information and data in eight propositions (1, 6, 9, 10, 15, 16, 19 and 20) placed in epistemic level I. A representative example for propositions 2 and 3 was:

> (2) We know that bright-colored males, this took place in other species such as birds, are primarily preferred by females in nature. (3) Therefore, being bright colored was considered by females as an indicator of ability to produce more fertile offspring.

In this example, for proposition 2, she referenced data from her previous knowledge and linked this data to theoretical knowledge regarding differential survival, in particular sexual selection. Since her proposition included statements at two different epistemic levels, her proposition was classified as epistemic levels II-V. For proposition 3, she utilized theoretical statement in order to clarify sexual sexual selection placed in epistemic level V. She used theoretical claims with identifying provided data in two propositions (9 and 20) classified as epistemic level III. She generated theoretical claim regarding heritability of genes and differential survival in 7 propositions (5, 7, 8, 11, 12, 13, and 14) placed in epistemic level IV. In 4, 17 and 18 propositions, she utilized general theoretical knowledge concerning prey/predator relationships and heritability of genes classified as epistemic level V.

In terms of the criterion of integration of claims across the levels, Burcu proposed evidenced claims at various levels. However, in terms of the criterion of the ratio of data statements to theoretical statements, she used eight data references in proportion to fourteen theoretical claims. In particular, theoretical claims were less frequently supported by data. Hence, although her argument was extensive, the epistemic quality of argument was relatively low.

4.1.1.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels for *Venezuelan Guppies* Scenario

Table 4.2 represented how Burcu justified her claims appealing to evolution conceptions documented in the use of evidenced claims at different epistemic levels for *Venezuelan Guppies* scenario. In the first example, she referenced data regarding key concept of evolution, in particular prey/predator relationship placed in epistemic level I. Then, she constructed new theoretical claim through using intentional reasoning and explained reason regarding prey/predator relation classified as epistemic level IV. Then, she appealed to theoretical statement with respect to the key concept of evolution, in particular, heritability of genes in order to back up her claim classified as epistemic level IV.

In the second example, she explicitly referenced data from the scenario. She utilized a theoretical claim regarding relation with being bright and fertility but she used teleological reasoning classified as epistemic level IV. Then, she constructed theoretical statement regarding sexual selection in order to back up the second explanation placed in epistemic level IV.

Table 4. 2 Articulation of evolution conceptions and argumentation practices for *Venezuelan Guppies* scenario

Burcu's Excerpts	**Argumentation Practices**	**Epistemic Levels**
(10) They (bright males) are hunted by predators in pools including lots of predators. (11) Therefore, they (bright males) learn to adjust their colors in long periods of time because of protection. (12) They become drab in pools where predators are abundant because this trait (being drab) found in sex cells are passed to offspring.	**Claim:** Explanation 3	(Not coded)
	Data: prey/predator relationship	Epistemic Level I
	New claim: learning to adjust colors **Warrant:** protection	Epistemic Level IV
	Backing: heritability of genes	Epistemic Level IV
(6) I observed that females are not bright in any circumstances. (7) Therefore, it is related to males because they (males) become bright colored in order to produce offspring. (8) That is to say, male guppies should be bright; despite of decrease chance of their survival, it is an indicator of ability to produce fertile offspring for females.	**Claim:** Explanation 2	(Not coded)
	Data: females not bright	Epistemic Level I
	New claim: related to males	(Not coded)
	Warrant: relation being bright with fertility	Epistemic Level IV
	Backing: sexual selection	Epistemic Level IV

4.1.2. Scenario II: Whales

Whales scenario deals with transition form (macroevolution) (see Appendix A). Burcu was provided with this scenario in which she was asked to several questions about the possible relationships among an extinct land mammal, an aquatic whale ancestor and modern whales. Following subsections described the results on each phase.

4.1.2.1. Criteria for Evaluating Validity of Explanation for *Whales* Scenario

After reading scenario, Burcu was asked to determine which of three alternative explanations was the most valid to explain the possible relationship among species. The following dialogue took place after she decided:

> Burcu: The third explanation is the most valid but I agree with the some parts of the second explanation. (<u>Explanation 3:</u> Pakicetus were some sort of mammal that can live both in land and in water. For this reason, it can be a transitional form. The ancestors of whales were living in land once and they had legs. As a result of changes of genes in the population, whales were born with small or no legs and when their environment changed, these whales with small or no legs became more advantageous and reproduced more. <u>Explanation 2:</u> Pakicetus is not related to whales. Pakicetus was some sort of wolf and Basilosaurus was a sea mammal. Modern Whales have similar structures to those of extinct species; Basilosaurus and Pakicetus. Basilosaurus had small hind limb but it does not indicate that they were vestigial organs. They might have had different function. Hence, they were totally different species.)
>
> Researcher: Why did you say that?
>
> Burcu: For the third explanation, when I looked at the figures, I observed that forelimbs of Whales and Pakicetus are similar. Flood may have taken placed and environment changed. Therefore, when the environment changed, living thing has to change in order to suite environment or died and became extinct. Hence, Pakicetus could be a transition form that can live in water.
>
> For the second explanation, I agree with the some parts of the second explanation. Pakicetus and Basilosaurus may have had a common ancestor and they could be different species: Basilosaurus may have been sea mammal and Pakicetus may have been transition form. Pakicetus, Basilosaurus and Whales have common structure in skulls. That’s why Pakicetus was a transition form and they come from common ancestor due to similarities. For example, human and chimpanzee come from common ancestor because of their similarities, so

> they (Pakicetus and Basilosaurus) were different species but come from common ancestor. Therefore, the second explanation could be true.

Burcu seemed to evaluate acceptability of alternative explanations of *Whales* scenario based on rigorous criteria. In particular, she evaluated the third explanation through considering how provided data fits with explanation and used existing theoretical knowledge regarding adaptation. For the second alternative, she criticized some parts of it but it was unclear. Then, she generated a new explanation through using a previous theoretical knowledge regarding common ancestry. Therefore, she took into consideration of how claims fit with scientific theories, in particular common ancestry and adaptation.

In the following, Burcu was asked to construct argument for *Whales* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.1.2.2. Conceptual Aspect of Argumentation Practices for *Whales* Scenario

For *Whales*, Burcu chose the second and third explanation. The latter was related to evolutionary theory. Although the former one included denial of evolution, she did not reject evolution. Instead, she constructed a new claim regarding common ancestry for this explanation. In addition, she rejected the inheritance of acquired traits and most frequently used key concepts of evolution to explain whale evolution for her arguments. Representative examples for these concepts were:

> Firstly, genes change and then, these genes are *passed to* sex chromosomes. After these genes become advantage, they are passed to next generation and they (organisms) *produce more offspring* and this process last long time.

In this example, she used the key concepts of evolution, in particular heritability of genes and overproduction of offspring. Besides, she used another key concept of evolution regarding differential survival but she explained this notion through using teleological reasoning as: "when the environment changed, living thing had to change *in order to* suite environment or died and became extinct." She seemed to perceive selection as a goal-driven process. In addition, she held cognitive bias concerning intentionality. A representative example for this bias was:

> Species like Modern Whales, Basilosaurus and Pakicetus *adapted themselves* to environments according to conditions of those environments they live.

In this example, she explained adaptation process as a process driven by a mental agent rather than a process by the species become more suited to environment through change in a trait (Futuyma, 2009). Therefore, she had also misconception regarding adaptation process.

Overall, although she mostly used the key concepts of evolution, she had a misconception regarding adaptation and cognitive biases with respect to teleology and intentionality based on Nehm et al.'s (2010) framework. For that reason, her conceptual understanding level was placed in partial understanding with specific misunderstanding (PU/MU) according to Abraham et al.'s (1992) framework.

4.1.2.3. Structural Aspect of Argumentation Practices for *Whales* Scenario

Burcu constructed six arguments in order to support her claim and rebut the other alternatives.

For the Level 2, she generated four arguments for the second and third explanations. One of the example quotations was given in Table 4.3. In this example, explanation 2 was considered as a claim in this argument. She used example of human and chimpanzee as a data and she justified common ancestry for Pakicetus and Whales. Then, she backed up her claim with adaptation and heritability of genes. Since her argument did not include any rebuttal, her argument was categorized as Level 2.

For the Level 4, she constructed two arguments. One of the example quotations was given in Table 4.3. In this example, the second explanation was considered as a claim. She generated a counter-claim for the second explanation and she strongly rebutted the second explanation through using similarity as a data and common ancestry and adaptation as a warrant. Since her argument consisted of only one rebuttal rather than multiple rebuttals, it was classified as Level 4.

Table 4.3 Burcu's excerpts at argumentation levels in *Whales* scenario

Argumentation Level	Burcu's excerpts
Level 2	*Humans and chimpanzees have common ancestor. Likewise, Pakicetus and Whales may have had common ancestor because they were also different species since they must had suited to different environments. That is to say, species like Modern Whales, Basilosaurus and Pakicetus adapted themselves to environments according to conditions of those environments they live and changes were passed to offspring.*
Level 4	*The second explanation also stated that they were totally different species. However, they were not totally different because they had similarities and so, they came from common ancestor and adapted to new environment*

4.1.2.4. Epistemic Aspect of Argumentation Practices for *Whales* Scenario

Figure 4.2 represents the distribution of Burcu's propositions across the epistemic levels for *Whales* scenario.

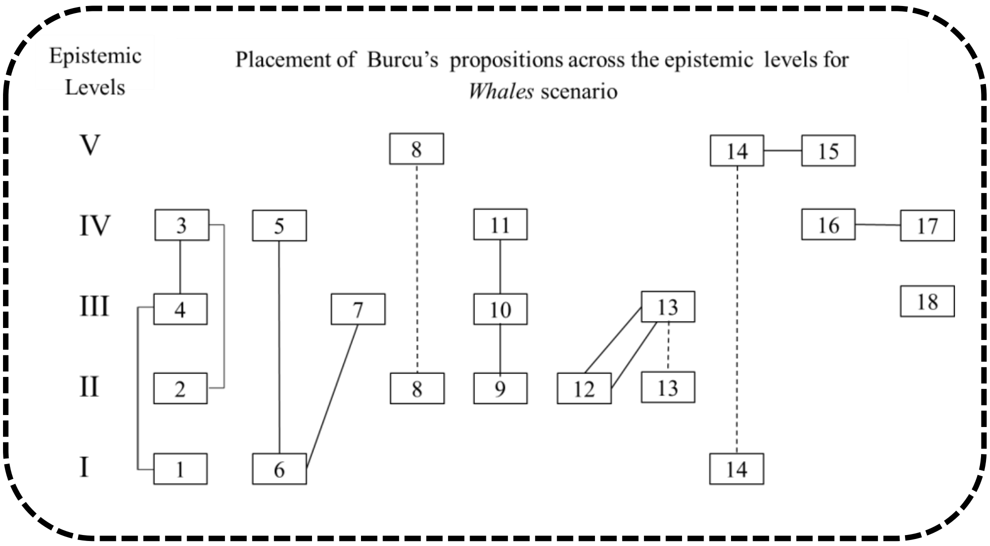

Figure 4.2 Burcu's argumentation structure by epistemic levels for *Whales* scenario

Based on the five epistemic levels framework, Burcu explicitly cited data from the task in three propositions (1, 6, and 14) classified as epistemic level I. She referenced data regarding common ancestry and environmental changes recalled previous knowledge in five propositions (2, 8, 9, 12 and 13). A representative example for propositions 12 and 13 was:

> (12) I'm confused because I remembered that life moved from water to land. (13) However, there is transition from land to water in this scenario, so a natural disaster may have taken place, for example, an earthquake or flood and then, they have to live in seas.

In this example, she referenced a data regarding transition from water to land recalled from existing knowledge in proposition 12 classified as epistemic level II. For proposition 13, she explained the process of transition from land to water through using data from previous knowledge with respect to environmental changes. Since her proposition included explanations for a process and explicitly referenced data, it was classified as epistemic levels II-III.

In addition, she also used theoretical claims regarding adaptation, common ancestry with identifying data in four propositions (4, 7, 10 and 18) placed in epistemic level III. She mostly used theoretical claims with respect to overproduction of offspring, heritability of genes and differential survival at level IV in this scenario in five propositions (3, 5, 11, 16 and 17). She also used general theoretical claims regarding common ancestry and heritability of genes in three propositions (8, 14 and 15) placed in epistemic level V.

In terms of criterion of integration of claims across the levels, Burcu proposed evidenced claims at various levels. On the other hand, in terms of the criterion of the ratio of data statements to theoretical ones, she used eight data statements in proportion to thirteen theoretical claims. In particular, data statements were insufficiently associated with theory in her argument. Therefore, epistemic quality of argument was relatively low.

4.1.2.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels for *Whales* Scenario

Table 4.4 represented how Burcu justified her claims appealing to evolution conceptions at different epistemic levels for *Whales* scenario. In the first example, she constructed new theoretical claim regarding common ancestry classified as epistemic level IV. Then, she used provided data with respect to similarities in structures placed in epistemic level I. She used this data to construct a theoretical statement regarding common ancestor transition form. In addition, she backed up her claim through using general theoretical claim with respect to common ancestry with identifying data concerning similarity of chimpanzee and human recalled form previous knowledge classified as epistemic levels II-V

In the second example, she generated a counter-claim for the explanation 1. She used provided data regarding rapid change in explanation 1 in order to reject the misconception of inheritance of acquired traits placed in epistemic levels I-V. Finally, she constructed a general theoretical knowledge including key concept of evolution, in particular heritability of genes to back up her counter-claim classified as epistemic level V.

Table 4. 4 Articulation of evolution conceptions and argumentation practices for *Whales* scenario

Burcu's Excerpts	Argumentation Practices	Epistemic Levels
(5) I agree with the some parts of the second explanation. Pakicetus and Basilosaurus may have had a common ancestor and they could be different species: Basilosaurus may have been sea mammal and Pakicetus may have been transition form. (6) Pakicetus, Basilosaurus and Whales have common structure in skulls. (7) That's why Pakicetus was a transition form and they come from common ancestor due to similarities. (8) For example, human and chimpanzee come from common ancestor because of their similarities, so they (Pakicetus and Basilosaurus) were different species but come from common ancestor.	**Claim:** Explanation 2 **New Claim:** common ancestry **Data:** similarities in skull **Warrant:** transition form and common ancestor due to similarity **Backing** **Data:** human and chimpanzee **Warrant:** common ancestry due to similarity	(Not Coded) Epistemic Level IV Epistemic Level I Epistemic Level III Epistemic Levels II-V
(14) Explanation 1 does not mention about the process of change in hind limb (Not coded). That's why, it seemed to mean that Pakicetus passed their traits to offspring rapidly and transformed to Basilosaurus but it is not correct because traits are not passed rapidly. (15) That is, organisms change as a result of producing fertile offspring in long periods of time.	**Claim:** Explanation 1 **Rebuttal** **Counter-claim:** not correct and not sufficient **Data:** rapid change **Warrant:** rejection of acquired traits **Backing:** overproduction of offspring	(Not Coded) (Not Coded) Epistemic Levels I-V Epistemic Level V

4.1.3. Scenario III: Lactose Intolerance

Lactose Intolerance scenario deals with gene-culture coevolution in humans (microevolution) (see Appendix A). Burcu was provided with this scenario in which she was asked to several questions about how lactose tolerance developed in humans. Following subsections described the results on each phase.

4.1.3.1. Criteria for Evaluating Validity of Explanation for *Lactose Intolerance* Scenario

After reading scenario, Burcu was asked to determine which of three alternative explanations was the most valid to explain how lactose tolerance developed in humans. The following dialogue took place after she decided:

> Burcu: The second and third explanations (Explanation 2: people started to consume milk and over time, in consequence of increasing the habit of drinking milk, this situation affects genes and increases the frequency of allele that causes lactase gene to be active in areas where milk is available. As a result, people who have high consumption of milk started to digest lactose. This development affects genes disparately at different population. Explanation 3: variation of digestion of lactose between communities and within communities is not related to consumption of milk. This is mostly based on whether randomly carrying lactose tolerance allele or not before dairy farming started. For instance, there are still people who do not digest milk in Europe where dairy farming started. That's why each person carries different lactose allele.)
>
> Researcher: Why did you say that?
>
> Burcu: For the third explanation, previously, people could digest lactose in particular regions of Europe but then, allele developed and became common. However, regarding variation of digestion of lactose within and between communities, although it has been a long time since dairy farming started, if there are still people who could not digest lactose in Europe, for instance in Holland, I deduced that each person has different allele.
>
> For the second explanation, I can give example from Africans; Africans started to animal cultivation 9000 years ago and thus, milk became their primary consumption source. Therefore, in this case, because they need to maintain their vital activities, this condition leaded to increase their habits of drinking milk and influenced their genes.

Burcu evaluated validity of alternative explanations of *Lactose Intolerance* scenario through using rigorous criteria. In particular, she took into consideration of how well data fits with claim since she explained her choice through associating provided data with claim. She did not attempt to use existing knowledge.

In the following, Burcu was asked to construct argument for *Lactose Intolerance* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.1.3.2. Conceptual Aspect of Argumentation Practices for *Lactose Intolerance* Scenario

She chose the second and third explanations for *Lactose Intolerance*. The former one includes misconception about Lamarckian evolution and the latter one is related to rejection of evolution. In line with her choices, she mostly used misconception and cognitive bias in her arguments. A representative example for her misconception was:

> The frequency of lactose tolerance allele increases and people who have *habits* of drinking milk start to digest lactose because when people have been *exposed to consumption of milk for a long time*, they carrying lactose allele adapt to digest it and this leads this allele to becoming active.

In this example, she explained the development of lactose tolerance based on Lamarck's theory of use and disuse. In particular, she explained evolution of digestion of lactose through habits of drinking milk. In addition, she had misconception about adaptation because in this example, she seemed to perceive adaptation as a reason for change in allele rather than a process by the species become more suited to environment through change in an allele (Futuyma, 2009).

She appealed key concept of evolution, in particular differential survival through using teleological reasoning. Put more specifically, she explained selection as a need-driven process:

> Therefore, in this case, because they *need to* maintain their vital activities, this condition leaded to increase their habits of drinking milk and influenced their genes. Because they either survive by consuming milk or die, so they *have to*

benefit from the products of animals because plant cultivation was rare and animal cultivation was only source of food.

Overall, she did not explained evolution of lactose tolerance through key concepts of evolution. She used differential survival incorrectly. In addition, she also had misconception of use and disuse based on Nehm et al.'s (2010) framework. Therefore, her conceptual level was categorized as specific misunderstanding (MU) according to Abraham et al.'s (1992) framework.

4.1.3.3. Structural Aspect of Argumentation Practices for *Lactose Intolerance* Scenario

Burcu generated six arguments to justify her claims and rebut the other alternatives for *Lactose Intolerance* scenario.

For the Level 2, she constructed four arguments for the second and third explanations. One of the example quotations was given in Table 4.5. In this example, she provided two data regarding variation among community from the task and then, she explained the reason of this variation as whether there is allele or not in genes. Since there was no attempt to rebut other alternatives, her argument was placed in Level 2.

For the Level 5, she generated an argument for the second explanation. One of the example quotations was given in Table 4.5. In this example, she supported the second explanation through data. Then, she rebutted the second explanation by justifying the third explanation through data and then, she created a new claim by reaching a conclusion from data. In addition, she provided a second rebuttal for the second explanation through using data from task and gave reason regarding evolutionary process. She attempted to rebut the second explanation twice, so her argument was classified as level 5. However, she did not attempt to provide rebuttal for the explanation 1.

Table 4.5 Burcu's excerpts at argumentation levels in *Lactose Intolerance* scenario

Argumentation Level	**Burcu's excerpts**
Level 2	*Africans carry allele that is different from that of Europeans. In addition, although it has been a long time since they have been exposed to consume milk, there are 50% of people could not digest lactose since it depends on whether there is allele or not in genes.*
Level 5	*Previously, people could digest lactose in particular regions of Europe but then, allele developed and became common. However, regarding variation of digestion of lactose within and between communities, although it has been a long time since dairy farming started, if there are still people who could not digest lactose in Europe, for instance in Holland, I deduced that each person has different allele.* *However, this may be specific case for Africans. Because there are still people who cannot digest lactose and the reason of it is that these people may not undergo evolutionary process.*

4.1.3.4. Epistemic Aspect of Argumentation Practices for *Lactose Intolerance* Scenario

Figure 4.3 represents the distribution of Burcu's propositions the across the epistemic levels for *Lactose Intolerance* scenario.

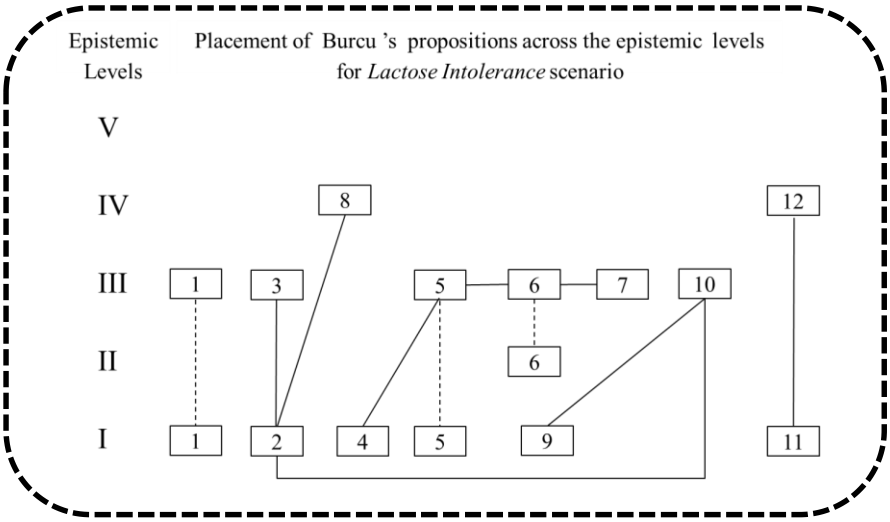

Figure 4.3 Burcu's argumentation structure by epistemic levels for *Lactose Intolerance* scenario

Based on the epistemic levels model, she cited figures from the task in six propositions (1, 2, 4, 5, 9 and 11) classified as epistemic level I. She referenced data regarding plant and animal cultivation based on her existing knowledge in only proposition 6. She generated theoretical claims regarding theory of use and disuse or explained the process of development of lactose tolerance in six propositions (1, 3, 5, 6, 7, and 10) placed in epistemic level III.

She also generated theoretical claims regarding differential survival specific to issue discussed in three propositions 8 and 12 classified as epistemic level IV. A representative example for the proposition 8 was:

> (8) However, this may be specific case for Africans (not coded). Because there are still people who cannot digest lactose and the reason of it is that these people may not undergo evolutionary process.

In this example, she explained the reason of variation through using theoretical knowledge concerning evolutionary process with identifying data from the task placed in epistemic level IV.

In terms of the criterion of integration of claims across the levels, Burcu proposed evidenced claims at various levels. However, she did not generate a general theoretical claim for this scenario. Besides, in terms of the criterion of the ratio of data statements to theoretical statements, she used seven data references in proportion to eight theoretical claims. That is, theoretical claims were sufficiently supported by data. Hence, epistemic quality of argument was relatively high.

4.1.3.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels for *Lactose Intolerance* Scenario

Table 4.6 illustrated how Burcu justified her claims appealing to evolution conceptions documented in the use of evidenced claims at different epistemic levels for *Lactose Intolerance.* In the first example, she referenced provided data form the task in order to support the second explanation placed in epistemic level I. Then, she reached a conclusion from data and proposed a new claim based on the misconception regarding theory of use and disuse with identifying data from task classified as epistemic levels I-III. Then, she used data regarding plant and animal cultivation retrieved from previous knowledge and then, provided warrant through using theoretical claim concerning a key concept of evolution, in particular differential survival but she used teleological reasoning in order to explain this concept since this proposition includes both theoretical claim and data recalled from existing knowledge, it was placed in epistemic levels II-III.

In the second example, she explicitly cited a map in the task in order to support her claim placed in epistemic level I. Then, she constructed a new theoretical claim regarding misconception with respect to theory of use and disuse based on data and then, she provided a theoretical claim regarded as a warrant to explain process through adaptation but she used this notion inaccurately placed in epistemic level IV.

Table 4. 6 Articulation of evolution conceptions and argumentation practices for *Lactose Intolerance* scenario

Burcu's Excerpts	Argumentation Practices	Epistemic Levels
(4) I can give example from Africans; Africans started to animal cultivation 9000 years ago and thus, milk became their primary consumption source. (5) Therefore, in this case, because they need to maintain their vital activities, this condition leaded to increase their habits of drinking milk and influenced their genes. (6) Because they either survive by consuming milk or die, so they have to benefit from the products of animals because plant cultivation was rare and animal cultivation was only source of food.	**Claim:** Explanation 2 **Data:** animal cultivation in Africa **New claim:** theory of use and disuse **Data**: animal cultivation is only source **Warrant:** differential survival	(Not coded) Epistemic Level I Epistemic Levels I-III Epistemic Levels II-III
(11) There is a map related to Europeans in 8000-9000 years ago and data from Africans, that is, dairy farming has been done since at that time and people have been exposed to consumption of milk. (12) Therefore, the frequency of lactose tolerance allele increases and people who have habits of drinking milk start to digest lactose because when people have been exposed to consumption of milk for a long time, they carrying lactose allele adapt to digest it and this leads this allele to becoming active.	**Claim:** Explanation 2 **Data:** the map (provided in scenario) **New claim:** theory of use and disuse **Warrant:** adaptation	(Not coded) Epistemic Level I Epistemic Level IV

4.1.4. Scenario IV: Cambrian Explosion

Cambrian Explosion scenario deals with gaps in the fossil record (macroevolution) (see Appendix A). Burcu was provided with this scenario in which she was asked to several questions about gaps in the fossil record as a consequence of gradual or rapid changes. Following subsections described the results on each phase.

4.1.4.1. Criteria for Evaluating Validity of Explanation for *Cambrian Explosion* Scenario

After reading scenario, Burcu was asked to determine which of three alternative explanations was the most valid to explain the reason of gaps in fossil records. The following dialogue took place after she decided:

> Burcu: Explanation 1 and 2 but explanation 2 is more correct. (<u>Explanation 1:</u> The lack of intermediate fossils is due to the fact that very few fossils from periods prior to 570 million years were formed or preserved. The evolution of multicellular organisms was a slow process proceeding by little steps. <u>Explanation 2:</u> The lack of intermediate fossils is due to the fact that these forms never existed. Multicellular organisms appeared as a consequence of abrupt changes.)
>
> Researcher: Why did you say that?
>
> Burcu: In the explanation 2, abrupt climatic changes took placed; Ice Age Epoch began and thus, different habitats developed, so species changed abruptly because these abrupt changes may have brought the necessity of suiting to environment suddenly and survival. It is also said that no fossil records were found. However, scientific knowledge is never absolute, it always exposed to change. The reason of it is that they have not been observed yet but it is not that they will not be observed. On the one hand, the hypothesis that fossil records were not observed might support the second explanation. On the other hand, this is because they might be preserved due to climatic changes. Hence, I cannot say that the second explanation is 100% correct because the first explanation is also correct since fossil records were not preserved.

Burcu evaluated acceptability of alternative explanations of *Cambrian Explosion* scenario through using rigorous and informal criterion. In particular, Burcu took into consideration of how well available data fits with claim. In particular, she used provided data regarding climatic change in order to confirm her choice. This is in line with rigorous criterion. She also constructed a relation through using her previous knowledge based on this data. This is in line with informal criteria since she seemed to consider consistency of personal inference by stating “so species change abruptly” without any attempt to reference theoretical knowledge. In addition, she also utilized theoretical knowledge regarding knowledge about nature of science and adaptation to evaluate validity of explanation which is line with rigorous criterion. Besides, she evaluated the acceptability of explanation in the light of other explanation. She used this filter when she did not distinguish between alternatives.

In the following, Burcu was asked to construct argument for *Cambrian Explosion* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.1.4.2. Conceptual Aspect of Argumentation Practices for *Cambrian Explosion* Scenario

She chose both explanations for this scenario. She mostly used evolutionary explanations such as differential survival, resource limitation and common ancestor in her arguments. Representative examples for these concepts were:

> For example, the Earth was in an Ice Age Epoch in that time but climate could have been different in each region. Therefore, species like arthropods and sponges could have adapted to different environments, that is to say, these species came from a *common ancestor* and then, adapted and *speciation* occurred.

> There were a few species that could live in Ice Age Epoch, so predators *hunted* them more intensively. Therefore, species *protected* from predators and also cold by means of their shells.

In the first example, she used the notions of common ancestor and speciation. In the second example, she applied the key concept of evolution regarding resource limitation, in particular pre/predator relationship in her arguments. However, she used teleological reasoning in several explanations. For instance, she explained the survival and adaptation process through goal-driven process. A representative example for this cognitive bias was:

> Sudden environmental changes may have brought the *necessity of suiting to environment* suddenly and survival.

Overall, although she most frequently used evolutionary explanations, she had cognitive bias regarding teleology based on Nehm et al.'s (2010) framework. Therefore, her conceptual level was placed in partial understanding with misunderstanding (PU/MU) according to Abraham et al.'s (1992) framework.

4.1.4.3. Structural Aspect of Argumentation Practice for *Cambrian Explosion* Scenario

Burcu constructed five arguments in order to support her claim and rebut the other alternatives.

For the Level 1, she constructed an argument for the second explanation. The example quotation was given in Table 4.7. In this example, she generated a new claim regarding evolution through reaching a conclusion from data. However, she used "these examples" as the data but this is not clear. Therefore, her argument was placed in Level 1.

For the Level 2, she generated three arguments. One of the example quotations was presented in Table 4.7. In this example, she used climatic and environmental changes as the data and explained the reason for sudden changes of species. Hence, her argument was classified as Level 2.

For the Level 5, she constructed an argument including two rebuttals for the explanation 2. The example quotation was given in Table 4.7. In this example, explanation 2 was considered as a claim. She generated a counter-claim regarding scientific knowledge and she explained reason of why there are no fossils. Then, she also provided a strong rebuttal for the second explanation. She generated a counter-claim and justified her claim through using warrant regarding preservation. Since she generated two strong rebuttals for the explanation 2, her argument was classified as Level 5. However, she did not attempt to rebut the notion of gradual process mentioned in the explanation 1.

Table 4.7 Burcu's excerpts at argumentation levels in *Cambrian Explosion* scenario

Argumentation Level	**Burcu's excerpts**
Level 1	*These examples showed that species like annelids, arthropods, chinoderms, chordata or sponges all evolved to different species that were able to suit to different habitats in Cambrian Period.*
Level 2	*In the explanation 2, abrupt climatic changes took placed; Ice Age Epoch began and thus, different habitats developed, so species changed suddenly because these abrupt changes may have brought the necessity of suiting to environment suddenly and survival.*
Level 5	*It is said that no fossil records were found. However, scientific knowledge is never absolute, it always exposed to change. Therefore, the reason why there are no fossils is that they have not been observed yet but it does not mean that they will not be observed. On the one hand, the hypothesis that fossil records were not observed might support the second explanation. On the other hand, this is because fossil records are formed rarely since they might be preserved due to climatic changes. Hence, I cannot say that the second explanation is 100% correct because the first explanation is also correct since fossil records were not preserved.*

4.1.4.4. Epistemic Aspect of Argumentation Practices for *Cambrian Explosion* Scenario

Figure 4.4 represents the distribution of Burcu's propositions across the epistemic levels for *Cambrian Explosion* scenario.

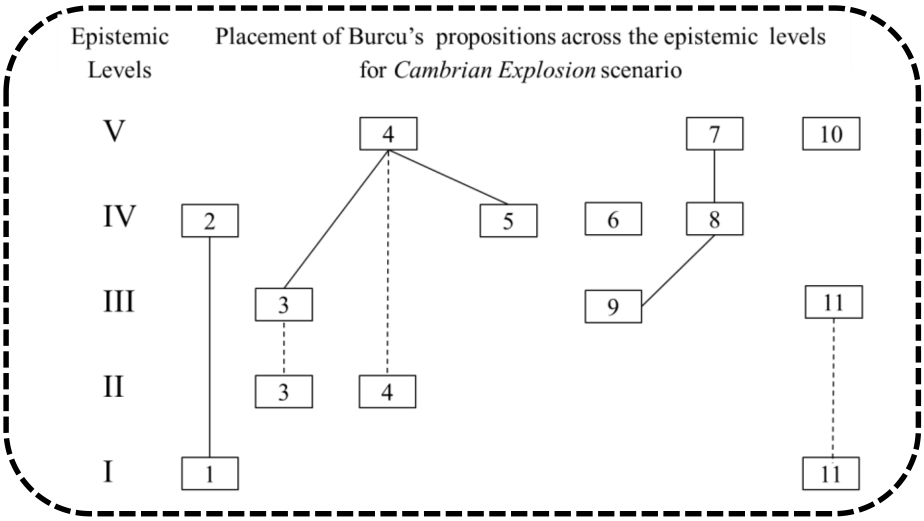

Figure 4.4 Burcu's argumentation structure by epistemic levels for *Cambrian Explosion* scenario

Based on the five epistemic levels model, she explicitly referenced data regarding climatic changes provided form task in two propositions (1 and 11) placed in epistemic level I. She also referenced data retrieved from her existing knowledge in two propositions (3 and 4) classified as epistemic level II.

In proposition 3, she used theoretical claims regarding adaptation with identifying data regarding shells retrieved from previous knowledge placed in epistemic levels II-III. A representative example for proposition 6 was:

> (6) These examples showed that species like annelids, arthropods, chinoderms, chordata or sponges all evolved to different species that were able to suit to different habitats in Cambrian Period.

In this example, she used theoretical claim regarding speciation and adaptation classified as epistemic level IV. Besides, she also utilized theoretical claims concerning adaptation, resource limitation, scientific knowledge and common ancestor at epistemic level IV in four propositions (2, 5, 6, and 8). In propositions 4, 7 and 10, she utilized general theoretical statements with respect to resource limitation, scientific knowledge and differential survival classified as epistemic level V.

In terms of criterion of integration of claims across the levels, Burcu proposed evidenced claims at various levels. Besides, in terms of the criterion of the ratio of data statements to theoretical statements, she used four data references in proportion to ten theoretical claims. That is, theoretical claims were insufficiently supported by data. Hence, her epistemic quality of argument was relatively low.

4.1.4.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels for *Cambrian Explosion* Scenario

Table 4.8 represented how Burcu justified her claims appealing to evolution conceptions documented in the use of evidenced claims at epistemic levels for *Cambrian Explosion* scenario. In the first explanation, she generated a new theoretical claim regarding adaptation through using teleological reasoning with identifying data retrieved from existing knowledge classified as epistemic epistemic levels II-III. Then, she also referenced data retrieved from her previous knowledge and to support her claim, she provided a general theoretical statement as a warrant regarding key concept of evolution, in particular prey/predator relationship classified as epistemic levels II-V. In order to back up her claim, she utilized theoretical claim with respect to prey/predator relation for this context placed in epistemic level IV.

In the second example, she generated a new claim regarding adaptation and in order to justify her claim, she provided general theoretical statement regarding key concept of evolution, in particular differential survival as a warrant classified as epistemic level V. Then, she provided backing through using data provided form task and theoretical statement regarding speciation and common ancestry as a reason placed in epistemic levels I-III.

Table 4. 8 Articulation of evolution conceptions and argumentation practices for *Cambrian Explosion* scenario

Burcu's Excerpts	**Argumentation Practices**	**Epistemic Levels**
(3) They (species)' shell may have hardened in order to resist cold weather and suit to conditions because soft-shell was vulnerable to damage.(4) This is so important because there were a few species that could live in Ice Age Epoch, so predators hunted them more intensively. (5) Therefore, species protected from predators and also cold weather by means of their shells.	**New claim:** hard-shell to adapt **Data:** vulnerability of soft-shell	Epistemic Levels II-III
	Data: few species in Ice Age Epoch **Warrant:** prey/predator relation	Epistemic Levels II-V
	Backing: prey/predator relation	Epistemic Level IV
(10) Abrupt changes should bring sudden adaptations because while species that suited to environment survive, others that do not suit to environment die and extinct and thus, different habitats provide different species. (11) For example, the Earth was in an Ice Age Epoch in that time but climate could have been different in each region. Therefore, species like arthropods and sponges could have adapted to different environments, that is to say, these species came from a common ancestor and then, adapted and speciation occurred.	**New claim:** sudden adaptation due to sudden changes **Warrant:** Differential survival	Epistemic Level V
	Backing **Data:** different climate in different regions **Warrant:** speciation and common ancestor	Epistemic Levels I-III

4.1.5. Burcu's Result across Scenarios

Profile of Burcu based on findings across the four scenarios in terms of criteria for evaluating alternatives, conceptual, structural and epistemic aspects of argumentation practices was presented in Table 4.9.

Table 4.9 Profile of Burcu

Evolutionary Scenarios	**Criteria**	**Conceptual Aspects**	**Structural Aspects**	**Epistemic Aspects**
Venezuelan Guppies	Rigorous and Informal Criteria	Partial Understanding with specific misunderstanding	Level 2 (Reason)-8 Level 4 (Rebuttal) -1	Coordination of 8 data statements with 14 theoretical statements
Whales	Rigorous Criteria	Partial Understanding with specific misunderstanding	Level 2 (Reason)-4 Level 4 (Rebuttal)-2	Coordination of 8 data statements with 13 theoretical statements
Lactose Intolerance	Rigorous Criteria	Specific Misunderstanding	Level 2 (Reason)-4 Level 5 (Rebuttal)-1	Coordination of 7 data statements with 8 theoretical statements
Cambrian Explosion	Rigorous and Informal Criteria	Partial Understanding with specific misunderstanding	Level 1 (Reason)-1 Level 2 (Reason)-3 Level 5 (Rebuttal)-1	Coordination of 4 data statements with 10 theoretical statements

In the following five subsections, Burcu's results across the four scenarios were described in detail and discussed.

4.1.5.1. Criteria for Evaluating Validity of Explanation across Scenarios

Burcu utilized both rigorous and informal criteria during decision-making phase across the four scenarios. However, she appealed mostly to rigorous criteria. In particular, she seemed to take into consideration the how well available data fits with explanation. She also voiced the importance of empirical criteria for persuasive argument as: "Arguments should be empirical, observable, consistent with other data, measurable. Evidences should support hypothesis." Besides, she also chose the explanation based on her previous knowledge. Mostly she used the criterion of how well claims fit with scientific theories based on her previous knowledge. However, previous knowledge was not always supported by scientific theories, so these criteria are in line with informal criteria. She also made personal inference from data provided in the scenario. As a result, although she mostly used scientifically appropriate criteria, she did not consider all criteria that scientists use such as coherence of explanations, sufficiency of data and adequacy of explanations.

4.1.5.2 Conceptual Aspects of Argumentation Practices across Scenarios

Burcu explained the evolutionary theory as "is the process of gaining new traits through inheritance of genes." and she put forward the reasons of acceptance as a valid theory:

> There are intermediate forms and homolog organs, that is, organs dissimilar in function but their structures are similar in origin. These are evidences that prove evolutionary theory. I think that evolution occurs through adaptation and as a result of characteristics of living process rather than as a result of random occurrences.

On the other hand, random factors such as mutations and genetic drift play role in evolution (Futuyma, 2009). In parallel of her explanations, she did not attempt to mention about variation through random events across the scenarios. In particular, she explained evolutionary phenomena through whole species change or evolve. This means that she underestimated within species variation, that is, she tended to consider species as sharing a common "essence". Therefore, she held cognitive bias regarding essentialism. Besides, Burcu mostly used key conceptions of evolutionary theory, in particular differential survival, heritability of genes, resource limitation and overproduction of offspring in her arguments. She applied the differential survival in each scenario. However, although she used evolutionary notion of differential survival accurately in two scenarios, she appealed this notion for *Lactose Intolerance* and *Whales* scenario through using teleological reasoning. This scenario is related to human evolution and that's why she might have perceived evolution as a goal-driven process for human. In addition to key concepts of evolution, she also mentioned about common ancestry and speciation in her arguments. Besides, she also held some misconceptions regarding adaptation and theory of use and disuse. She most frequently used the notion of adaptation but mostly inaccurately. She also had cognitive biases with respect to teleology and intentionality. She used mostly teleological reasoning in her arguments. In particular, she used this reasoning in all scenarios. This means that she may perceive evolutionary change as a need for species. Examples of her evolution conceptions were presented in Table 4.10.

Table 4.10 Burcu's conceptions across the four scenarios

Conceptions		**Examples**
Key Concepts	Differential Survival	"We know that bright-colored males, this took place in other species, are primarily *preferred* by females in nature."
	Resource Limitation	"There were a few species that could live in Ice Age Epoch, so predators *hunted* them more intensively. Therefore, species protected from predators and also cold by means of their shells."
	Overproduction of offspring	"After these genes become advantage, they are passed to next generation and they (organisms) produce more offspring and this process last long time."
	Heritability of genes	"If a trait found in sex cells is favorable, it will be *passed to next generation*."
Misconceptions	Adaptation	"Species like Modern Wahles, Basilosaurus and Pakicetus adapted them to environments according to conditions of those environments they live"
	Use and Disuse	"People who have habits of drinking milk start to digest lactose because when people have been exposed to consumption of milk for a long time"
Cognitive Biases	Teleology	"When the environment changed, living thing has to change in order to suite environment or died and became extinct"
	Intentionality	"They (bright males) *learn* to adjust their colors in long periods of time"
	Essentialism	"*Species* changed abruptly because these abrupt changes may have brought the necessity of suiting to environment suddenly and survival."

Based on these conceptions regarding evolutionary theory, Burcu's conceptual understandings were analyzed across the six conceptual levels (see in Figure 4.5). As seen in the Figure 4.5, her conceptual levels were accumulated around mostly PU/MU category. This means that she had some basic knowledge regarding evolutionary theory. On the other hand, she also held some misconceptions and cognitive biases with respect to evolutionary theory.

In *Lactose Intolerance* scenario, she did not attempt to appeal to evolutionary concepts except for differential survival but she explained this notion through purposeful change. Besides, her conceptual understandings did not differ between microevolution and macroevolution.

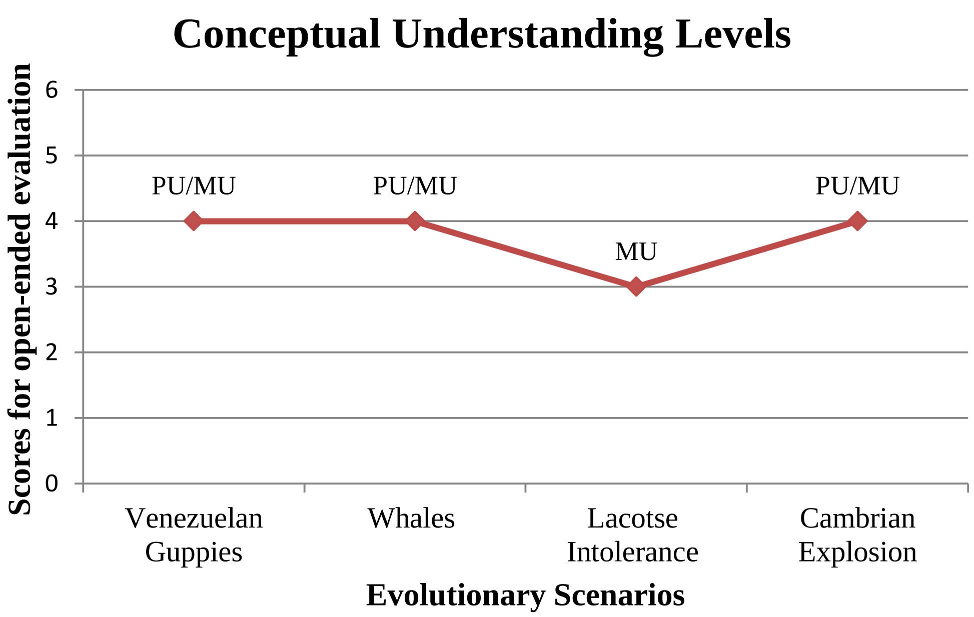

Figure 4.5 Burcu's conceptual understanding levels across the scenarios

4.1.5.3. Structural Aspects of Argumentation Practices across Scenarios

Burcu's argumentation levels were presented in Figure 4.6. As seen in the figure, she constructed eighteen arguments at Level 2 which includes claim supported by either data, warrant or backing. She utilized an argument at Level 1 which includes claim vs claim. In addition, she constructed strong rebuttals at Level 4 for two scenarios and for last two scenarios, she generated more than one strong rebuttal at

Level 5. There was no argument placed in Level 3. This means that she always supported her counter-claims through either data or warrant across the four scenarios. Her arguments for *Venezuelan Guppies* and *Whales* included one rebuttal for each alternative. The reason of this may be related to unfamiliarity of the alternative explanations. It has to be noted that although her conceptual understanding level was low in *Lactose Intolerance* scenario, her argumentation level was high based on Erduran et al.'s (2004) analytical framework. The reason of this may be that this analytical framework did not evaluate the quality of conceptual understanding, so her justifications and rebuttals were strong even if they included misconceptions or cognitive biases. Overall, she most frequently justified her chosen claims instead of rebutting other alternatives.

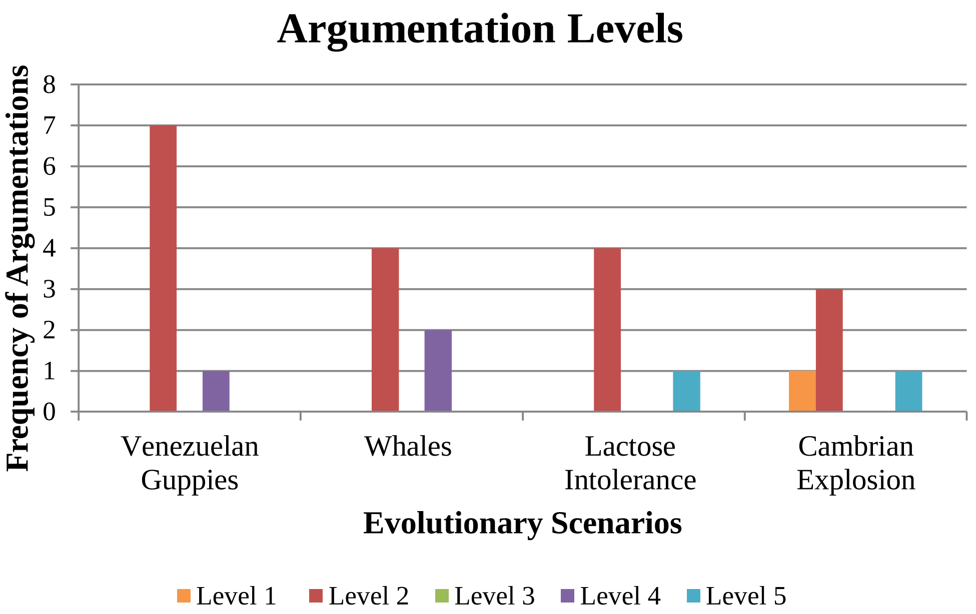

Figure 4.6 Burcu's argumentation levels across the scenarios

4.1.5.4. Epistemic Aspects of Argumentation Practices across Scenarios

As seen in Table 4.11, most evidenced claim she utilized classified as epistemic levels I, III and IV. In particular, she mostly referenced data provided from the scenario. She frequently used theoretical claims specific to issue discussed. This may be related to her conceptual understandings. That is to say, she used several key concepts of evolution in a form of theoretical propositions. In addition, she less frequently used propositions at epistemic level II which is related to retrieved data from previous knowledge. This may be related that although she held some theoretical knowledge regarding evolution, she had inadequate knowledge regarding empirical data with respect to evolutionary theory. Overall, in terms of ratio of data and theoretical claims, she referenced 28 data statements for 45 theoretical claims.

Table 4.11 The distribution of Burcu's propositions across the epistemic levels

Epistemic Levels	**N**	**Percent**
Epistemic Level V- General Theoretical Claims	11	15.1 %
Epistemic Level IV-Theoretical Claims	18	24.7 %
Epistemic Level III- Theoretical Claims with data	16	21.9 %
Epistemic Level II- Retrieved Data	9	12.3 %
Epistemic Level I- Provided Data	19	26 %

Figure 4.7 represented the evidenced claims across the evolutionary scenarios that Burcu constructed. As seen in the figure, she utilized evidence claims at different epistemic levels across the scenarios. In first two scenarios, she constructed extended arguments. In the first scenario, she mostly used data and specific and general theoretical statements. However, she scarcely attempted to connect data to theory. In the second scenario, she mostly used evidenced claims at level II, III and IV. This may be related to familiarity of this context. This means that she proposed theoretical claims and data recalled from her previous knowledge. In the next scenario, she connected data statements to specific theoretical arguments. This may be interpreted to mean that she constructed relevance her previous theoretical knowledge with available evidences. In the last scenario, she mostly used theoretical claims in *Cambrian Explosion* scenario, perhaps due to content of scenario. In particular, this scenario includes most general statements regarding gradualism and punctuated equilibrium.

Overall, she most frequently used theoretical assertions in proportion to data statements. This may be related to unfamiliarity with the use of evidence to support her claims.

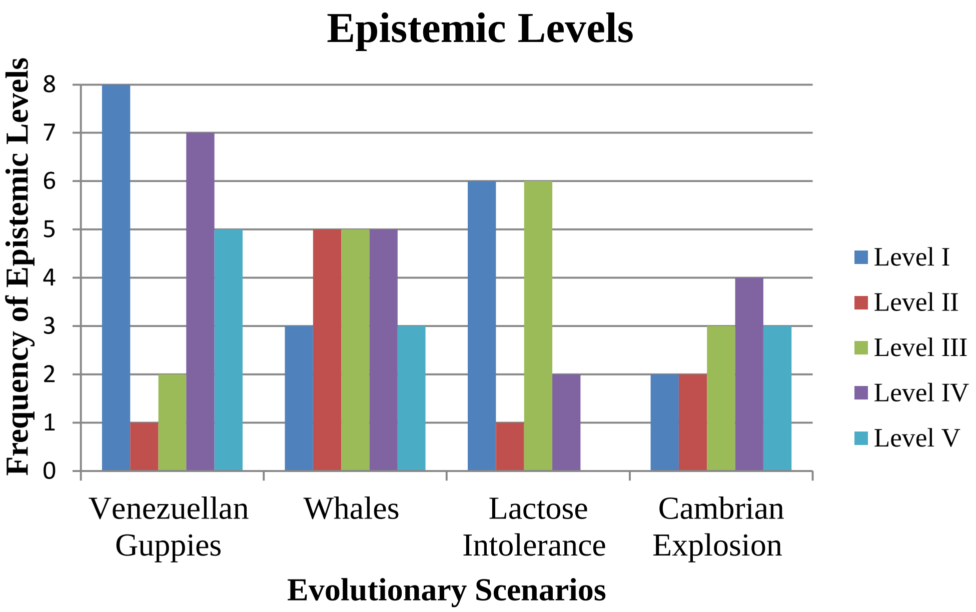

Figure 4.7 Burcu's epistemic levels across the scenarios

4.1.5.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels across Scenarios

She appealed to several key concepts of evolution in mostly theoretical propositions for her arguments to provide warrants and backings for her claims. In particular, she used general and specific theoretical claims regarding differential survival, heritability of genes, overproduction of offspring and resource limitation. In addition, she also appealed to common ancestry, adaptation and speciation concepts to support or rebut the explanations. Besides, she provided warrant and backings in the form of theoretical statements to generate a counter-argument for rejecting misconception of inheritance of acquired traits. She also brought scientifically valid examples recalled from existing knowledge such as ancestral relationship between human and chimpanzee and sexual selection in birds. In addition to her evolutionary concepts, she also appealed to misconceptions regarding adaptation and theory of use and disuse and cognitive biases with respect to intentionality and teleology in her theoretical statements in order to justify her claim and rebut the alternatives.

4.2. Leyla's Case

She was 27 years old and graduated from Department of Elementary Science Education, METU in 2010. She took biology courses including general biology I and II, physiology and evolution courses and science methods courses including instructional planning and principles and methods of teaching science courses in which argumentation was introduced. She completed *Evolution* course with a grade of DC (1,5/4). She was doing her M.S. in Elementary Science Education at Hacettepe University. She took the course including argumentation studies during her M.S. She was working at private school. She was in the first year of teaching profession during the data collection and she taught to 5th grade. She did not have any teaching experience on evolutionary theory.

In the following sections, the results of Leyla were presented under the five dimensions including criteria for evaluating validity of explanation, argumentation practices in terms of conceptual, structural and epistemic aspects as well as the articulation of conceptual knowledge regarding evolutionary theory and argumentation practices at different epistemic levels. The results of these analyses were discussed for each scenario separately.

4.2.1. Scenario I: Venezuelan Guppies

Venezuelan Guppies scenario deals with natural and sexual selection (microevolution) (see Appendix A). Leyla was provided with this scenario in which she was asked to several questions about the reason of observed variation in the coloration within male guppies. Following subsections described the results on each phase.

4.2.1.1. Criteria for Evaluating Validity of Explanation for *Venezuelan Guppies* Scenario

After reading scenario, Leyla was asked to determine which of three alternative explanations was the most valid or acceptable to explain the reason of coloration in Venezuelan Guppies. The following dialogue took place after she decided:

> Leyla: I accept the third explanation. (The species of guppy try to appear very flashy like many other types of fish. However, when individual migrate into different pools, they need to adjust their coloration in order to avoid predators. As a result, some become drab in order to better fit in with a new habitat. This new trait is then passed down to their offspring because it is useful.)
>
> Researcher: Why did you say that?
>
> Leyla: Because when I looked at the pools, I observed that the number of bright (males) vary across the pools in the first place. Then, I realized that drab males displaced. The number of drab males increases while those of bright males decreases. Explanation 3 supports this. When they moved, they need to adjust their colors. Probably, they changed their colors in that way.

Leyla evaluated validity of alternative explanations of *Venezuelan Guppies* scenario based on both rigorous and informal criteria for this scenario. This means that she evaluated alternative explanations based on the criterion of how well available data fits with the claim, so this is in line with rigorous criterion including reasons that are utilized in science context. On the other hand, she also reached a conclusion based on the comparison of the number of bright and drab males by making personal inference without any attempt to support her inference with scientific theories, so this is in line with informal criterion consisting of reasons that are mostly utilized in everyday context.

In the following, Leyla was asked to construct argument for *Venezuelan Guppies* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.2.1.2. Conceptual Aspect of Argumentation Practices for *Venezuelan Guppies* Scenario

Leyla chose the third explanation which includes misconceptions about intentionality and Lamarckian evolution (inheritance of acquired traits). She does not apply any evolutionary explanations for her arguments. In addition, she used teleological and intentional reasoning and explanations regarding adaptation inaccurately in her argument. Representative examples were:

> When predators are abundant, bright males are few, that is, *in order not to* attract attention and *not to be* hunted by predator, they (bright males) turn into drab.
>
> One of the reasons for undergoing adaptation of living things is protection, that is to say, many species undergo adaptation *on the purpose of* protection.

This example illustrated that she had a cognitive bias regarding evolution since she explained the reason for coloration with goal-directed process. In the second example, she seemed to perceive adaptation as a goal-directed process rather than a process by the species become more suited to environment through change in a trait (Futuyma, 2009).

In addition, she held cognitive bias regarding intentionality which means that a mental agent direct the events. The following example indicates this cognitive bias: "They (species) *adjust* their colors depend on particular environment in order not to be hunted by predators." In this example, she explained the phenomena of coloration through mental agent that rather than through natural and sexual selection.

Besides, she confused evolution of camouflage with the chameleons' color changing, she said "color change in chameleons depends on environment and also the color of polar bears' skin is white. These are all example of adaptation." Color change in polar bear is an example of evolution of camouflage but color change in chameleons is not.

Overall, she held misconceptions regarding adaptation, and cognitive bias with respect to teleology and intentionality. Besides, she did not explain phenomena through evolutionary conceptions based on Nehm et al.'s (2010) framework. Hence, her conceptual level was placed in the level of specific misunderstanding (MU) according to Abraham et al.'s (1992) framework.

4.2.1.3. Structural Aspect of Argumentation Practices for *Venezuelan Guppies* Scenario

She generated six arguments at level 2 and level 3 so as to support and criticize the alternative explanations.

For the level 2, she generated four arguments for the third explanation. One of the example quotations was illustrated in Table 4.12. In this example, explanation 3 was considered as a claim. She utilized comparison of changes in color of male guppies and number of predators as a data. She explained the reasons for color changes with the purpose of protection. Therefore, this argument was placed in level 2.

For the Level 3, she constructed two arguments to rebut the other alternatives. The quotation regarding this level of argument was given in Table 4.12. She weakly rebutted the other alternatives with warrant that is insufficiency of line of reasoning and its inadequacy of data. However, she provided a weak data to justify her rebuttal and she did not explain why the second explanation is insufficient.

Table 4.12 Leyla’s excerpts at argumentation levels in *Venezuelan Guppies* scenario

Argumentation Level	**Leyla’s excerpts**
Level 2	*When the number of predators is abundant, the number of bright males is few, that is, in order not to attract attention and not to be hunted by predators, they (bright males) turn into drab. (…) When the number of predators decreases, the number of bright males increases since threat is gone.*
Level 3	*There are predators in the pool, so this (coloration) should be related to predators. I predict that this relation is constructed by the third explanation. That is to say, predators eat them (male guppies). There is no explanation regarding predators in other alternatives. In only explanation 2, there is an explanation dealing with this relationship but this does not make sense.*

4.2.1.4. Epistemic Aspects of Argumentation Practices for *Venezuelan Guppies* Scenario

Figure 4.8 illustrates Leyla’s propositions across the epistemic levels. In this figure, each sentence was labeled with numbers and sentences served as a propositions. Each of propositions was categorized by epistemic levels and mapped in order to indicate ties across the epistemic levels. Lines connecting propositions represents explicit links between propositions and dashed lines represents the propositions including statements at two epistemic levels.

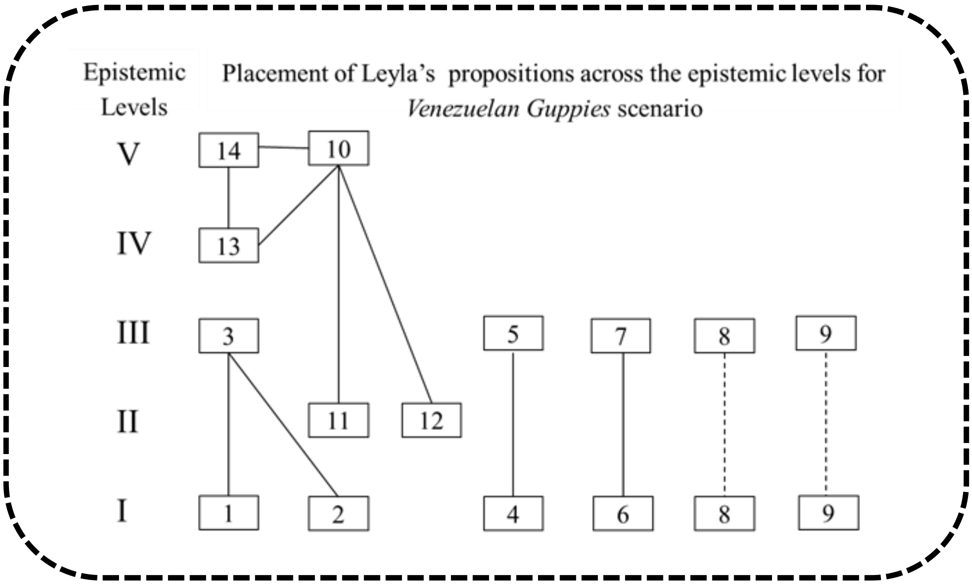

Figure 4.8 Leyla's argumentation structure by epistemic levels for *Venezuelan Guppies* scenario

Based on the figure 4.8, she cited information from provided data in six propositions (1, 2, 4, 6, 8 and 9) classified as epistemic level 1. In proposition 3, she explained the process of coloration through supporting by propositions 1 and 2 and it was placed in epistemic level III. A representative example for propositions 4 and 5 was:

> (4) The third explanation stated that they (male guppies) change their color and the percent of them is (bright males) 3 and then, the percent becomes 41 in the table. It is related to males not females. (5) Thus, Being numerically few or abundant bright and drab males may be related to their mating preferences.

In this example, proposition 4 explicitly referenced to percentages of bright male guppies from provided table classified as epistemic level I. In proposition 5, she explained changes in number of males with mating preferences placed in epistemic level III. In proposition 7, the process of prey/predator relationship explained by data in proposition 6. In addition, she interpreted the process of changes in number of males and predators by citing data in propositions 8 and 9. In propositions 10 and 14, she used general theoretical knowledge about adaptation was classified as V. In propositions 11 and 12, she gave example recalled from previous knowledge. In proposition 13, she appealed her previous knowledge to coloration of Venezuelan guppies classified as epistemic level IV.

Overall, in terms of integration of claims across the levels, Leyla generated claims at different epistemic levels. In addition, in terms of the criterion of the ratio of data statements to theoretical statements, she used four data references in proportion to ten theoretical claims. She used six data statements in proportion to eight theoretical claims. Therefore, epistemic quality of her argument was relatively high.

4.2.1.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels for *Venezuelan Guppies* Scenario

Table 4.13 represented how Leyla justified her claims appealing to evolution conceptions at different epistemic levels for Venezuelan Guppies scenario. In the first example, Leyla justified her choice by prey/predator relationship with explicitly referenced data from the task classified as epistemic levels I- III but she used teleological explanations for this.

In the second explanation, she generated a general theoretical claim regarding adaptation but she used adaptation process inaccurately for this claim placed in epistemic level V. She used examples from previous knowledge in order to support her claim classified as epistemic level II. However, she confused evolution of camouflage with the chameleons' color changing in this example. Then, she connected the claim and data by explaining variation in colors of guppies classified as epistemic level IV but she also used teleological explanation for her warrant. Lastly, she generalized examples of adaptation for the other species placed in epistemic level V.

Table 4. 13 Articulation of evolution conceptions and argumentation practices for *Venezuelan Guppies* scenario

Leyla's Excerpts	Argumentation Practices	Epistemic Levels
(8) While number of predators increases, the number of bright males decreases, that is, in order not to attract attention and not to be hunted by predator. (9) When the number of predators decreases, the number of bright males increases since threat is gone.	**Claim:** Explanation 3	(Not coded)
	Data: comparison of bright males and predators **Warrant:** prey/predator relationship	Epistemic Levels I - III
	Data: comparison of bright males and predators **Warrant:** prey/predator relationship	Epistemic Levels I - III
(10) One of the reasons for undergoing adaptation of living things is protection, that is to say, many species undergo adaptation on the purpose of protection. (11) For instance, color change in chameleons depends on environment and (12) also the color of polar bears' skin is white. (13) Therefore, they (male guppies) turn to be drab in order not to attract attention and then, they were protected. (14) These are all example of adaptation since they *(species) adjust their colors depend on particular environment in order not to be hunted by predators.*	**Claim:** Explanation 3	(Not coded)
	New claim: adaptation due to protection	Epistemic Level V
	Data: polar bear and chameleons' adaptation	Epistemic Level II
	Warrant: adjust color due to protection	Epistemic Level IV
	Backing: adaptation due to protection from predator	Epistemic Level V

4.2.2. Scenario II: Whales

Whales scenario deals with transition form (macroevolution) (see Appendix A). Leyla was provided with this scenario in which she was asked to several questions about the possible relationships among an extinct land mammal, an aquatic whale ancestor and modern whales. Following subsections described the results on each phase.

4.2.2.1. Criteria for Evaluating Validity of Explanation for *Whales* Scenario

After reading scenario, Leyla was asked to determine which of three alternative explanations was the most valid to explain the possible relationship among species. The following dialogue took place after she decided:

> Leyla: The third explanation. Actually at first, I think the first and third explanation but the third one is the most valid. (Pakicetus were some sort of mammal that can live both in land and in water. For this reason, it can be a transitional form. The ancestors of whales were living in land once and they had legs. As a result of changes of genes in the population, whales were born with small or no legs and when their environment changed, these whales with small or no legs became more advantageous and reproduced more.)
>
> Researcher: Why did you say that?
>
> Leyla: Because similarities between them (Pakicetus, Basilosaurus and Whales) were explicitly given. Transitional forms occur in other species. I remembered example of frogs because frogs live in water at early ages and then, they move to land, so this is similar process. In addition, in the first explanation, there is a sudden migration, that is, primitive mammal that lived in land migrated suddenly to water when environment changed. It is not easy like this since here is a possibility to easily adapt to environment and pass genes to new generation but it is very low possibility because evolution is gradual process.

Leyla evaluated acceptability of alternative explanations of *Whales* scenario through using both rigorous and informal criteria. That In particular, she evaluated alternative explanations based on the criterion of how well available data fits with the claim. In particular, she took into account of how provided data regarding similarities of species and existing of small and weak legs consistent with the claim and these are in line with the rigorous criteria. Besides, she also evaluated explanations based on coherence of an explanation in the light of other alternative. In particular, she used this criterion with through using scientific theoretical knowledge regarding gradual process and she denied the inheritance of acquired traits. This is also an example of rigorous criterion. However, she appealed to analogy through giving frog example based on previous knowledge, this is in line with informal criterion.

In the following, Leyla was asked to construct argument for *Whales* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.2.2.2. Conceptual Aspects of Argumentation Practices for *Whales* Scenario

Leyla chose the third explanation which includes evolutionary explanation regarding transitional form. She utilized only one evolutionary explanation with respect to heritability of genes in her argument. The following excerpt indicated this explanation:

> After that, it (genetic change) will *show its effect on offspring* and it showed; it (whale) does not use them (hind limbs) but still they appear.

In addition, she denied the inheritance of acquired traits as "there is a possibility to easily adapt to environment and pass genes to new generation but it is very low possibility because evolution is gradual process." However, she chose the explanation regarding inheritance of acquired traits and generated explanations to support that for previous scenario. Therefore, there was not any coherence in Leyla's explanations regarding this misconception in different context.

Although she chose the alternative regarding evolutionary theory, she had misconceptions about adaptation and use and disuse. She explained adaptation process as "change of genes occurs as a result of adaptation process" and she also stated "while a living thing tries to adapt to environment, it actually undergo evolution." However, adaptation is a process in which species suited to environment through change in genes (Futuyma, 2009). Besides, she appealed to Lamarckian evolution in her argument:

> It weakens but still it shows its effect even if it's small and weak. This is a *Lamarck's theory*.

Besides, Leyla held cognitive biases regarding teleology and intentionality. For instance, she said “when environment changed, in order to *adapt themselves* to new environment and in order to survive, several changes in genes are required.” She seemed to perceive process of adaptation and changes of genes as a goal-driven process. In addition, she mentioned mental agent that direct the events. For example, she said “while a living thing *tries to* adapt to environment, it actually undergo evolution”.

In addition, she confused transitional form with metamorphosis of frogs; she said “Transitional forms occur in other species. I remembered example of frogs because frogs live in water at early ages and then, they move to land. ”

Overall, although she mentioned about heritability of genes, she had misconceptions about use and disuse, and adaptation. She also held cognitive bias regarding teleology and intentionality based on Nehm et al.’s (2010) framework. Hence, her conceptual understanding was categorized as partial understanding with specific misunderstanding (PU/MU) based on Abraham et al.’s (1992) framework.

4.2.2.3. Structural Aspect of Argumentation Practices for *Whales* Scenario

Leyla constructed seven arguments in order to support her claim and rebut the other alternatives.

For the level 2, she constructed five arguments for the third explanation. One of the example quotations was given in Table 4.14. In this example, explanation 3 was regarded as a claim. She used small and weak legs as data to support the claim and she constructed new claim regarding genetic change and explained the reason of appearing legs by genetic change and she backed up her claim with adaptation process. Therefore, her argument was classified as Level 2.

For the Level 4, she generated two arguments for the alternative explanations. She rejected inheritance of acquired traits by explaining the reasons why rapid changes does not occur. She backed up her rebuttal with evolution theory. This was a strong rebuttal because she supported her rejection with data, warrant and backing. Hence, her argument was placed in Level 4.

Table 4.14 Leyla's excerpts at argumentation levels in *Whales* scenario

Argumentation Level	Leyla's excerpts
Level 2	*In the third explanation, Basilosaurus was a transitional form because there was a leg even if it was small and weak. This occurs by genetic changes because when environment changed, in order to adapt themselves to new environment and in order to survive, several changes in genes are required. After that, it (genetic change) will show its effect on offspring and it showed because it (whale) does not use them (hind limbs) but still they appear.*
Level 4	*In the first explanation, there is a sudden migration, that is, primitive mammal that lived in land migrated suddenly to water when environment changed. It is not easy like this since there is a possibility to easily adapt to environment and pass genes to new generation but it is very low possibility because evolution is gradual process. According to evolution theory, changes occur in cells and then, more small transitional forms occur over time.*

4.2.2.3. Epistemic Aspect of Argumentation Practices for *Whales* Scenario

Figure 4.9 represents the distribution of Leyla's propositions across the epistemic levels for *Whales* scenario.

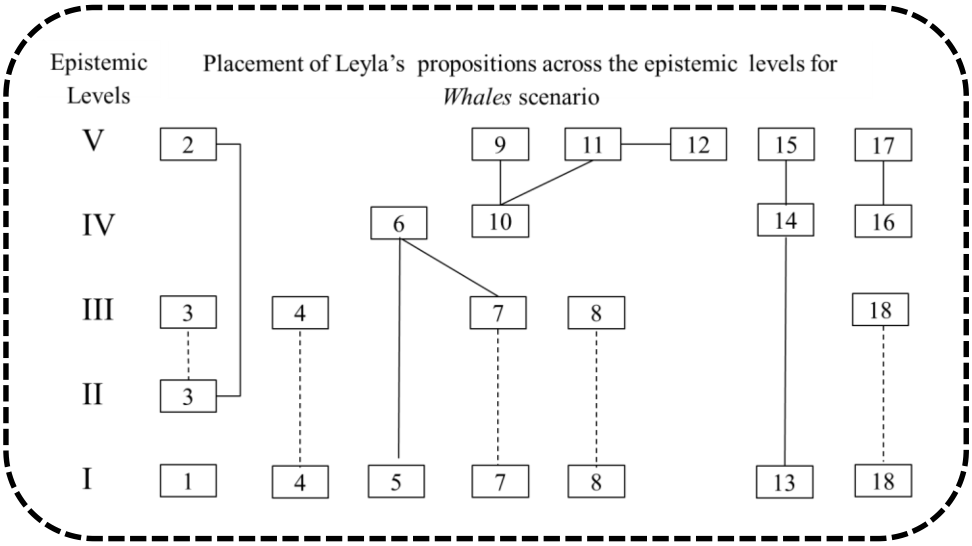

Figure 4.9 Leyla's argumentation structure by epistemic levels for *Whales* scenario

Based on the five epistemic levels model, she referenced information and figure from the task in seven propositions (1, 4, 5, 7, 8, 13 and 18) classified as epistemic level I. In proposition 2, she utilized general theoretical knowledge regarding transitional forms and gave an example of transitional form recalled from previous knowledge and connected the transition forms in proposition 3 classified as epistemic levels II-III. In proposition 4, she used theoretical knowledge regarding inheritance of acquired traits with identifying data with respect to sudden migration in the first explanation placed in epistemic level III. In addition to 4, theoretical knowledge about genetic changes and adaptation with identifying data regarding hind limbs were explained in propositions 7, 8 and 18. Theoretical knowledge regarding adaptation was explained in propositions 6 and 10. While she used general theoretical knowledge in adaptation and evolution process in propositions 9, 11, 15, 12 and 17, she applied this general knowledge to Whales evolution in propositions 14 and 16. A representative example for propositions 13, 14 and 15 was:

> (13) The third explanation mentioned about transitional forms and genetic changes. (14) All of these indicated that living thing is able to live both circumstances. Then, when conditions changed, it (Pakicetus) moved to water and it (hind limb) weakens after permanently disusing. It weakens but still it shows its effect though it's small and weak. (15) This is a Lamarck's theory: traits that are used constantly strengthen, traits that are disused weaken.

In this example, she referenced data from task in 13 and based on this data, she explained process of migration of Pakicetus in proposition 14. Then, she generalized this process to Lamarck's use and disuse theory in proposition 15.

Based on criterion of integration of claims across the levels, Leyla proposed evidenced claims at various levels. Besides, in terms of the criterion of the ratio of data statements to theoretical statements, she used eight data references in proportion to fifteen theoretical claims. That is, theoretical claims were not sufficiently supported by data. Hence, epistemic quality of her argument was relatively low.

4.2.2.5. Articulation of Argumentation practices and Evolution Conceptions in Epistemic Levels for *Whales* Scenario

Table 4.15 illustrated how Leyla justified her claims appealing to evolution conceptions documented in the use of evidenced claims at epistemic levels for Whales scenario. In the first example, she proposed a new claim stating a general theoretical knowledge about transitional forms classified as epistemic level IV. She gave example of metamorphosis of frogs for this theoretical claim classified as epistemic levels II-III but she confused transitional forms with developmental stages of frogs since she perceived that both are similar process.

In the second example, she used small and weak legs of Basilosaurus as a data classified as epistemic level I. In order to justify this data, she constructed general theoretical knowledge about adaptation and genetic changes placed in epistemic level V. However, she used teleological and intentionality reasoning in her justification. Lastly, she backed up her claim with a key concept of evolution (heritability of traits).

Table 4. 15 Articulation of evolution conceptions and argumentation practices for *Whales* scenario

Leyla's Excerpts	Argumentation Practices	Epistemic Levels
(2)Transitional forms occur in other species. (3) I remembered example of frogs because frogs live in water at early ages and then, they move to land and this is similar process.	**Claim:** Explanation 3	(Not coded)
	New claim: transitional forms in other species	Epistemic Level V
	Data: metamorphism of frogs	Epistemic Levels II-III
	Warrant: similarity of metamorphosis and transitional forms	
(5) In the third explanation, Basilosaurus was a transitional form because there was a leg even if it was small and weak. (6) This occurs by genetic changes because when environment changed, in order to adapt themselves to new environment and in order to survive, several changes in genes are required. (7) After that, it (genetic change) will show its effect on offspring and it showed because it (whale) does not use them (hind limbs) but still they appear.	**Claim:** Explanation 3	(Not coded)
	Data: small and weak leg	Epistemic Level I
	New claim: by genetic change	(Not coded)
	Warrant: relation of adaptation and genetic changes	Epistemic Level IV
	Backing: heritability of genes	Epistemic Levels I-III

4.2.3. Scenario III: Lactose Intolerance

Lactose Intolerance scenario deals with gene-culture coevolution in humans (microevolution) (see Appendix A). Leyla was provided with this scenario in which she was asked to several questions about how lactose tolerance developed in humans. Following subsections described the results on each phase.

4.2.3.1. Criteria for Evaluating Validity of Explanation for *Lactose Intolerance* Scenario

After reading scenario, Leyla was asked to determine which of three alternative explanations was the most valid to explain how lactose tolerance developed in humans. The following dialogue took place after she decided:

> Leyla: I accepted the second explanation (People started to consume milk and over time, in consequence of increasing the habit of drinking milk, this situation affects genes and increases the frequency of allele that causes lactase gene to be active in areas where milk is available. As a result, people who have high consumption of milk started to digest lactose. This development affects genes disparately at different population.)
>
> Researcher: Why did you say that?
>
> Leyla: Because provided information indicated that allele that causes lactase gene to be active is related to consuming milk. It was observed that lactose tolerance is very high in areas where dairy farming developed shown in map. Therefore in there, they can digest lactose and then, it (lactose tolerance allele) was moved to certain geographical areas because it is related to milk consumption. That is, by means of consumption of milk, genes adapted, that is to say, based on this map, I think that genes formed in that way. Hence, people increase their habits of drinking milk which affect genes and they acquired trait that provides to digest milk as explanation 2 mentioned.

Leyla evaluated validity of alternative explanations of *Lactose Intolerance* scenario through using rigorous criteria. In particular, Leyla chose the second explanation based on criterion of how well available data fits with the claim. More specifically, she seemed to consider how provided data and information regarding lactose tolerance in Europeans and Africans are consistent with the explanation.

Besides, she seemed to take into consideration of how well scientific knowledge regarding adaptation fits with the claim.

In the following, Leyla was asked to construct argument for *Lactose Intolerance* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.2.3.2. Conceptual Aspect of Argumentation Practices for *Lactose Intolerance* Scenario

Leyla chose the second explanation which includes Lamarckian evolution. She did not use any evolutionary explanations in her arguments. In addition, she had a specific misconception with respect to use and disuse and held also cognitive bias regarding teleology. A representative example for this misconception and teleological reasoning was:

> Something that can be eaten is able to change structure in body. For example, ferocious animals' teeth became sharp *in order to* eat meat, teeth must be sharp.

In this example, she used Lamarck's theory of use and disuse explaining that species evolve by use and disuse of body parts in their lifetime. She explained modification through the use of an organ as a reason for development of lactose tolerance. In the second sentence, she used teleological reasoning and explained modification as goal-driven process.

Besides, she accepted evolution which consists of misconception regarding change due to acquired traits for this scenario and she also used this misconception to justify her claim. However, she rejected it for previous scenario. As I mentioned before, there is lack of coherence for this misconception in her explanations.

Overall, she did not apply any evolutionary explanations and she had misconception and cognitive bias in her arguments based on Nehm et al.'s (2010) framework. Hence, her conceptual understanding was placed in specific misunderstanding (MU) according to Abraham et al.'s (1992) framework.

4.2.3.3. Structural Aspect of Argumentation Practices for *Lactose Intolerance* Scenario

Leyla generated five arguments at Level 2, Level 3 and Level 4 to justify her claims and rebut the other alternatives.

For the Level 2, she generated three arguments for the second explanation. One of the example quotations was given in Table 4.16. In this example, she proposed a new claim regarding modification through the use of organs. She gave examples of modification of ferocious animals' teeth and birds' beaks as a data. Then, linked this data with milk consumption regarded as warrant. Hence, her argument was placed in Level 2.

For the Level 3, she generated one argument. Example quotation was presented in Table 4.16. In this example, she weakly rebutted explanation 1 since she provided weak warrant that is inadequacy of it. However, she did not attempt to explain why this relation is important for argument. Hence, she did not justify her rebuttal adequately.

For the Level 4, she constructed an argument in order to counter alternative explanation. Example of quotation was given in Table 4.16. In this argument, she rebutted the third explanation through the use of data and warrant that construct the relationship. Hence, her argument included a strong rebuttal.

Table 4.16 Leyla's excerpts at argumentation levels in *Lactose Intolerance* scenario

Argumentation Level	Leyla's excerpts
Level 2	*Something that can be eaten is able to change structure in body. For example, ferocious animals' teeth became sharp in order to eat meat, teeth must be sharp. Besides, birds' beaks change depends on seeds that they eat. As a result, because milk is a thing that can be consumed, it affects genes in our body.*
Level 3	*In explanation 1, there is no reason regarding how change in allele frequency is related to milk consumption.*
Level 4	*In explanation 3, it was said that there is no relationship between digestion of lactose and lactase gene being active. However, provided information and data illustrate that lactose tolerance develops in areas where dairy farming is common.*

4.2.3.4. Epistemic Aspect of Argumentation Practices for *Lactose Intolerance* Scenario

Figure 4.10 represents the distribution of Leyla's propositions across the epistemic levels for *Lactose Intolerance* scenario.

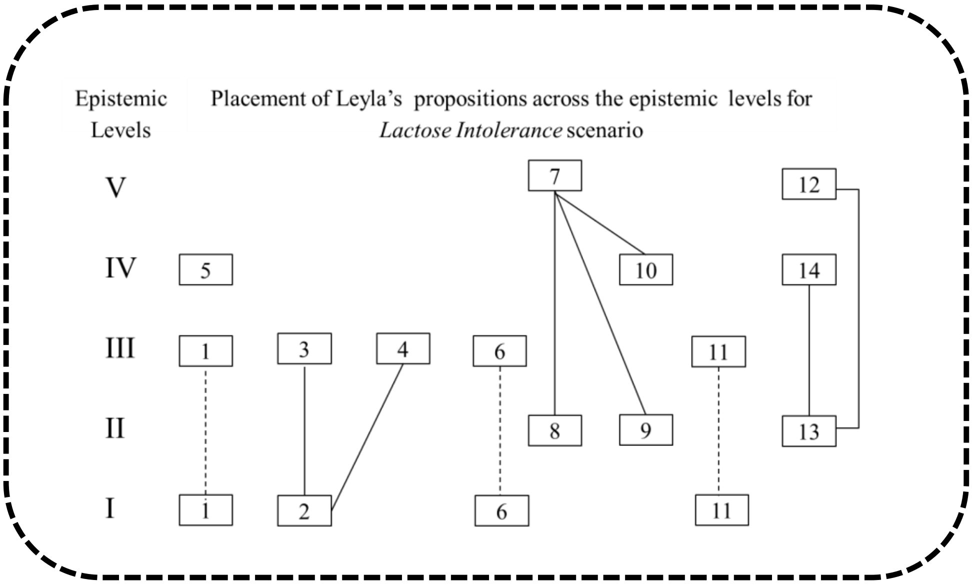

Figure 4.10 Leyla's argumentation structure by epistemic levels for *Lactose Intolerance* scenario

Based on the five epistemic levels model, she explicitly referenced provided information and data in four propositions (1, 2, 6 and 11) classified as epistemic level I. She gave examples regarding other species' modified structure in three propositions (8, 9 and 13) classified as epistemic level II. She constructed theoretical claim with identifying provided data in five propositions (1, 3, 4, 6 and 11). In propositions 5, and 14, she generated theoretical claim regarding inheritance of acquired traits and genetic change. In proposition 12, she stated general theoretical knowledge regarding relation structure in body and diet classified as epistemic level V. A representative example for propositions 7, 8, 9 and 10 was:

> (7) Something that can be eaten is able to change structure in body. (8) For example, ferocious animals' teeth became sharp in order to eat meat, teeth must be sharp. (9) Besides, birds' beaks change depends on seeds that they eat. (10) As a result, because milk is a thing that can be consumed, it affects genes in our body.

In this example, proposition 7 stated a general theoretical knowledge regarding changes in structure due to diet placed in epistemic level IV. Then, examples for different species other than human recalled from existing knowledge were given in propositions 8 and 9 classified as epistemic level II. In proposition 10, she generalized these examples for this context.

In terms of criterion of integration of claims across the levels, Leyla proposed evidenced claims at various levels. Besides, in terms of the criterion of the ratio of data statements to theoretical statements, she used seven data references in proportion to ten theoretical claims. This means that theoretical claims were frequently supported by data. Hence, epistemic quality of her argument was relatively high.

4.2.3.4. Articulation of Argumentation practices and Evolution Conceptions at Different Epistemic Levels for *Lactose Intolerance* Scenario

Table 4.17 represented how Leyla justified her claims appealing to evolution conceptions at different epistemic levels for *Lactose Intolerance* scenario. In the first example, she constructed relationship between milk consumption and increase in lactose tolerance allele classified at epistemic level III. She backed up this relation through using adaptation of genes with identifying provided data placed in epistemic level III. However, she justified her claim through using theoretical claim including misconception regarding change due to acquired traits and theory of use and disuse classified as epistemic level IV.

In the second example, she generated a new claim in the form of general theoretical claim which consists of misconception regarding Lamarck’s theory of use and disuse classified as epistemic level V. Besides, she justified her claim through using data based on this theory classified as epistemic level II. Lastly, she used theoretical assertion through appealing to this misconception in this context placed in epistemic level IV.

Table 4. 17 Articulation of evolution conceptions and argumentation practices for *Lactose Intolerance* scenario

Leyla's Excerpts	Argumentation Practices	Epistemic Levels
(2) It was observed that lactose tolerance is very high in areas where dairy farming developed shown in map. (3) Therefore in there, they can digest lactose and then, it (lactose tolerance allele) was moved to certain geographical areas because it is related to milk consumption. (4) That is, by means of consumption of milk, genes adapted, that is to say, based on this map, I think that genes formed in that way. (5) People increase their habits of drinking milk which affect genes and they acquired trait that provides to digest milk.	**Claim:** Explanation 2	(Not coded)
	Data: Geographic distribution of dairy farming and allele frequency across Europe and Turkey	Epistemic Level I
	Warrant: relationship between dairy farming and digestion of lactose	Epistemic Level III
	Backing 1: Adaptation	Epistemic Level III
	Backing 2: Inheritance of acquired trait and use and disuse	Epistemic Level IV
(12) Species' physical structure change depends on their diet. (13) For instance, bees feed pollen, it becomes worker bees and if bees feed milk, it becomes queen bees. (14) Therefore, in this case, there is no physical changes in body depend on consumption milk but there must be a genetic change since milk consumption influenced it.	**Claim:** Explanation 2	(Not coded)
	New claim: change in structure related with diet	Epistemic Level V
	Data: diets of bees	Epistemic Level II
	Warrant: relationship between milk consumption and genetic change	Epistemic Level IV

4.2.4. Scenario IV: Cambrian Explosion

Cambrian Explosion scenario deals with gaps in the fossil record (macroevolution) (see Appendix A). Leyla was provided with this scenario in which she was asked to several questions about gaps in the fossil record as a consequence of gradual or rapid changes. Following subsections described the results on each phase.

4.2.4.1. Criteria for Evaluating Validity of Explanation for *Cambrian Explosion* Scenario

After reading scenario, Leyla was asked to determine which of three alternative explanations was the most valid to explain the reason of gaps in fossil records. The following dialogue took place after she decided:

> Leyla: I accepted the second explanation (The lack of intermediate fossils is due to the fact that these forms never existed. Multicellular organisms appeared as a consequence of abrupt changes.)
>
> Researcher: Why did you say that?
>
> Leyla: I did not think that change between species did not occur rapidly in first place because evolution is a change that starts in genes and over time, living things developed. However, increasing oxygen level, decreasing temperature, occurrence of ice age epoch on Earth was taken placed in this period. Therefore, sudden changes in species occur because it's a kind of response to these sudden environmental changes, that is, they adapted rapidly. Actually, sudden changes influenced my opinion.

Leyla evaluated validity of alternative explanations of *Cambrian Explosion* scenario through using rigorous criterion. In particular, she evaluated the first explanation based on the criterion of how her previous knowledge regarding scientific theory fits with the claim. However, her thoughts about the rate of evolution were influenced by data embedded in scenario. Therefore, she made her decision on the basis of the criterion of how well the claim fits with available data.

In the following, Leyla was asked to construct argument for *Cambrian Explosion* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.2.4.2. Conceptual Aspect of Argumentation Practices for *Cambrian Explosion* Scenario

She chose the second explanation which was about punctuated equilibrium suggesting that evolutionary changes occur in a short period of time (Eldredge & Gould, 1977). She used theoretical knowledge regarding microevolution in her argument. The following quotation illustrates this evolutionary notion: "Evolution is a change that starts in genes and over time, living things developed". Furthermore, based on punctuated equilibrium theory, dramatic environmental changes lead to high rates of selection which in turn, causes rapid evolution (Eldredge & Gould, 1977) as she explained dramatic climate changes as a cause of rapid evolution.

However, she did not apply any key concepts regarding evolution in her arguments. In addition, she did not have any misconception or cognitive bias for this context based on Nehm et al.'s (2010) framework. For that reason, her conceptual level was placed in No Understanding (NU) according to Abraham et al.'s (1992) framework.

4.2.4.3 Structural Aspect of Argumentation Practices for *Cambrian Explosion* Scenario

Leyla generated five arguments at Level 2 and Level 4 for this scenario to justify and rebut explanations.

For the Level 2, she generated three arguments for the second explanation. One of the example quotations was given in Table 4.18. In this example, the second explanation was regarded as a claim. She used data regarding sudden transition among species and she provided warrant that is relation climatic changes with sudden changes in organisms.

For the Level 4, she constructed two arguments in order to counter alternative explanation. One of the example quotations was given in Table 4.18. In this argument, she firstly supported the first explanation with a justification. Then, she strongly rebutted the first explanation through using provided data regarding sudden transition and climatic change and she reached a conclusion from data.

Table 4.18 Leyla's excerpts at argumentation levels in *Lactose Intolerance* scenario

Argumentation Level	Leyla's excerpts
Level 2	*In the second explanation, at first, there were soft-shell organisms and then, transition occurred from soft-shell to hard-shell organisms. In this period, there was a sudden transition to hard-shell organisms. Because climatic changes could have caused these sudden changes in organisms.*
Level 4	*Explanation 1 is not insufficient because evolution is a slow process proceeding by little steps. This is not wrong but there are conditions here specific to case and these are not consistent with explanation 1. Sudden transition from soft-shell to hard-shell and dramatic climatic changes was mentioned in here. Therefore, I think that rapid evolution is expected to occur when these conditions were taken into consideration*

4.2.4.4. Epistemic Aspect of Argumentation Practices for *Cambrian Explosion* Scenario

Figure 4.11 represents the distribution of Leyla's propositions across the epistemic levels for *Cambrian Explosion* scenario.

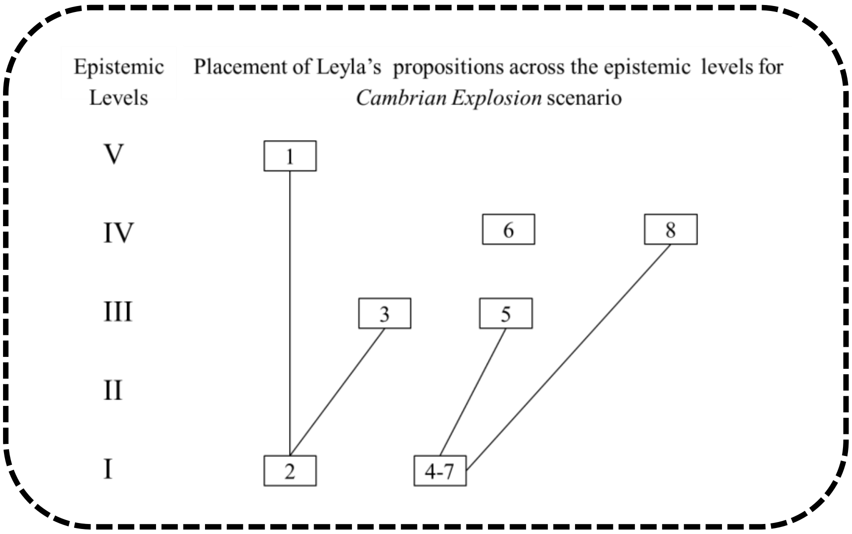

Figure 4.11 Leyla's argumentation structure by epistemic levels for *Cambrian Explosion* scenario

Based on the five epistemic levels model, Leyla explicitly cited data from the task in two propositions (2 and 4) classified as epistemic level I. Proposition 7 includes data mentioned in proposition 4. In proposition 1, she utilized theoretical claim regarding microevolution placed in epistemic level V. In proposition 3, she used theoretical claim by identifying provided data regarding environmental changes placed in epistemic level III. The following quotation indicates propositions 4 and 5:

> (4) In the second explanation, at first, there were soft-shell organisms and then, transition occurred from soft-shell to hard-shell organisms. In this period, there was a sudden transition to hard-shell organisms. (5) Because climatic changes could have caused these sudden changes in organisms.

In this example, she referenced data regarding sudden transition from task in proposition 4 classified as epistemic level I. Then, she constructed cause and effect relation regarding the process of sudden changes based on this data in proposition 5 classified as epistemic level III.

Besides, she utilized theoretical claims regarding gradual process and rapid evolution in propositions 6 and 8 classified as epistemic level IV.

Based on criterion of integration of claims across the levels, Leyla proposed evidenced claims at various levels. In addition, in terms of the criterion of the ratio of data statements to theoretical statements, she used three data statements in proportion to five theoretical claims. However, data statements were not sufficiently associated with theory in her argument. Therefore, epistemic quality of her argument was relatively low.

4.2.4.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels for *Cambrian Explosion* Scenario

Table 4.19 represented how Leyla justified her claims appealing to evolution conceptions documented in the use of evidenced claims at different epistemic levels for *Cambrian Explosion* scenario. In the first example, she did not rebut the first explanation in the general sense but she did when considering specific conditions. She explained reason for rejection through using general theoretical claim regarding microevolution placed in epistemic level V. In order to justify her counter-claim, she used provided data regarding environmental changes placed in epistemic level I and constructed relation with regard to adaptation placed in epistemic level III.

In the second example, she accepted the first alternative as a valid explanation in general but she rejected it for this specific case. She used theoretical claim explaining evolution as a gradual process placed in epistemic level IV. Then, she constructed counter-argument which included provided data classified as epistemic level I and theoretical claim regarding rapid evolution placed in epistemic level IV.

Table 4. 19 Articulation of evolution conceptions and argumentation practices for *Cambrian Explosion* scenario

Leyla's Excerpts	**Argumentation Practices**	**Epistemic Levels**
(1) I did not think that change between species did not occur rapidly in the first place because evolution is a change that starts in cells and over time, living things developed. (2) However, increasing oxygen level, decreasing temperature, occurrence of ice age epoch on Earth was taken placed in this period. (3)Therefore, sudden changes in species occur because it's a kind of response to these sudden environmental changes, that is, they adapted rapidly.	**Claim:** not rapid evolution **Warrant:** Microevolution **Rebuttal** **Counter-claim:** Explanation 2 **Data:** climatic changes **Warrant:** adapted rapidly	(Not Coded) Epistemic Level V (Not Coded) Epistemic Level I Epistemic Level III
(6) Explanation 1 is not insufficient because evolution is a slow process proceeding by little steps. (7) This is not wrong but there are conditions here specific to case and these are not consistent with explanation 1 (not coded). Sudden transition from soft-shell to hard-shell was mentioned in here. (8) Therefore, I think that rapid evolution process is expected to occur when these conditions were taken into consideration.	**Claim:** not sufficient **Warrant:** gradual process **Rebuttal** **Counter-claim:** true but not specific to issue discussed **Data:** sudden transition and **New claim:** rapid evolution by dramatic changes	(Not Coded) Epistemic Level IV (Not coded) Epistemic Level I Epistemic Level IV

4.2.5. Leyla's Result across Scenarios

Profile of Leyla based on findings across the four scenarios in terms of criteria for evaluating alternatives, conceptual, structural and epistemic aspects of argumentation practices was presented in Table 4.20.

Table 4.20 Profile of Leyla Teacher

Evolutionary Scenarios	**Criteria**	**Conceptual Aspects**	**Structural Aspects**	**Epistemic Aspects**
Venezuelan Guppies	Rigorous and Informal Criteria	Specific misunderstanding	Level 2 (Reason)-4 Level 3 (Rebuttal)-2	Coordination of 6 data statements with 8 theoretical statements
Whales	Rigorous and Informal Criteria	Partial Understanding with specific misunderstanding	Level 2 (Reason)- 5 Level 4 (Rebuttal)-2	Coordination of 8 data statements with 15 theoretical statements
Lactose Intolerance	Rigorous Criteria	Specific misunderstanding	Level 2 (Reason)-3 Level 3 (Rebuttal)-1 Level 4 (Rebuttal) -1	Coordination of 7 data statements with 10 theoretical statements
Cambrian Explosion	Rigorous Criteria	No Understanding	Level 2 (Reason)-3 Level 4 (Rebuttal)-2	Coordination of 3 data statements with 5 theoretical statements

In the following five subsections, Leyla's results across the four scenarios were described in detail and discussed.

4.2.5.1. Criteria for Evaluating Validity of Explanation across Scenarios

Leyla used several filters based on rigorous and informal criteria during decision-making phase. On the other hand, she mostly appealed to rigorous criteria, especially to how well available data fits with the claim across the four scenarios. Besides, she declared the emphasis of evidence for persuasive argument and she said "The more you have evidences, the more your argument is persuasive." In addition to this criterion, she scarcely used the other rigorous criteria, in particular how well claims fits with scientific theories and consistency with coherence of an explanation. She used these two criteria based on her previous knowledge. However, she used informal criteria such as the criterion of consistency with personal inference and appeled to analogy even if she scarcely used them across the four scenarios. As a result, although she used scientifically appropriate criteria, she did not consider all criteria that scientists use such as sufficiency of data and adequacy of explanation.

4.2.5.2. Conceptual Aspects of Argumentation Practices across Scenarios

She explained evolutionary theory as "is the process of transformation of species to another species through undergoing different physical and genetic changes." and she declared the reasons for acceptance as a valid theory:

> Evidences are abundant. There are similarities between species. For example, it was observed that our, gorillas and chimpanzees' gene maps are similar. Besides, we and rats share similar structures and functions and that's why, rats are used for test subject. Hence, it is possible that species transform into each other.

Transformation of species is the Lamarck's theory and a misconception about evolutionary theory (Kampourakis & Zogza, 2007). In line with her explanations, Leyla had misconceptions regarding adaptation, inheritance of acquired traits, use and disuse and cognitive biases with respect to teleology and intentionality. She most frequently used teleological explanations and Lamarck's theory of use and disuse in her arguments across the four scenarios. In particular, she explicitly referenced Lamarck's theory in order to explain the evolutionary phenomena. In addition, she confused camouflage with chameleons' color changing and transitional form with metamorphosis of frogs. In more general sense, she did not mention about the variation among species, so she tended to consider species as sharing a common "essence". Thus, she mostly used essential reasoning across the scenarios. She utilized just one key concept of evolution which is heritability of genes and she frequently explained evolutionary phenomena through using adaptation. Moreover, there was not coherence in her statements regarding misconception about inheritance of acquired traits across three scenarios. This may be related to different context. In particular, her misconception about inheritance of acquired traits was arisen in two scenarios which are related to microevolution. Table 4.21 illustrated her evolution conceptions.

Table 4.21 Leyla's conceptions across the four scenarios

Conceptions		**Examples**
Key Concepts	Heritability of genes	"It (genetic change) will *show its effect on offspring"*
Misconceptions	Inheritance of acquired traits	"People increase their habits of drinking milk which affect genes and they *acquired trait* that provides to digest milk."
	Use and Disuse	"When conditions changed, it (Pakicetus) moved to water and it (hind limb) *weakens after permanently disusing*"
	Adaptation	"Change of genes occurs as a result of adaptation process"
Cognitive Biases	Teleology	"Ferocious animals' teeth became sharp *in order to* eat meat"
	Intentionality	"While a living thing *tries* to adapt to environment, it actually undergo evolution."
	Essentialism	"Bright males are few, that is, in order not to attract attention and not to be hunted by predator, they (bright males) turn into drab."

Leyla's conceptual knowledge levels were analyzed across the six conceptual levels (see in Figure 4.12). As seen in the Figure 4.12, her conceptual levels varied across the scenarios. It was more likely related to context. This means that each scenario was designed based on different evolution concepts and alternative explanations included distinct misconceptions and alternative theories.

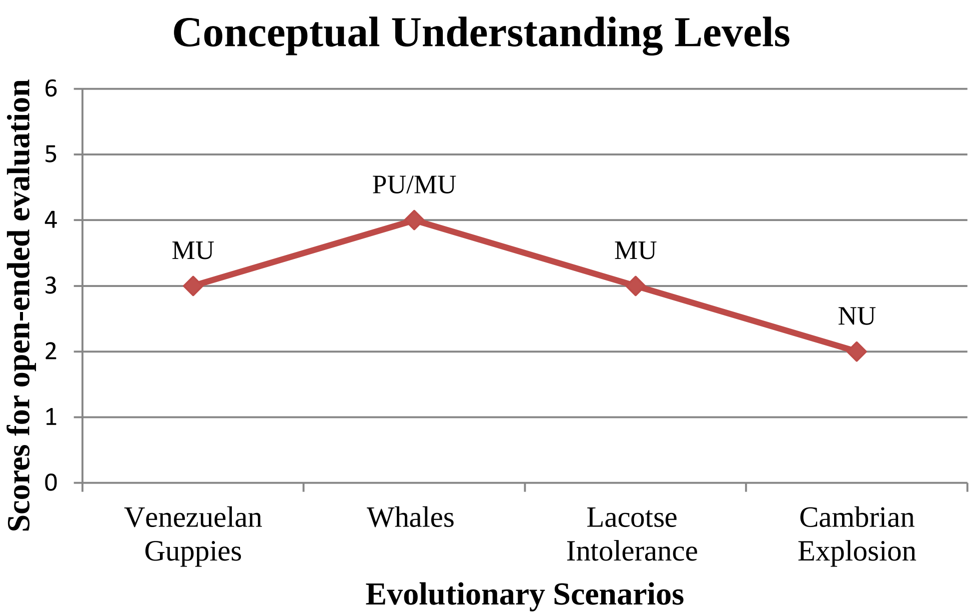

Figure 4.12 Leyla’s conceptual understanding levels across the scenarios

Her arguments included generally misconceptions and cognitive biases. Leyla utilized misconceptions regarding evolutionary theory mostly in *Whales* scenarios. However, she used a key concept regarding heritability of genes only in this scenario. In Cambrian Explosion scenario, she did not use any key concepts or misconceptions regarding evolution. She may not have been familiar with this concept. In addition, she did not use any key concepts of evolution in *Venezuelan Guppies* and *Lactose Intolerance* and used merely misconceptions and cognitive biases. Overall, these may be interpreted that she held misconceptions and cognitive biases for both microevolution and macroevolution. However, misconception regarding change due to inheritance of acquired traits is specific to content regarding microevolution.

4.2.5.3. Structural Aspect of Argumentation Practices across Scenarios

Leyla’s argumentation levels were presented in Figure 4.13. As seen in the figure 4.13, she frequently constructed arguments at Level 2 which includes claim supported by either data, warrant or backing. She did not utilized argument at Level 1 which includes claim vs counter-claim. This means that she mostly justified her claim and supported her counter-claim either weakly or strongly. In addition, she constructed strong rebuttals for the last three scenarios at Level 4. It has to be noted that her argumentation levels were relatively higher in *Whales* scenario than in the others since her arguments included five arguments at Level 2 and two arguments at Level 4 and conceptual understanding level was relatively high in this scenario. The reason of it may be that her conceptual understanding contributed to her justifications. On the other hand, her argumentation levels were also high in *Cambrian Explosion* scenario although her conceptual understanding level was very low, in particular explanations did not include any key concepts of evolution since she rebutted alternative through using data provided in scenario. Hence, these variations among argumentation levels may illustrate that arguments vary depend on the content of scenarios.

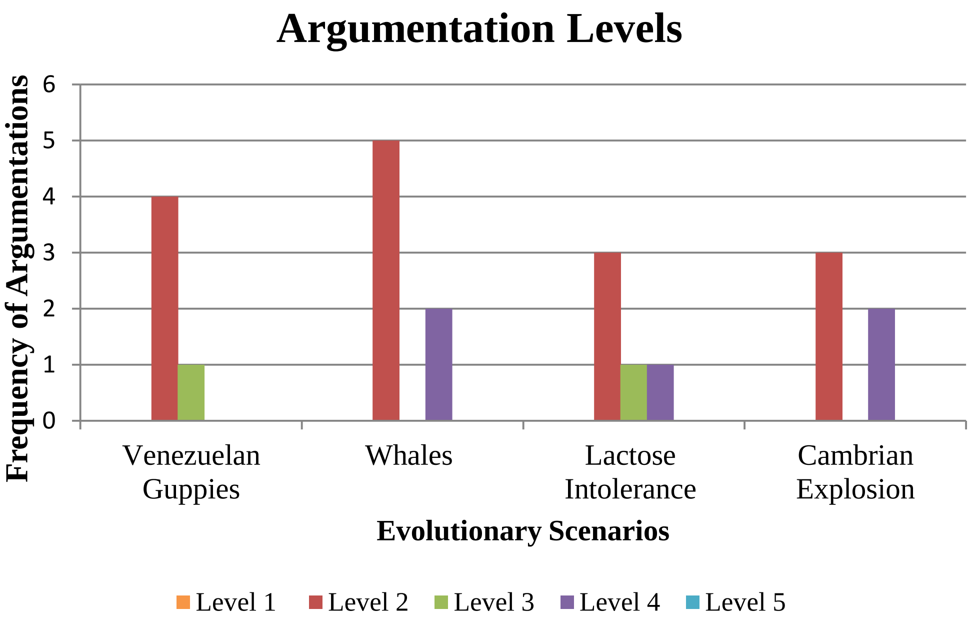

Figure 4.13 Leyla's argumentation levels across the scenarios

Overall, her argumentations were low level since she did not construct any argument at Level 5 which consists of more than one rebuttal across the four scenarios. This may be related to low level of her conceptual understanding. Put it differently, she rebutted alternatives mostly through referencing available data and constructing relations data and theoretical claims regarding mostly adaptation and the processes. However, she did not attempt to take this a step further to construct more sophisticated arguments since she had inadequate knowledge regarding evolutionary theory.

4.2.5.4. Epistemic Aspects of Argumentation Practices across Scenarios

As seen in the Table 4.22, most evidenced claims she used were placed in epistemic level I and epistemic level III across the four scenarios. Specifically, she frequently used propositions making explicit reference to empirical data provided from the tasks and propositions in the form of processes illustrated with data specific to the issue discussed in her argument. In addition, she less frequently used evidenced claim at epistemic level II. In particular, she did not mostly use retrieved data to support or criticize the claims. In terms of ratio of data and theoretical claims, she referenced 24 data statements for 38 theoretical claims. This means that she proposed mostly specific or general theoretical assertions which are insufficiently connected to data statements.

Table 4.22 The distribution of Leyla's propositions across the epistemic levels

Epistemic Levels	**N**	**Percent**
Epistemic Level V- General Theoretical Claims	11	17.7 %
Epistemic Level IV-Theoretical Claims	10	16.1 %
Epistemic Level III- Theoretical Claims with data	17	27.4 %
Epistemic Level II- Retrieved Data	6	8 %
Epistemic Level I- Provided Data	19	30.6 %

Figure 4.14 represented the evidenced claims across the evolutionary scenarios that Leyla constructed. As seen in the figure, she utilized evidence claims at different epistemic levels across the scenarios, especially for *Whales* and *Lactose Intolerance* scenarios. Nevertheless, her theoretical claims were not sufficiently connected by the data statements in *Whales* scenario. However, she sufficiently supported her arguments in *Venezuelan Guppies* and *Lactose Intolerance* scenarios. Hence, quality of her arguments in these scenarios was considered high. In *Cambrian Explosion* scenario, she scarcely brought theoretical claims to context. This may be because she scarcely appealed to her previous knowledge regarding evolution.

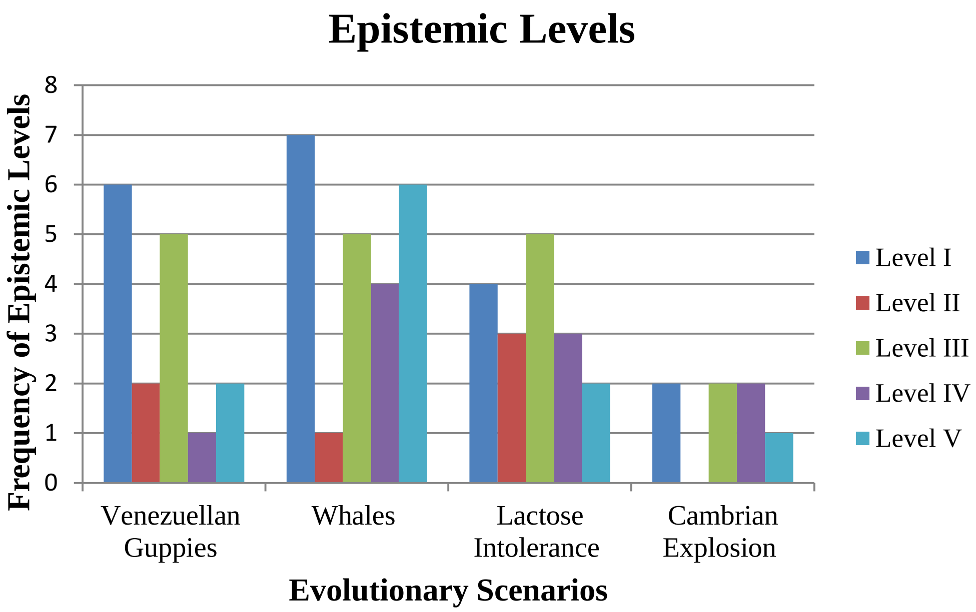

Figure 4.14 Leyla's epistemic levels across the scenarios

Taken together, she most frequently utilized theoretical claims in each scenario. This may be related to her conceptual understanding. This means that since her conceptual understanding was not adequate in order to connect theory and data.

4.2.5.5 Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels across Scenarios

She rarely appealed to evolutionary concepts in her argument. In particular, she used heritability of genes in the form of theoretical assertion in order to justify her claim regarding transition form in *Whales* scenario. Besides, she used general theoretical claim regarding microevolution to support the claim supporting the notion of evolution as a gradual process. In addition, she denied misconception about change due to inheritance of acquired traits in order to offer rebuttal. However, she appealed mostly to misconceptions and cognitive biases in her theoretical justifications. She most frequently utilized teleological explanations and explanations based on theory of use and disuse to justify her claims and less frequently appealed to intentional explanations. It has to be noted that she frequently appealed to notion of adaptation in her theoretical claims to justify her claim but she mostly used this notion inaccurately.

Besides, she provided data recalled from previous knowledge but some of them were not appropriate for evolution context. In particular, she gave chameleons' color changing as an example of camouflage in species and metamorphosis of frogs as an example of transition form.

4.3. Selin' Case

She was 26 years old and graduated from Department of Elementary Science Education, METU in 2011. She took biology courses including general biology I and II, physiology and evolution courses and science methods courses including instructional planning and principles and methods of teaching science courses in which argumentation was introduced. She completed Evolution course with a grade of BA (3,5/4). She was doing her M.S. in Elementary Science and Mathematics Education at METU. She was working at a private school. She had 4 years of teaching experience and she taught to 6th, 7th and 8th grades. She had experience on teaching evolutionary theory.

In the following sections, the results of Selin were presented under the five dimensions including criteria for evaluating validity of explanation, argumentation practices in terms of conceptual, structural and epistemic aspects as well as the articulation of conceptual knowledge regarding evolutionary theory and argumentation practices at different epistemic levels. The results of these analyses were represented for each scenario separately.

4.3.1. Scenario I: Venezuelan Guppies

Venezuelan Guppies scenario deals with natural and sexual selection (microevolution) (see Appendix A). Selin was provided with this scenario in which she was asked to several questions about the reason of observed variation in the coloration within male guppies. Following subsections described the results on each phase.

4.3.1.1. Criteria for Evaluating Validity of Explanation for *Venezuelan Guppies* Scenario

After reading scenario, Selin was asked to determine which of three alternative explanations was the most valid to explain the reason of coloration in Venezuelan Guppies. The following dialogue took place after she decided:

> Selin: It may be explanation 2 and 3. (<u>Explanation 2:</u> Female guppies prefer to mate with brightly colored males. As a result, bright males tend to attract more mates and produce more offspring. When there are lots of predators in a habitat, however, brightly colored males do not survive long enough to reproduce. <u>Explanation 3:</u> The species of guppy try to appear very flashy like many other types of fish. However, when individual migrate into different pools, they need to adjust their coloration in order to avoid predators. As a result, some become drab in order to better fit in with a new habitat. This new trait is then passed down to their offspring because it is useful).
>
> Researcher: Why did you say that?
>
> Selin: In explanation 2, when looking at the table, the number of bright males are abundant, total number of guppies are abundant and reproduce more because females mostly prefer bright males in here. That is, table confirms explanation 2. For the third explanation, the number of drab males is relatively more than the number of bright one. The reason is that they (males) turn into drab in order to suit to environment and they survive.

Selin seemed to evaluate the acceptability of alternative explanations of Venezuelan Guppies scenario based on rigorous criteria valued in science. In particular, Selin evaluated the second explanation based on the criterion of how well data fits with claim since she explicitly referenced from table provided from task and she also evaluated line of reasoning of explanation, that is, she evaluated the reason of color variation established in the second alternative. For the third one, she used two rigorous criteria. More specifically, she seemed to consider consistency of data from table and claim and she appealed to previous theoretical knowledge as to adaptation.

In the following, Selin was asked to construct argument for *Venezuelan Guppies* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.3.1.2. Conceptual Aspects of Argumentation Practices for *Venezuelan Guppies* Scenario

Selin chose the second and third explanations for this scenario. The former one includes evolutionary explanations and the latter consists of misconceptions regarding inheritance of acquired traits and cognitive biases with respect to intentionality and teleology. In line with her choices, she used some key concepts and misconception and cognitive biases in her arguments. Representative examples for key concept of evolution were:

> According to my previous knowledge, males have different colors and traits to *attract females*, like birds. This leads to *competition* among them.
>
> As far as I understood, predators *hunted* bright males.

In the first example, she mentioned about sexual selection (differential survival) among bright males and females and linked it to another key concept, in particular competition. In the second example, she used resource limitation, in particular prey/predator relationship by contrasting relationship between predators and bright males (prey). However, she utilized a misconception regarding adaptation with cognitive bias in her arguments:

> *In order to* suit to environment and *in order to* protect from predators, adaptation may have occurred.

In this example, she explained adaptation process through teleological reasoning. Specifically, she seemed to perceive adaptation process as a need-driven process rather than a process by the species become more suited to environment through change in a trait (Futuyma, 2009).

In parallel of chosen explanation, she also used intentional reasoning in her explanations. For example, she said: "in order to survive, they (males) may have *wanted* to turn into drab" Therefore, she attempted to explain process of color change through a process directed by a mental agent.

Overall, although she appealed to key concepts of evolution regarding differential survival, heritability of genes, resource limitation and competition, she also held misconception such as adaptation and cognitive biases with respect to intentionality and teleology based on Nehm et al.'s (2010) framework. For this reason, her conceptual level was placed in partial understanding with specific misunderstanding (PU/MU) according to Abraham et al.'s (1992) framework.

4.3.1.3. Structural Aspects of Argumentation Practices for *Venezuelan Guppies* Scenario

She generated six arguments at Level 2 and Level 3 for this scenario in order to justify and rebut the alternatives.

For the Level 2, she constructed five arguments to support the second and third explanations. One of the example quotations was presented in Table 4.23. In this example, explanation 3 was regarded as a claim. She referenced the number of predators and drab males as a data and she gave the reason for this through explaining prey/predator relationship. Then, she backed up her claim with evidence with regard to comparison of reproduction rate. However, she did not provide any rebuttal for this argument. Hence, her argument was categorized at Level 2.

For the Level 3, she generated an argument to criticize the first explanation. The example quotation was given in Table 4.23. In this example, she rebutted this explanation with a weak warrant that is unscientific. However, she did not attempt to provide reason why it is unscientific and she also criticized its insufficiency but she did not explain the importance of this insufficiency. Since she weakly rebutted the first explanation, her argument was placed in Level 3.

Table 4.23 Selin's excerpts at argumentation levels in *Venezuelan Guppies* scenario

Argumentation Level	**Selin's excerpts**
Level 2	*In pool I, predators are abundant and drab males are also abundant, so the reason is that predators preferred to bright males and thus, the number of them (bright males) is few, that is to say, as far as I understood, predators hunted bright males. Therefore, they reproduce less and bright males become rare.*
Level 3	*Creation is not a scientific explanation. In addition, this explanation does not include detailed information about the reason of coloration*

4.3.1.4. Epistemic Aspects of Argumentation Practices for *Venezuelan Guppies* Scenario

Figure 4.15 illustrates Selin's propositions across the epistemic levels. In this figure, each sentence was labeled with numbers and sentences served as a propositions. Each of propositions was categorized by epistemic levels and mapped in order to indicate ties across the epistemic levels. Lines connecting propositions represents explicit links between propositions and dashed lines represents the propositions including statements at two epistemic levels.

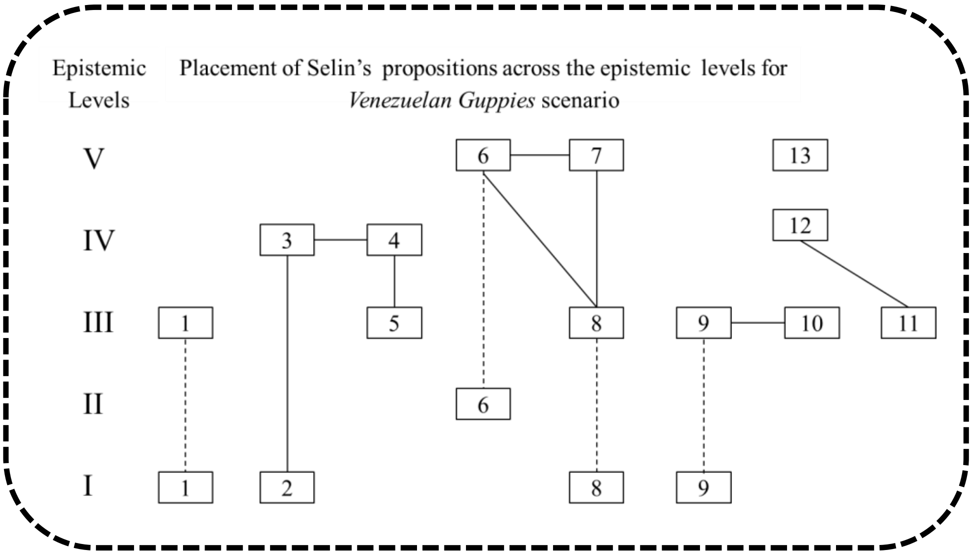

Figure 4.15 Selin's argumentation structure by epistemic levels for *Venezuelan Guppies* scenario

Based on the five epistemic level model, she explicitly referenced table provided from scenario in four propositions (1, 2, 8, and 9) classified as epistemic level I. She also gave data retrieved from previous knowledge regarding sexual selection placed in epistemic level II. In six propositions (1, 5, 8, 9, 10, and 11), she used theoretical claims and explained the processes as to sexual selection, prey/predator relation and the process of coloration with identifying data classified as epistemic level III. A representative example for proposition 11 and 12 was:

> (11) When predators are abundant, drab males are also abundant because in order to suit to environment, in order to protect from predators, adaptation may have occurred. (12) Since in order to protect and hide from predators, they may have turn into drab in deep and dark pools.

In this example, she utilized a theoretical claims regarding adaptation through identifying data placed in epistemic level III. Then, she also appealed to theoretical claims with respect to prey/predator relationship specific to issue discussed categorized in epistemic level IV. Besides, she used theoretical claims concerning heritability of traits and adaptation at epistemic level IV. In addition, she used general theoretical claims with respect to competition, differential survival and creation.

Overall, in terms of integration of claims across the levels, Selin generated claims at different epistemic levels. In addition, in terms of the criterion of the ratio of data statements to theoretical statements, she used five data statements in proportion to twelve theoretical claims. Put it differently, theoretical claims are less frequently supported by data statements. Therefore, epistemic quality of her argument was relatively low.

4.3.1.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels for *Venezuelan Guppies* Scenario

Table 4.24 represented how Selin justified her claims appealing to evolution conceptions documented in the use of evidenced claims at different epistemic levels for *Venezuelan Guppies* scenario. In the first example, she explicitly referenced data from provided table to support the third explanation classified as epistemic level I. Then, she utilized theoretical claim regarding adaptation of drab males in order to justify her claim placed in epistemic level IV. However, she explained this theoretical knowledge through teleological reasoning. Then, she appealed to key concept of evolution concerning heritability of variation in order to back up her claim categorized at epistemic level IV. Then, she also provided a backing regarding a process of preferences and reproduction with identifying data placed in epistemic level III.

In the second example, she generated a new claim in the form of general theoretical claim with respect to sexual selection with identifying an example with respect to a key concept concerning sexual selection retrieved from her previous knowledge placed in epistemic levels II-V since this proposition includes both data recalled from previous knowledge and theoretical claim. Then, she also constructed new general theoretical claim dealing with the key concept of evolution, in particular competition. After that, in order to justify her claim, she appealed to key concepts regarding prey/predator relation and sexual selection in theoretical claim with explicitly referencing data from provided table.

Table 4. 24 Articulation of evolution conceptions and argumentation practices for *Venezuelan Guppies* scenario

Selin's Excerpts	**Argumentation Practices**	**Epistemic Levels**
(2) For the third explanation, the number of drab males relatively more than the number of bright one. (3) The reason is that they (males) turn into drab in order to suit to environment and thus, they survive. (4) In that way, their (drab males) offspring become drab, that is to say, adaptation. (5) Therefore, females do not prefer and they reproduce less in the environment.	**Claim:** Explanation 3	(Not coded)
	Data: comparison of bright males and drab ones	Epistemic Level I
	Warrant: adaptation	Epistemic Level IV
	Backing 1: heritability of variation/adaptation	Epistemic Level IV
	Backing 2: process of preferences and reproduction	Epistemic Level III.
(6) According to my previous knowledge, males have different colors and traits to attract females, like birds (7) This leads to competition among them. (8) Here, the number of offspring is more in pool 4 because when there no predators, the number of bright males becomes abundant, that is, they reproduce easily and they attract more females and thus, they reproduce more.	**Claim:** Explanation 2	(Not coded)
	New claim: Differential survival (Sexual Selection)	Epistemic Levels II-V
	Data: example of sexual selection	
	New claim: Competition	Epistemic Level V
	Data: offspring in pool 4 **Warrant:** sexual selection and prey/predator relation	Epistemic Levels I-III

4.3.2. Scenario II: Whales

Whales scenario deals with transition form (macroevolution) (see Appendix A). Selin was provided with this scenario in which she was asked to several questions about the possible relationships among an extinct land mammal, an aquatic whale ancestor and modern whales. Following subsections described the results on each phase.

4.3.2.1. Criteria for Evaluating Validity of Explanation for *Whales* Scenario

After reading scenario, Selin was asked to determine which of three alternative explanations was the most valid to explain the possible relationship among species. The following dialogue took place after she decided:

> Selin: It could be third explanation. (Pakicetus were some sort of mammal that can live both in land and in water. For this reason, it can be a transitional form. The ancestors of whales were living in land once and they had legs. As a result of changes of genes in the population, whales were born with small or no legs and when their environment changed, these whales with small or no legs became more advantageous and reproduced more.)
>
> Researcher: Why did you say that?
>
> Selin: It was said that it (Pakicetus) could live in both land and sea because it was mentioned in the first paragraph that ear region of the skull is not exactly similar to land mammals but it is somewhere between that of land mammals and fully aquatic mammals and thus, it could be a mammal live in both water and land. I think that Pakicetus could be common ancestor of whales because they had legs and then, they did not use them and become small and thus, they began to live water due to change in genes in population. Besides, according to my previous knowledge, I remembered that there was a transition in evolutionary process. Therefore, the third explanation is scientific and correct explanation.

Selin seemed to evaluate acceptability of alternative explanations of *Whales* scenario through using rigorous criteria. More specifically, for the third explanation, she seemed to take into consideration of how well data embedded in scenario fits with claim since she reached a conclusion from evidence regarding similarity. Also, she utilized the criterion of how well claims fit with scientific theory as regards common ancestry and scientific knowledge about transition from land to water.

In the following, Selin was asked to construct argument for *Whales* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.3.2.2. Conceptual Aspect of Argumentation Practices for *Whales* Scenario

She chose the third explanation including evolutionary explanations. In line with her choice, she mostly appealed to key concepts of evolution regarding differential survival (natural selection), overproduction of offspring, variation, heritability of genes and generational changes in the distribution in her arguments. Besides, she rejected Lamarck's theory such as change due to inheritance of acquired traits. A representative example for key concept of evolution was:

> I know that evolution occurred as a consequence of *variation* in genes in population and these genes *passed to next generation*.
>
> *Natural selection*; species suited to environment can survive.

In the first example, she explained evolution via variation in genes and heritability of this variation. In the second example, she defined the natural selection for whale evolution. In addition to key concepts, she appealed to other evolutionary concepts such as common ancestry and homologous organs in her arguments. A representative example for this concept was:

> It was showed anatomical similarity between Pakicetus' forelimbs that it used for walking and other species' fins. Here, it was mentioned about *homologous organs* and it's evidence because according to *Darwin's theory*, homologous organs are evidence for evolution.

Overall, since she mostly appealed to key concepts and she did not use any misconception and cognitive bias in her explanations based on Nehm et al.'s (2010) framework, her conceptual understanding for this scenario was placed in sound understanding (SU) according to Abraham et al.'s (1992) framework.

4.3.2.3. Structural Aspect of Argumentation Practices for *Whales* Scenario

Selin constructed eight arguments at Level 2 and Level 4 in order to support her claim and rebut the other alternatives for *Whales* scenario.

For the Level 2, she constructed six arguments for the third explanation. One of the example quotations was given in Table 4.25. In this example, the third explanation was considered as a claim. She used similarity of forelimbs as a data and she provided a warrant through explaining species' closeness via using homologous organs as an evidence for evolution. Then, she backed up her claim through explaining what homologous organ is.

For the Level 4, she generated two arguments for the first and second explanations. One of the example quotations was given in Table 4.25. In this example, explanation 2 was regarded as a claim and "unscientific explanation" as a counter-claim. She strongly rebutted the second explanation through referencing data regarding transition from land to water.

Table 4.25 Selin's excerpts at argumentation levels in *Whales* scenario

Argumentation Level	**Selin's excerpts**
Level 2	*It was showed anatomical similarity between Pakicetus' forelimbs that it used for walking and other species' fins. Here, it was mentioned about homologous organs and it's evidence because according to Darwin's theory, homologous organs are evidence for evolution. Organs having same physical features and different functions are found within species close to each other.*
Level 4	*Explanation 2 stated that while one is land mammal, the other is sea mammals and there is no relationship between them. However, based on my previous knowledge, evolution occurred from land to sea, so the second explanation is inaccurate. That is to say, that they are different species is not scientific explanation.*

4.3.2.4. Epistemic Aspects of Argumentation Practices for *Whales* Scenario

Figure 4.16 represents the distribution of Selin's propositions across the epistemic levels for *Whales* scenario.

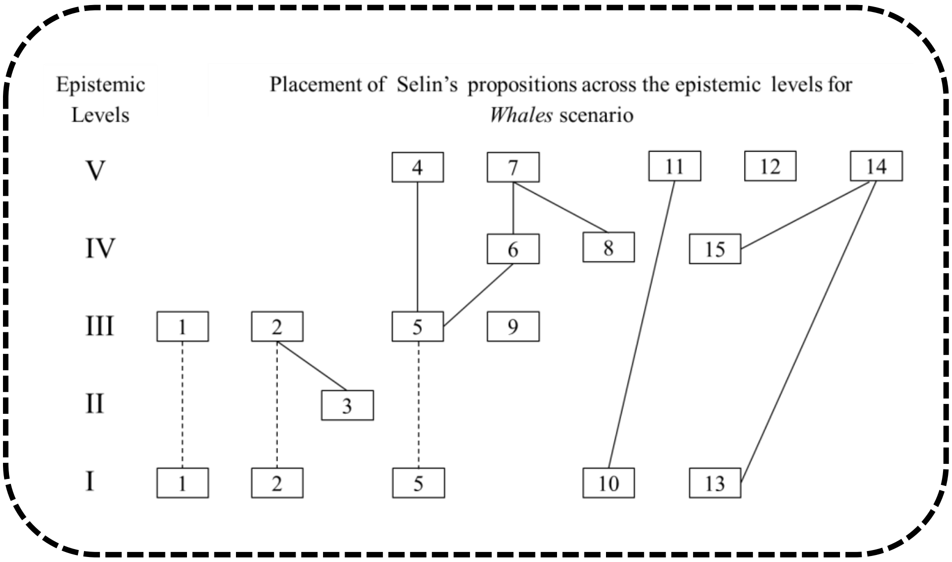

Figure 4.16 Selin's argumentation structure by epistemic levels for *Whales* scenario

Based on the five epistemic level model, she explicitly cited data provided from the task in five propositions (1, 2, 5, 10 and 13) classified as epistemic level I. A representative example for propositions 2 and 3 were:

> (2) Pakicetus could be common ancestor of whales because they had legs and then, they did not use them and become small and thus, they began to live water due to change in genes in population. (3) According to my previous knowledge, I remembered that there was a transition from land to water in evolutionary process.

She used a theoretical claim regarding common ancestry with identifying data embedded in scenario. Since this proposition includes both theoretical claim and explicitly referenced data, it was placed in epistemic levels I-III. In addition, she also referenced data retrieved from previous knowledge with respect to transition in proposition 3 placed in epistemic level II.

She also used theoretical claims regarding common ancestry and variation with identifying provided data in three propositions (1, 5, and 9) classified as epistemic level III. In propositions 6, 8 and 15, she utilized theoretical claims regarding differential survival, adaptation and Lamarck's evolution theory specific to issue discussed categorized at epistemic level IV. Besides, she used general theoretical claims with respect to heritability of genes, natural selection, homologous organs and theory of inheritance of acquired traits in five propositions classified as epistemic level V.

In terms of criterion of integration of claims across the levels, Selin proposed evidenced claims at various levels. Besides, in terms of the criterion of data statements to theoretical statements, she used six data references in proportion to thirteen theoretical claims. This means that theoretical claims were not sufficiently supported by data. Hence, epistemic quality of her argument was relatively low.

4.3.2.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels for *Whales* Scenario

Table 4.26 illustrated how Selin justified her claims appealing to evolution conceptions at different epistemic levels for Whales scenario. In the first example, explanation 3 was considered as a claim. She generated a new general theoretical claim regarding variation and heritability of genes placed in epistemic level V. She explained the process of change of legs with identifying in order to justify her claim classified as epistemic level III. Then, she backed up her claim with general and specific theoretical claims with respect to adaptation, generational changes and natural selection.

In the second example, explanation 1 was regarded as a claim. She opposed it by a counter-claim. Then, she explicitly referenced data embedded in explanation 1 placed in epistemic level I. She used general theoretical claim regarding rejection of Lamarck's theory as a warrant to justify her claim classified as epistemic level V. Then, she backed up her counter-claim through using theoretical claim concerning inheritance of acquired traits for whale evolution placed in epistemic level IV.

Table 4. 26 Articulation of evolution conceptions and argumentation practices for *Whales* scenario

Selin's Excerpts	Argumentation Practices	Epistemic Levels
(4) I know that evolution occurred as a consequence of variation in genes in population and these genes passed to next generation. (5) In the third explanation, it is mentioned about change of genes in population, it's important because this change in genes provide to form small and weak hind limbs. (6) This (small and weak legs) becomes common in population because it provides species to suit to their environment, that is, adaptation occurred, that is, one of the mechanism of evolution. (7) That is to say, natural selection, species suited to environment can survive. (8) Here, species which have small and weak legs suit to their environment because they are common as a consequence of natural selection.	**Claim:** Explanation 3	(Not coded)
	New claim: variation and heritability of genes	Epistemic Level V
	Data: changes in genes **Warrant:** weak and small legs	Epistemic Level III
	Backing 1: Adaptation /Generational changes	Epistemic Level IV
	Backing 2: Natural selection	Epistemic Level V
	Backing 3: Natural selection	Epistemic Level IV
(13) I did not choose Explanation 1 because it seemed to mean that physical features are passed to next generations. (14) It is not correct (Not coded). Since this is Lamarck's theory and it was collapsed and (15) here, physical features or changes are not passed to next generations.	**Claim:** Explanation 1	(Not coded)
	Rebuttal	
	Counter-claim: It's not correct	(Not coded)
	Data: inheritance of acquired traits	Epistemic Level I
	Warrant: rejection of Lamarck's theory	Epistemic Level V
	Backing: rejection of inheritance of acquired traits.	Epistemic Level IV

4.3.3. Scenario III: Lactose Intolerance

Lactose Intolerance scenario deals with gene-culture coevolution in humans (microevolution) (see Appendix A). Selin was provided with this scenario in which she was asked to several questions about how lactose tolerance developed in humans. Following subsections described the results on each phase.

4.3.3.1. Criteria for Evaluating Validity of Explanation for *Lactose Intolerance* Scenario

After reading scenario, Selin was asked to determine which of three alternative explanations was the most valid to explain how lactose tolerance developed in humans. The following dialogue took place after she decided:

> Selin: I think explanation 1 and explanation 3 (Explanation 1: Since consuming milk is advantageous, the frequency of lactose tolerance allele increases in areas where dairy farming is common. As a result, digesting lactose becomes common in population. This process took placed in different geographical regions through change in the frequency of different allele which has same effects. Explanation 3: variation of digestion of lactose between communities and within communities is not related to consumption of milk. This is mostly based on whether randomly carrying lactose tolerance allele or not before dairy farming started. For instance, there are still people who do not digest milk in Europe where dairy farming started. That's why each person carries different lactose allele.)
>
> Researcher: Why did you say that?
>
> Selin: For the explanation 1, it was observed that the frequency of lactose tolerance allele is high in areas where dairy farming developed. The reason of this is that they (people) consumed milk to fed and survive and thus, people digest lactose survive and others die by natural selection based on Darwin's theory. (…) It could be the third explanation because while some people may have active lactase gene, others do not. It was mentioned about genetic drift; Darwin's evidences that support evolution, and it (genetic drift) leads to variation because it (variation) occurred completely randomly. Therefore, both of them (explanation 1 and 3) are scientifically valid.

Selin seemed to evaluate validity of alternative explanations of *Lactose Intolerance* scenario through using rigorous criteria. More specifically, she seemed to take into consideration of how well provided data fits with the claim. However, she mostly used the criterion of how well claims fit with scientific theories. In particular, she supported explanation 1 and 3 due to theoretical knowledge regarding natural selection and genetic drift and she explained the reason for her choices as "scientifically valid".

In the following, Selin was asked to construct argument for *Lactose Intolerance* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.3.3.2. Conceptual Aspect of Argumentation Practices for *Lactose Intolerance* Scenario

Selin chose the first and third explanation for this scenario. While one includes evolutionary explanations, the other consists of rejection of evolution. However, she did not reject the evolution. Instead, she brought to bear evolutionary explanations to third explanation. A representative example for this notion:

> It is *genetic drift*; Darwin's evidences that support evolution, and here, it (genetic drift) leads to *variation* because it (variation) occurred completely randomly.

In this example, she explained one of the mechanisms of evolution, in particular genetic drift that is defined as allele or gene variants in population due to random sampling (Futuyma, 2009) and a key concept regarding variation. In addition to genetic drift and variation, she mostly appealed to key concepts of evolution as regard to heritability of variation, differential survival, overproduction of offspring and generational changes in allele frequency. Representative examples for these concepts were:

> They (people) consumed milk to fed and survive and thus, people digest lactose *survive* and others *die* by *natural selection* based on *Darwin's theory.* The frequency of lactose tolerance allele becomes high since consuming milk becomes advantage.

> People who digest lactose become *abundant* and *common* in population.

In first example, she appealed to concept of differential survival (natural selection) and in the second example, she explained key concepts concerning generational changes in the frequency of variation.

Overall, since she mostly appealed to key concepts of evolution and she did not utilize any misconception and cognitive bias in her arguments, her conceptual understanding for this scenario was placed in sound understanding (SU) according to Abraham et al.'s (1992) framework.

4.3.3.3. Structural Aspect of Argumentation Practices for *Lactose Intolerance* Scenario

Selin generated five arguments to justify her claims and rebut the other alternatives for *Lactose Intolerance* scenario.

For the level 2, she constructed four arguments for the first and third explanations. One of the example quotations was given in Table 4.27. In this example, explanation 1 was considered a claim. She used a data with respect to dairy farming in Africa embedded in scenario to support her claim. Then, she reached a conclusion and generated a new claim with respect to heritability of genes. Since argument consisted of justification, her argument was placed in Level 2.

For the level 4, she generated an argument for the second explanation. The example quotation was presented in Table 4.27. In this example, the second explanation was regarded as a claim. She opposed this explanation by a counter-claim that is unscientific. She provided a data as to Lamarck's theory and then, she provided a warrant why it is not correct, so she rejected inheritance of acquired traits. Since she strongly rebutted the second explanation through using data and warrant, her argument was classified as Level 4.

Table 4.27 Selin's excerpts at argumentation levels in *Lactose Intolerance* scenario

Argumentation Level	Selin's excerpts
Level 2	*In Africa, dairy farming started 9000 years ago. Therefore, they consumed milk and people who digest lactose have been common and their allele, genes was passed to next generations.*
Level 4	*Explanation 2 stated that increasing habits of drinking milk influences genetic. However, this is not scientific. It supports the Lamarck's theory. That is to say, I may have some physical features or habits but it does not mean that my children have same habits or features and this is not passed to genes and that's why it is not correct.*

4.3.3.4. Epistemic Aspect of Argumentation Practices for *Lactose Intolerance* Scenario

Figure 4.17 represents the distribution of Selin's propositions across the epistemic levels for *Lactose Intolerance* scenario.

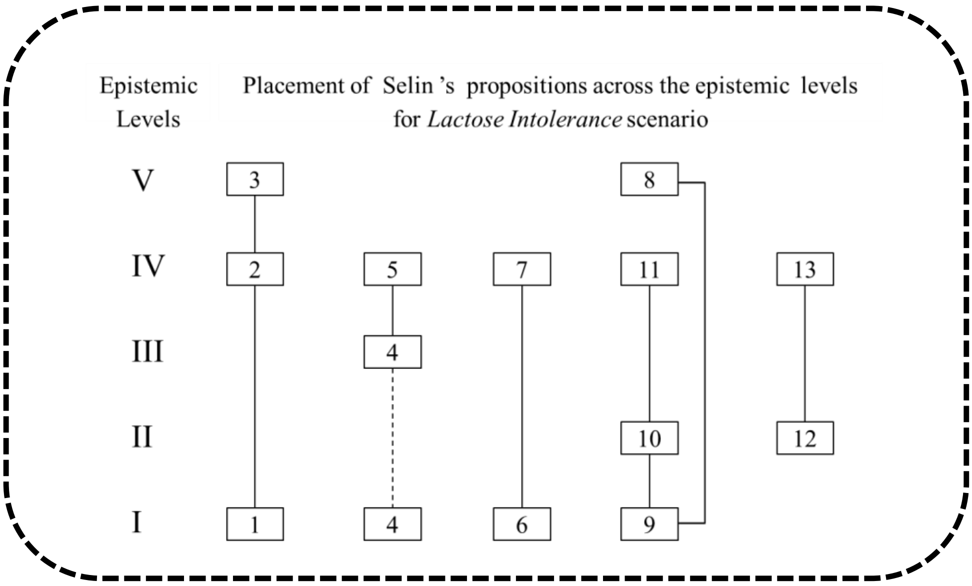

Figure 4.17 Selin's argumentation structure by epistemic levels for *Lactose Intolerance* scenario

Based on five level epistemic model, she explicitly referenced data provided in scenario in four propositions (1, 4, 6 and 9) classified as epistemic level I. She also referenced data retrieved from her previous knowledge in two propositions (10 and 12) placed in epistemic level II. In proposition 4, she used theoretical claim regarding differential survival with referencing provided data classified as epistemic level III. She also used specific theoretical claims concerning generational changes, heritability of genes, genetic drift and inheritance of acquired traits in five propositions (2, 5, 7, 11 and 13) placed in epistemic level IV. In 3 and 8 propositions, she used general theoretical claims with respect to genetic drift and natural selection categorized at epistemic level V. A representative example for 1, 2 and 3 was:

> (1) It was observed that the frequency of lactose tolerance allele is high in areas where dairy farming developed. (2) The reason of this is that they (people) consumed milk to fed and survive and thus, people digest lactose survive and others die by natural selection based on Darwin's theory. (3) Because natural selection means that living things that suited to environment selected, others extinct and thus, evolution occurred.

In this example, she explicitly cited data provided from the task. Then, she used theoretical claim with respect to natural selection specific to issue discussed placed in epistemic level IV. Besides, she used general theoretical claim regarding natural selection classified as epistemic level V.

Overall, based on criterion of integration of claims across the levels, Selin proposed evidenced claims at various levels. Besides, in terms of the criterion of the ratio of data statements to theoretical assertions, she used six data references in proportion to eight theoretical claims. That is, theoretical claims were sufficiently supported by data. Hence, epistemic quality of her argument was relatively high.

4.3.3.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels for *Lactose Intolerance* Scenario

Table 4.28 illustrated how Selin justified her claims appealing to evolution conceptions at different epistemic levels for *Lactose Intolerance.* In the first example, explanation 2 was regarded as a claim. She justified her claim through using theoretical claim regarding key concept of evolution, in particular differential survival regarded as warrant with explicitly referencing data from the scenario to support her claim placed in epistemic levels I-III.

In the second example, explanation 3 was considered as a claim. She used a new general theoretical claim with respect to evolutionary notion, in particular genetic drift classified as epistemic level V. Then, she explicitly cited data provided form scenario placed in epistemic level I and she also provided data retrieved from her previous experience placed in epistemic level II in order to support her claim. She explained the reason of variation through using specific theoretical claim regarding genetic drift classified as epistemic level IV.

Table 4. 28 Articulation of evolution conceptions and argumentation practices for *Lactose Intolerance* scenario

Selin's Excerpts	**Argumentation Practices**	**Epistemic Levels**
(4) The frequency of lactose tolerance allele becomes high since consuming milk becomes advantage based on this map. (5) Therefore, people who digest lactose become abundant and common in population.	**Claim:** Explanation 2	(Not coded)
	Data: frequency of lactose tolerance allele **Warrant:** Differential Survival	Epistemic Levels I-III
	Backing: Generational changes in allele frequency	Epistemic Level IV
(8) It could be the third explanation because while some people may have active lactase gene, others do not (Not coded). It was mentioned genetic drift; Darwin's evidences that support evolution, it (genetic drift) leads to variation because it (variation) occurred completely randomly. (9) Here, for instance, some people who can digest lactose and others who cannot digest lactose are live together, more specifically, while 10 % of Americans can digest lactose, rest of the do not. (10) In Turkey, while many people can digest lactose, my family and I have problems with digestion of milk. (11) Therefore, different allele was formed due to genetic variation, that is to say, genetic drift.	**Claim:** Explanation 3	(Not coded)
	New claim: Genetic Drift	Epistemic Level V
	Data: Variation among people	Epistemic Level I
	Data: example of herself	Epistemic Level II
	Warrant: variation due to genetic drift	Epistemic Level IV

4.3.4. Scenario IV: Cambrian Explosion

Cambrian Explosion scenario deals with gaps in the fossil record (macroevolution) (see Appendix A). Selin was provided with this scenario in which she was asked to several questions about gaps in the fossil record as a consequence of gradual or rapid changes. Following subsections described the results on each phase.

4.3.4.1. Criteria for Evaluating Validity of Explanation for *Cambrian Explosion* Scenario

After reading scenario, Selin was asked to determine which of three alternative explanations was the most valid to explain the reason of gaps in fossil records. The following dialogue took place after she decided:

> Selin: I selected Explanation 1. (The lack of intermediate fossils is due to the fact that very few fossils from periods prior to 570 million years were formed or preserved. The evolution of multicellular organisms was a gradual process proceeding by little steps.)
>
> Researcher: Why did you choose that?
>
> Selin: Because it is true. People who rejected evolution said why monkey are not still evolving into human since they don’t understand that (gradual process), that is to say, evolution is a gradual process. The reason of non-exiting of fossils is that sudden climatic changed, environmental conditions changed and different habitats formed. Therefore, fossils may not have either protected or been founded yet or they (fossils) did not endure climatic conditions changing very fast. They (fossils) did not endure climatic conditions changing very fast.

Selin evaluated acceptability of alternative explanations of *Cambrian Explosion* scenario through using rigorous criteria. In particular, she evaluated the first explanation based on the criterion of how well her previous knowledge regarding gradual process fits with the claim since she declared “It is true”. She decided simply based on her existing knowledge and her knowledge based on scientific theory. That is, she took into consideration of how well scientific theory fits with claim.

In the following, Selin was asked to construct argument for *Cambrian Explosion* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.3.4.2. Conceptual Aspects of Argumentation Practices for *Cambrian Explosion* Scenario

She chose the first explanation which is related evolution through gradual process. She used one key concept of evolution, in particular generational changes in the distribution in her arguments. Besides, she mentioned about Darwin’s theory of gradual process. The representative examples for these concepts were:

> For instance, when whales began to live in water, their legs shortened *slowly* and then, their offspring adapted to sea environment. They did not move to sea instantly.
>
> According to Darwin, evolutionary process *takes long time* and it is a *slow changing process* that lasts hundreds of years for multicellular organisms.

In the first example, she gave example regarding generational changes from *Whales* scenarios. Besides, she explained the Darwin’s gradual evolution. She did not hold any misconceptions and cognitive biases for this scenario. However, she used only one key concept of evolution. For that reason, her conceptual understanding level was placed in partial understanding (PU) according to Abraham et al. (1992) framework.

4.3.4.3. Structural Aspects of Argumentation Practices for *Cambrian Explosion* Scenario

Selin constructed four arguments at Level 2 and 4 in order to support her claim and rebut the other alternative.

For the Level 2, she constructed three arguments to support the first explanation. One of the example quotations was presented in Table 4.29. In this example, explanation 1 was considered as a claim. She provided regarding climatic and environmental changes. Then, she reached a conclusion and generated a new claim. However, she did not attempt to oppose to alternative one. Hence, her argument was placed in Level 2.

For the Level 5, she generated an argument for the first explanation. One of the example quotations was given in Table 4.29. In this example, explanation 2 was regarded as claim. She generated a counter-claim that is “not correct”. Then, she supported this claim by a warrant that is her previous knowledge. Then, she gave examples for intermediate forms as a data and explained relation gradual process with intermediate forms regarded as a warrant. Since she strongly rebutted the second explanation twice though justifications, her argument was classified as Level 5.

Table 4.29 Selin’s excerpts at argumentation levels in *Cambrian Explosion* scenario

Argumentation Level	**Selin’s excerpts**
Level 2	*The reason of non-exiting of fossils is that sudden climatic changed, environmental conditions changed and different habitats formed. Therefore, fossils may not have either protected or been founded yet or they (fossils) did not endure climatic conditions changing very fast.*
Level 5	*It (second explanation) is not correct. I know that this occurs in long periods of time by gradually. Besides, intermediate forms mostly formed, we saw them in evolution course such as between human and ancestor, because there is no abrupt changes, it occurs gradually in a long periods of time that allow them to form.*

4.4.4.3. Epistemic Aspect of Argumentation Practices for *Cambrian Explosion* Scenario

Figure 4.18 represents the distribution of Selin’s propositions across the epistemic levels for *Cambrian Explosion* scenario.

Based on five epistemic levels model, she explicitly cited data as to climatic and environmental changes provided in scenario in proposition 2 classified as epistemic level I. She referenced data retrieved from previous knowledge in four propositions (1, 5, 6, and 9) placed in epistemic level II. In propositions 1 and 3, she used theoretical claims and process regarding gradual process with identifying data placed in epistemic level III. A representative example for proposition 1 was:

(1) People who rejected evolution said why monkey are not still evolving into human since they don’t understand that (gradual process), that is, evolution is a gradual process.

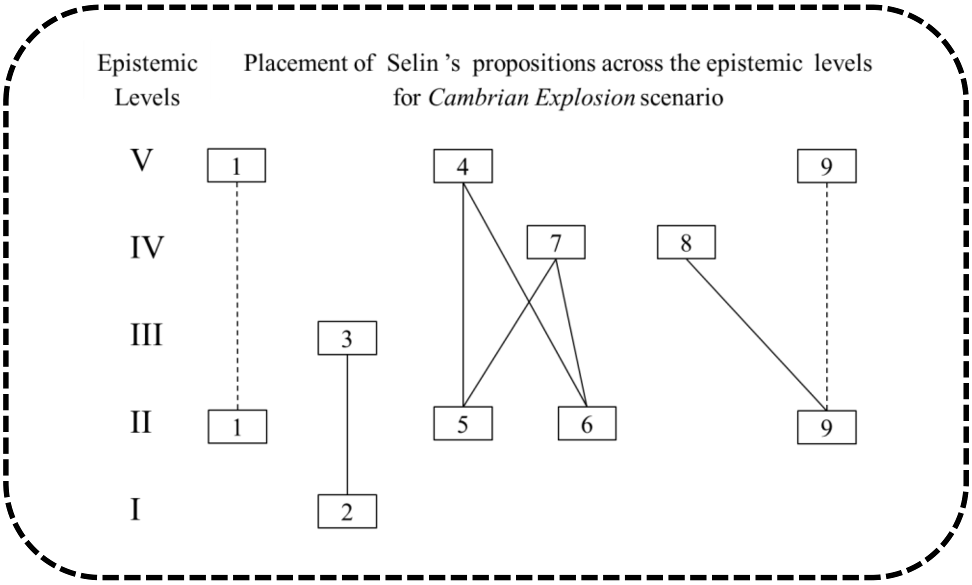

Figure 4.18 Selin's argumentation structure by epistemic levels for *Cambrian Explosion* scenario

In this example, she used theoretical claim regarding gradual process with identifying data retrieved from her previous knowledge or experience regarding common misconception among people classified as epistemic levels II-III.

Furthermore, she used two propositions (7 and 8) in the form of theoretical claim regarding gradual process specific to issue discussed placed in epistemic level IV and she also used general theoretical claim dealing with Darwin's theory and intermediate forms in propositions 4 and 9 categorized at epistemic level V.

Based on criterion of integration of claims across levels, Selin proposed evidenced claims at various levels. Besides, in term of the criterion of ratio of data statements to theoretical ones, she used five data references in proportion to six theoretical claims. Hence, theoretical claims were sufficiently supported by data. Hence, her epistemic quality of argument was relatively high.

4.3.4.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels for *Cambrian Explosion* Scenario

Table 4.30 represented how Selin justified her claims appealing to evolution conceptions documented in the use of evidenced claims at different epistemic levels for *Cambrian Explosion* scenario. In the first explanation, explanation 1 was regarded as a claim. She generated general theoretical claim as a new claim concerning an evolutionary notion, in particular evolution through gradual process placed in epistemic level V. She referenced data retrieved from her previous knowledge regarding whale evolution and also human evolution to support her claim classified as epistemic level II. In addition, she also appealed to a key concept of evolution, in particular generational changes in distribution for her data statement. Then, she used theoretical claim regarding evolutionary time in order to justify her claim categorized at epistemic level IV.

In the second example, explanation 2 which is about punctuated equilibrium considered as a claim. She opposed it by a counter-claim. Then, she utilized a general theoretical claim regarding relation of gradual process with formation of intermediate forms with identifying example from previous knowledge such as intermediate forms regarded as a data placed in epistemic levels II-V.

Table 4. 30 Articulation of evolution conceptions and argumentation practices for *Cambrian Explosion* scenario

Selin's Excerpts	Argumentation Practices	Epistemic Levels
(4) According to Darwin, evolutionary process takes long time and it is a slow changing process that lasts hundreds of years for multicellular organisms. (5) For instance, when whales began to live in water, their legs shortened slowly and then, their offspring adapted to sea environment. They did not move to sea instantly. (6) Besides, for human evolution, there is a popular photo in which monkey stand up on feet slowly rather than suddenly. (7) Because this process takes very long time.	**Claim:** Explanation 1 **New claim:** Gradual process **Data:** Whale evolution **Data:** Human evolution **Warrant:** takes long time	(Not coded) Epistemic Level V Epistemic Level II Epistemic Level II Epistemic Level IV
It (second explanation) is not correct (Not coded). (…) (9) Intermediate forms mostly formed, we saw them in evolution course such as between human and ancestor, because there is no abrupt changes, it occurs gradually in a long periods of time that allow them to form.	**Claim:** Explanation 2 **Rebuttal** **Counter-claim:** not correct **Data:** intermediate forms **Warrant:** relation gradual process with formation of intermediate forms	(Not coded) (Not coded) Epistemic Levels II-V

4.3.5. Selin's Result across Scenarios

Profile of Selin based on findings across the four scenarios in terms of criteria for evaluating alternatives, conceptual, structural and epistemic aspects of argumentation practices was presented in Table 4.31.

Table 4.31 Profile of Selin

Evolutionary Scenarios	**Criteria**	**Conceptual Aspects**	**Structural Aspects**	**Epistemic Aspects**
Venezuelan Guppies	Rigorous Criteria	Partial Understanding with specific misunderstanding	Level 2 (Reason)-5 Level 3 (Rebuttal) -1	Coordination of 5 data statements with 12 theoretical statements
Whales	Rigorous Criteria	Sound Understanding	Level 2 (Reason)-6 Level 4 (Rebuttal)-2	Coordination of 6 data statements with 13 theoretical statements
Lactose Intolerance	Rigorous Criteria	Sound Understanding	Level 2 (Reason)-4 Level 4 (Rebuttal)-1	Coordination of 6 data statements with 8 theoretical statements
Cambrian Explosion	Rigorous Criteria	Partial Understanding	Level 2 (Reason)-3 Level 5 (Rebuttal)-1	Coordination of 5 data statements with 6 theoretical statements

In the following five subsections, Selin's results across the four scenarios were described in detail and discussed.

4.3.5.1. Criteria for Evaluating Validity of Explanation across Scenarios

Selin seemed to use several filters based on rigorous criteria during decision-making phases across the four scenarios. She most frequently made her decision through appealing to the criterion of how scientific theories fit with the claims. In particular, she applied her previous knowledge to distinguish between alternatives. In addition, she also used the criterion of how available data fits with claims during decision phase. She also emphasized the necessity of evidence in a persuasive argument as “argument should include evidences, they must be reliable and evidences should be consistent with the claim.” Besides, she also added “an individual should also critique her/his own argument before he/she presented to persuade others.” However, this statement is not consistent with her structure of arguments since she did not attempt to generate rebuttal indicating circumstances under which argument was not valid. As a result, although she used scientifically appropriate criteria, she did not consider all criteria that scientists use such as sufficiency of data, coherence and adequacy of explanations.

4.3.5.2. Conceptual Aspects of Argumentation Practices across Scenarios

Selin explained the evolutionary theory as a “process of appearing of new traits in long periods of time as a consequence of change in gene frequency within population due to particular reasons.” and she stated the reasons for acceptance as a valid theory:

> There are evidences for this theory, for instance, similarity of fish fins with wings of bat, Darwin’s finches that have different shapes of beaks, birds evolved from dinosaurs and 95-96 % similarity in gene sequences between humans and chimpanzees.

In line with her explanations, she mostly used key concepts of evolution regarding differential survival, heritability of genes, variation, overproduction of offspring, generational changes, resource limitation and competition across the four scenarios. She used differential survival and heritability of genes in almost all scenarios. In addition to key concepts, she explained evolutionary phenomena through using some evolutionary notions of common ancestry, genetic drift, homologous organs and Darwin’s theory of gradual evolution. She was also aware of misconceptions with respect to Lamarck’s theories (change due to inheritance of acquired traits and use and disuse) since she explicitly referred to misconceptions embedded in alternative explanations as an unscientific Lamarck’s theory. However, she used teleological and intentional reasoning for *Venezuelan Guppies* scenario in line with her choice but her explanations for other scenarios did not includes any cognitive biases. It might be related to context of scenarios since one of the alternative explanations includes these cognitive biases. Therefore, a plausible explanation for this inconsistency is that she might have had cognitive biases regarding intentionality and teleology and these may have arisen in this context. Furthermore, in general sense, she mentioned about variation among individuals within population in some scenarios. Therefore, it can be said that she did not hold cognitive bias about essentialism. Examples of her evolution conceptions were presented in Table 4.32.

Table 4.32 Selin's conceptions across the four scenarios

Conceptions		**Examples**
Key Concepts	Differential survival	"They (people) consumed milk to fed and *survive* and thus, people digest lactose survive and others *die* by natural selection based on Darwin's theory."
	Heritability of genes	"They consumed milk and people who digest lactose have been common and their allele, genes was *passed* to next generations."
	Variation	"I know that evolution occurred as a consequence of *variation* in genes in population and these genes passed to next generation."
	Overproduction of offspring	"They (people) *reproduce more* because they are fitter."
	Generational changes	" People who digest lactose become abundant and common in population"
	Resource limitation	"As far as I understood, predators *hunted* bright males.
	Competition	"According to my previous knowledge, males have different colors and traits to *attract females,* like birds. This leads to *competition* among them"
Misconceptions	Adaptation	"*In order to* suit to environment and *in order to* protect from predators, adaptation may have occurred."
Cognitive Biases	Teleology	*In order to* suit to environment and *in order to* protect from predators
	Intentionality	"In order to survive, they (males) may have *wanted* to turn into drab"

Based on these conceptions regarding evolution, Selin's conceptual understandings were analyzed across the six conceptual levels (see in Figure 4.19).

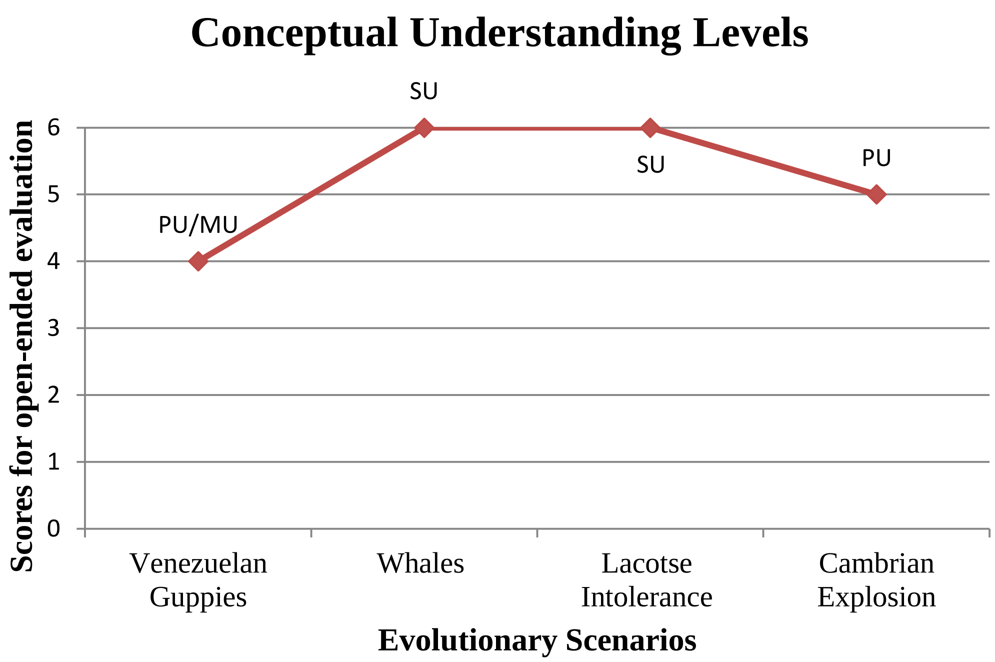

Figure 4.19 Selin's conceptual understanding levels across the scenarios

As seen in the figure 4.19, her conceptual understanding levels vary across the scenarios. She mostly used key concepts of evolution for whales and lactose intolerance scenarios. Besides, as I mentioned before, her cognitive biases may be specific to context for the first scenario. In addition, she did not mostly appealed key concepts in her explanations for *Cambrian Explosion* scenario. It might be related to content of this scenario. In particular, it discusses the more general evolutionary theories concerning evolution through gradual process or abrupt evolutionary changes (punctuated equilibrium). Her conceptual understandings did not differ between microevolution and macroevolution.

4.3.5.3. Structural Aspects of Argumentation Practices across Scenarios

Selin's argumentation levels were presented in Figure 4.20. As seen in the figure, she constructed fifteen arguments at Level 2 including justifications by either data, warrant or backing. She generated one weak rebuttal at Level 3 in *Venezuelan Guppies* scenario. However, she constructed strong rebuttals in last three scenarios. This means that she justified her rebuttals through either data or warrant. It may be related to her theoretical knowledge. Put it differently, she might have used conceptions regarding evolutionary theory to oppose alternatives. Besides, providing few rebuttals for two scenarios may also related to her choices, that is to say, in *Lactose Intolerance* and *Venezuelan Guppies* scenario, she chose two alternatives as a valid explanation, so in these scenarios she provided rebuttal for just one alternative. It should be noted that although she did not sufficiently appealed to key concepts of evolution to rebut the other alternative in *Cambrian Explosion* scenario, her argument level was high. This is because she used examples from previous knowledge and experience to rebut the alternative explanation.

Overall, she mostly attempted to justify her claim rather than rebut the other alternatives.

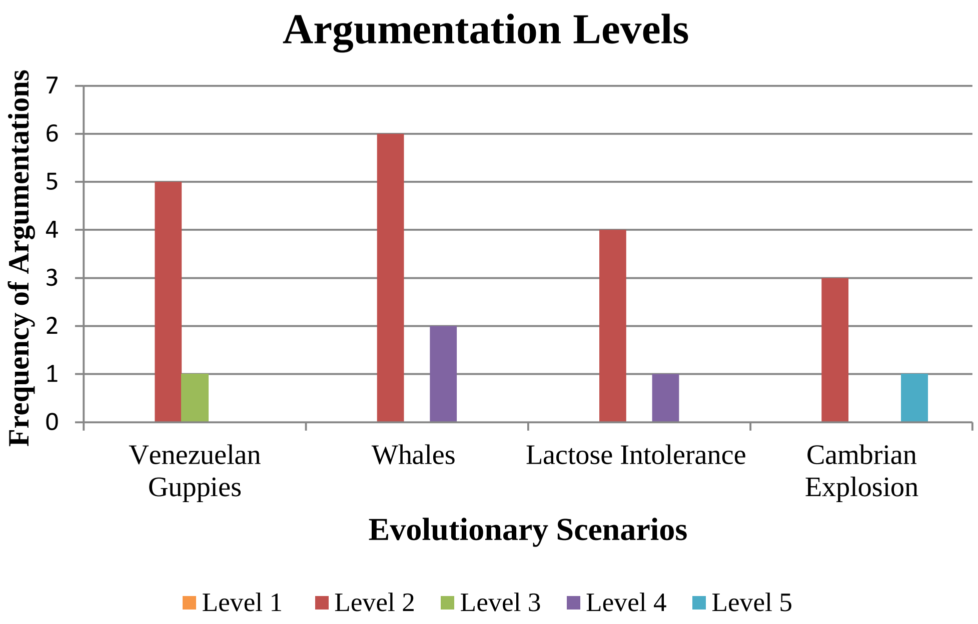

Figure 4.20 Selin's argumentation levels across the scenarios

4.3.5.4. Epistemic Aspects of Argumentation Practices across Scenarios

As seen in Table 4.33, most evidenced claim she utilized classified as epistemic level I. This means that she most frequently referenced data embedded or provided with figure and tables in scenarios. In terms of ratio of data and theoretical claims, she referenced 22 data statements for 38 theoretical claims. In general sense, she frequently used general or specific theoretical claim supported by insufficient use of data. Moreover, she also brought to bear examples from her previous knowledge and experiences at eight data statements in her argument.

Table 4.33 The distribution of Selin's propositions across the epistemic levels

Epistemic Levels	**N**	**Percent**
Epistemic Level V- General Theoretical Claims	12	20%
Epistemic Level IV-Theoretical Claims	13	21.7%
Epistemic Level III- Theoretical Claims with data	13	21.7 %
Epistemic Level II -Retrieved Data	8	13.3%
Epistemic Level I- Provided Data	14	23.3%

Figure 4.21 represented the evidenced claims across the evolutionary scenarios that Selin constructed. As seen in the figure, she developed evidenced claims at different epistemic levels across the scenarios. However, epistemic level she mostly used in each scenario varies across them. In particular, she most frequently explained theoretical claims or processes with identifying data in the first scenario. The reason of this may be that she established relevance between data and theory. In the second scenario, she mostly referenced data from scenario and appealed to general theoretical claims. This may be due to her conceptual understanding, that is to say she mostly appealed to key concepts of evolution. In the third scenario, she generated specific theoretical claims, that is, she connected her previous knowledge regarding evolutionary theory to whale evolution context. Lastly, she gave examples retrieved from her previous knowledge indicating that she was familiar with the concept of evolution through gradual process.

Taken together, although she developed evidenced claims at each epistemic level for each scenario, she most frequently used theoretical assertions in proportion to data representations. This means that she did not sufficiently support her claims. The reason of this may be related to her conceptual understanding regarding evolutionary theory. More specifically, she justified or rebutted her claims through appealing to previous theoretical knowledge. However, it could be related to unfamiliarity with the use of data to support her theoretical claims.

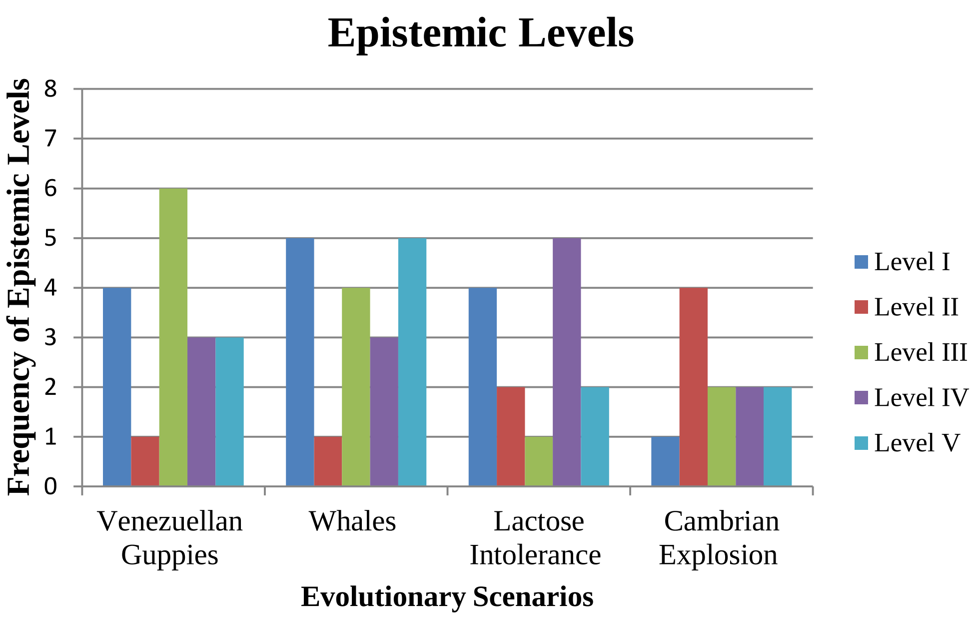

Figure 4.21 Selin's epistemic levels across the scenarios

4.3.5.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels across Scenarios

In general, she frequently appealed to key concepts of evolution in the form of theoretical claims in order to provide warrant and back up her claims and counter-claims. In addition to key concepts, she appealed to some evolutionary notions such as common ancestry, genetic drift and homologous organs in the forms of general theoretical claims or she connected them into specific issue discussed in scenarios. However, she also justified and rebutted alternatives through using teleological and intentional reasoning in her theoretical statements. In addition to theoretical claims, she referenced data either from scenario or her previous knowledge and experiences.

She brought to bear scientifically valid examples such as sexual selection within birds or intermediate forms between human and ancestor to justify her claims.

4.4. Beste' Case

She was 26 years old and graduated from Department of Elementary Science Education, METU in 2011. She took biology courses including general biology I and II, physiology and evolution courses and science methods courses including instructional planning and principles and methods of teaching science courses in which argumentation was introduced. She completed *Evolution* course with a grade of BB (3/4). She was master's student in Elementary Science and Mathematics Education at METU and she was working on her thesis. She was working at public school. She had two years of experiences on teaching and she taught evolution to 8th grade.

In the following sections, the results of Beste were presented under the five dimensions including criteria for evaluating validity of explanation, argumentation practices in terms of conceptual, structural and epistemic aspects as well as the articulation of conceptual knowledge regarding evolutionary theory and argumentation practices at different epistemic levels. The results of these analyses were represented for each scenario separately.

4.4.1. Scenario I: Venezuelan Guppies

Venezuelan Guppies scenario deals with natural and sexual selection (microevolution) (see Appendix A). Beste was provided with this scenario in which she was asked to several questions about the reason of observed variation in the coloration within male guppies. Following subsections described the results on each phase.

4.4.1.1. Criteria for Evaluating Validity of Explanation for *Venezuelan Guppies* Scenario

After reading scenario, Beste was asked to determine which of three alternative explanations was the most valid to explain the reason of coloration in Venezuelan Guppies. The following dialogue took place after she decided:

> Beste: I accepted explanation 2 (Explanation 2: Female guppies prefer to mate with brightly colored males. As a result, bright males tend to attract more mates and produce more offspring. When there are lots of predators in a habitat, however, brightly colored males do not survive long enough to reproduce.)
>
> Researcher: Why did you say that?
>
> Beste: I did not choose explanation 1 because it mentioned about creation. Then, I used elimination method. Explanation 3 mentioned about modification. Modification is not passed to offspring and that's why I did not choose the third one. For the second explanation, when looking at the table, the percentages of bright males and predators are related to each other.

Beste seemed to evaluate the acceptability of alternative explanations of *Venezuelan Guppies* scenario based on rigorous criteria consisting of reasons that are used in science context. In particular, she evaluated the first and third alternatives based on the criterion of how well scientific theories fit with claim. In particular, she appealed to her previous knowledge regarding creation and modification in order to eliminate alternatives. This means that she appealed to her existing knowledge when evaluating explanation in the light of other explanations. For the second explanation, she used the criterion of how well available data fits with the claim and line of reasoning fits with the claim since she took into consideration of data from provided table and she thought about the relations based on data.

In the following, Beste was asked to construct argument for *Venezuelan Guppies* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.4.1.2. Conceptual Aspect of Argumentation Practices for *Venezuelan Guppies* Scenario

For *Venezuelan Guppies*, she chose the second explanation which is about evolutionary theory. In line with her choice, she used some key concepts of evolution, in particular differential survival and resource limitation for her argument according to Nehm et al.'s (2010) framework. Representative examples for these concepts were:

> In the table, there are not bright females, and bright males are abundant since brightness *attracts* females, so males become bright.
>
> Cichlids may recognize bright ones and *attacked* them.

In the first example, she explained the reason of coloration through differential survival (sexual selection). In the next one, she explained another key concept of evolution dealing with prey/predator relationship by constructing relationship between cichlids and bright males. In addition to key concepts, she rejected to Lamarck's theory regarding inheritance of acquired traits as "modification is not passed to next generations". She also rejected to Lamarck's theory as to use and disuse as "This is Lamarck's theory since he stated that while organs used permanently strengthen, organs disused constantly weaken and that turned out to be not true". Overall, she did not use any misconceptions and held any cognitive biases and she also used some key concepts of evolution but not all of them. For that reason, her conceptual level was categorized as partial understanding (PU) according to Abraham et al.'s (1992) framework.

4.4.1.3. Structural Aspects of Argumentation Practices for *Venezuelan Guppies* Scenario

Beste generated four arguments at Level 2 and Level 5 for this scenario in order to justify and rebut the alternatives for *Venezuelan Guppies* scenario.

For the Level 2, she generated two arguments for the second explanation. One of the example quotations was presented in table 4.34. In this example, she reached a conclusion through examining data and generated a new claim for the relationship.

Then, she provided a data based on comparison numbers and explained the reason for existing of bright males regarded as warrant. Since, she justified her claim through data and warrant, her argument was placed in Level 2.

For the Level 5, she generated two arguments which contain more than one rebuttal for each. One of the example quotations was given in Table 4.34. In this example, explanation 1 was considered as a claim. She generated a counter-claim that is "I don't believe in it" for the first explanation. Then, she provided a warrant in order to explain the reason of it. Besides, she also provided rebuttal for it through another warrant in order to indicate circumstances when the first explanation holds true. Therefore, since she strongly rebutted the first explanation twice, her argument was placed in Level 5.

Table 4.34 Beste's excerpts at argumentation levels in *Venezuelan Guppies* scenario

Argumentation Level	**Beste's excerpts**
Level 2	*When looking at the table, there is a relationship between percentages of bright males and predators. In the table, there are not bright females, and bright males are abundant since brightness attracts females, so males become bright.*
Level 5	*I don't believe in explanation 1 because I don't think that they (guppies) were created either to be drab or bright, I think that they evolved. If they were created either to be bright or drab, their numbers would have been the same, for instance 20% to 20 % but their numbers are different.*

4.4.1.4. Epistemic Aspect of Argumentation Practices for *Venezuelan Guppies* Scenario

Figure 4.22 illustrates Beste's propositions across the epistemic levels. In this figure, each sentence was labeled with numbers and sentences served as a propositions. Each of propositions was categorized by epistemic levels and mapped in order to indicate ties across the epistemic levels. Lines connecting propositions represents explicit links between propositions and dashed lines represents the propositions including statements at two epistemic levels.

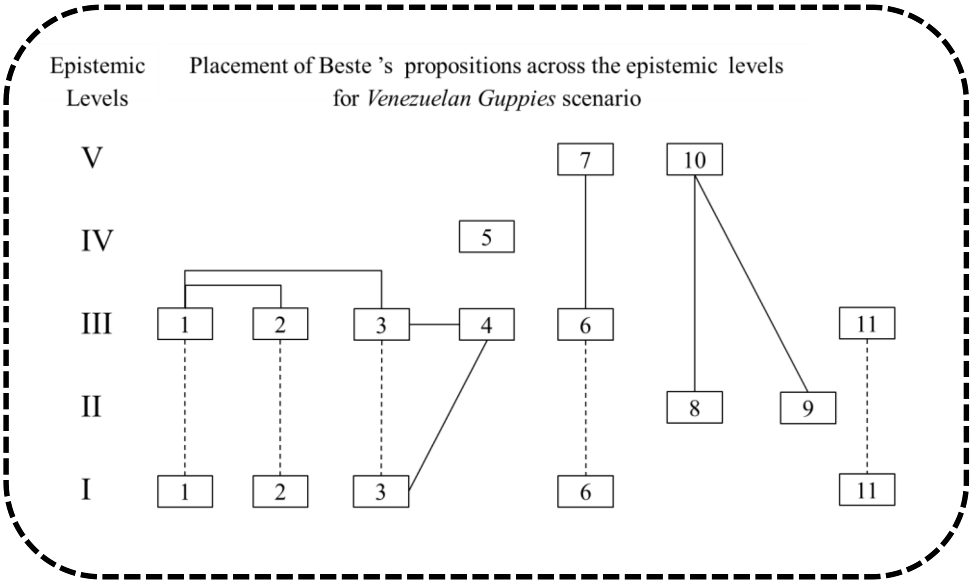

Figure 4.22 Beste's argumentation structure by epistemic levels for *Venezuelan Guppies* scenario

Based on the five epistemic level model, she explicitly referenced data from the provided table in five propositions (1, 2, 3, 6 and 11) placed in epistemic level I. Besides, she also used the data recalled from previous knowledge in propositions 8 and 9 placed in epistemic level II. A representative example for these propositions was:

> (8) For instance, rats' tails were cut throughout twenty generations and twentieth generation was still born with tails. (9) Besides, people were wearing iron shoes in order to have small feet. However, their children's feet were not small in China.

In addition, she used theoretical claims or explained the process regarding sexual selection, prey/predator relation, modification and coloration process with identifying data in six propositions (1, 2, 3, 4, 6, and 11) placed in epistemic level III. In propositions 5, 7 and 10, she used specific and general theoretical claims with respect to evolution and Lamarck's theory classified as epistemic level IV and V.

Overall, in terms of integration of claims across the levels, Beste generated claims at different epistemic levels. Besides, in terms of the criterion of the ratio of data statements to theoretical statements, she used seven data statements in proportion to nine theoretical claims. Specifically, theoretical claims are frequently supported by data statements. Therefore, epistemic quality of her argument was relatively high.

4.1.1.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels for *Venezuelan Guppies* Scenario

Table 4.35 represented how Beste justified her claims appealing to evolution conceptions documented in the use of evidenced claims at different epistemic levels for *Venezuelan Guppies* scenario. In the first example, she generated a new claim in the form of theoretical claim regarding process of coloration based on the provided table. Since this proposition includes both explicitly referenced data and theoretical claim, it was placed in epistemic levels I-III. Then, she used theoretical claim with respect to key concept, in particular differential survival (sexual selection) based on data provided from table in order to justify her claim classified as epistemic levels I-III. Besides, she also used another theoretical claim regarding a key concept of evolution, in particular prey/predator relationship with identifying data from provided table placed in epistemic levels I-III. Then, she backed up her claim by explaining the process of change in number of bright males placed in epistemic level III.

In the second example, explanation 3 was regarded as a claim. Then, she constructed a counter-claim. She rebutted the third explanation through utilizing theoretical claim related to rejection of common misconception regarding inheritance of acquired traits with identifying data embedded in scenario classified as epistemic levels I-III. Then, she backed up her rebuttal with a general theoretical claim related to inaccuracy of Lamarck's theory and she also rejected Lamarck's another theory regarding common misconception of change due to use and disuse in this claim classified as Level V.

Table 4. 35 Articulation of evolution conceptions and argumentation practices for *Venezuelan Guppies* scenario

Beste's Excerpts	**Argumentation Practices**	**Epistemic Levels**
(1) When looking at the table, the percentages of bright males and predators are related to each other. (2) In the table, there are not bright females, and bright males are abundant since brightness attracts females, so males become bright. (3) However, drab males are abundant in pool 1 since cichlids may recognize bright ones and attacked them. (4)Accordingly, they (bright males) do not survive enough to reproduce and their numbers decrease.	**Claim:** Explanation 2	(Not coded)
	New claim: relation bright males and predators **Data:** Table embedded in scenario	Epistemic Levels I-III
	Data: comparison of the number of bright males and females **Warrant:** Sexual selection	Epistemic Levels I-III.
	Data: bright males in pool 1 **Warrant:** prey/predator relation	Epistemic Levels I-III
	Backing: decreasing numbers	Epistemic Level III
(6) The third explanation is not true since it mentioned about modification but modification is not passed to next generations. (7)This is Lamarck's theory since he stated that while organs used permanently strengthen, organs disused constantly weaken and that turned out to be not true.	**Claim:** Explanation 3	(Not coded)
	Rebuttal **Counter-claim:** not true	(Not coded)
	Data: modification **Warrant:** rejection of inheritance of acquired traits	Epistemic Levels I-III
	Backing: rejection of Lamarck's theory	Epistemic Level V

4.4.2. Scenario II: Whales

Whales scenario deals with transition form (macroevolution) (see Appendix A). Beste was provided with this scenario in which she was asked to several questions about the possible relationships among an extinct land mammal, an aquatic whale ancestor and modern whales. Following subsections described the results on each phase.

4.4.2.1. Criteria for Evaluating Validity of Explanation for *Whales* Scenario

After reading scenario, Beste was asked to determine which of three alternative explanations was the most valid to explain the possible relationship among species. The following dialogue took place after she decided:

> Beste: Explanation 3 is more acceptable. (Pakicetus were some sort of mammal that can live both in land and in water. For this reason, it can be a transitional form. The ancestors of whales were living in land once and they had legs. As a result of changes of genes in the population, whales were born with small or no legs and when their environment changed, these whales with small or no legs became more advantageous and reproduced more.)
>
> Researcher: Why did you say that?
>
> Beste: Because it is correct. That is to say, while genes that suit to environment are passed, others that do not suit to environment are lost.

Beste seemed to evaluate acceptability of alternative explanations of *Whales* scenario through using rigorous criterion. More specifically, she evaluated the alternatives based on the criterion of how claim fits with scientific theory of differential survival. In particular, she declared as "correct" for alternative that indicates that she made decision on the basis of her existing knowledge.

In the following, Beste was asked to construct argument for *Whales* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.4.2.2. Conceptual Aspect of Argumentation Practices for *Whales* Scenario

For *Whales*, she chose the third explanation for this scenario. In parallel of her choice, she applied key concepts of evolution regarding heritability of genes, differential survival, and variation in her arguments according to Nehm et al.'s (2010) framework. The representative examples for these concepts were:

> While genes that suit to environment are *passed*, others that do not suit to environment are *lost*.
>
> There is *variation* in populations; some people carry genes and organs appeared even if they (organs) atrophy or they are useless.

In these examples, she appealed to differential survival and variation among individuals in a population. In addition to key concepts, she also explained an evolutionary notion with respect to common ancestry in her explanations. A representative example for this notion was:

> Appearing of small and useless hind limbs in whales indicates that they (have) *inherited these genes* from their *ancestors*.

In this example, she mentioned about ancestral relation and she also used a key concept, in particular heritability of genes. In addition to evolutionary concepts, she rejected a common misconception with respect to inheritance of acquired trait embedded in scenario as "modifications are not passed to next generations".

Overall, she did not utilize any misconceptions and cognitive biases and even rejected misconception, however, she used mostly key concepts of evolution but not all of them. For that reason, her conceptual level was placed in partial understanding (PU) based on Abraham et al.'s (1992) framework.

4.4.2.3. Structural Aspect of Argumentation Practices for *Whales* Scenario

Beste constructed five arguments at Level 2, Level 3 and Level 4 in order to support her claim and rebut the other alternatives for *Whales* scenario.

For the Level 2, she constructed three arguments for the third explanation. One of the example quotations was given in Table 4.36. In this example, explanation 3 was regarded as a claim. She used similarity of ear region as a data to justify her claim and she provided warrant through linking data and the claim. Since she did not attempt to provide rebuttal, her argumentation was placed in Level 2.

For the Level 3, she generated an argument to rebut the second explanation. The example quotation was shown in Table 4.36. The second explanation was considered as a claim. She weakly rebutted this explanation since she provided an unclear warrant that is “having different perspectives”. Since she did not provide a strong justification for her rebuttal, her argument was categorized as Level 3.

For the Level 4, she constructed an argument to oppose to the first explanation. The example quotation was given in Table 4.36. Explanation 1 was regarded as a claim. She provided a strong rebuttal through using data and warrant concerning modification. Since her rebuttal includes strong justification, her argument was classified as Level 4.

Table 4.36 Beste’s excerpts at argumentation levels in *Whales* scenario

Argumentation Level	**Beste’s excerpts**
Level 2	*Pakicetus’ ear region in skull is not exactly similar to land mammals but it is somewhere between that of land mammals and aquatic mammals, which proves that it was a transition form.*
Level 3	*I cannot say why the second explanation is not valid exactly but this may be related to my knowledge about nature of science and previous knowledge. However, explanation 3 is close to my knowledge.*
Level 4	*It (explanation 1) includes explanations regarding modification, that is to say, their (Pakicetus) legs changed and became small because they did not need to use them. This could not have happened in that way because modification are not passed to next generations*

4.4.2.4. Epistemic Aspect of Argumentation Practices for *Whales* Scenario

Figure 4.23 represents the distribution of Beste’s propositions across the epistemic levels for *Whales* scenario.

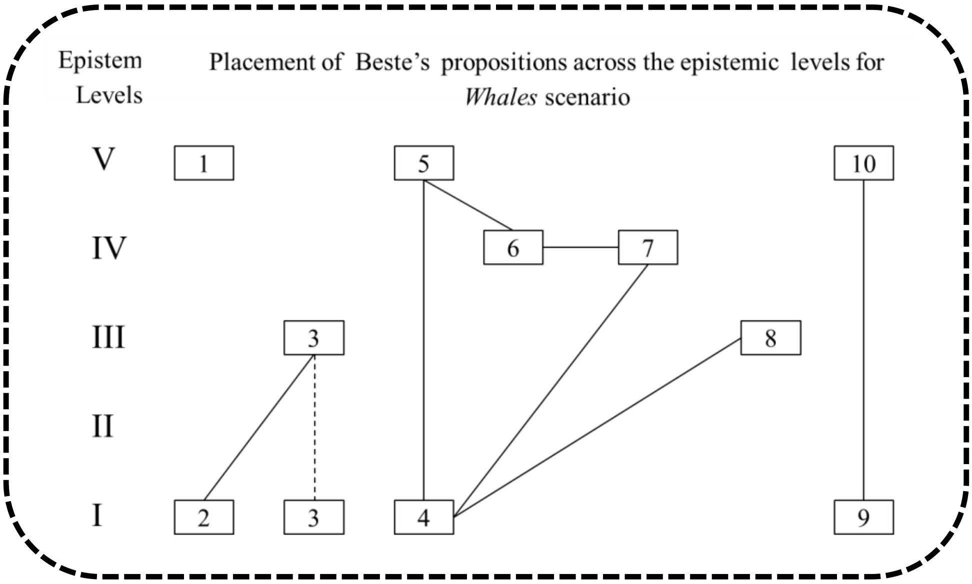

Figure 4.23 Beste's argumentation structure by epistemic levels for *Whales* scenario

Based on the five epistemic level model, she explicitly referenced data provided in scenario in four propositions (2, 3, 4 and 9) placed in epistemic level I. She provided theoretical claim regarding transition form, ancestral relation and heritability of genes with identifying data in propositions 3 and 8 classified as epistemic level III. In propositions 6 and 7 she utilized specific theoretical claim regarding variation and differential survival placed in epistemic level IV. A representative example for proposition 1 was:

> (1) While genes that suit to environment are passed, others that do not suit to environment are lost.

In this example, she used general theoretical claim regarding differential survival placed in epistemic level V. In addition to this, she also utilized general theoretical claims with respect to inheritance of acquired traits and variation in two propositions (1, 5 and 10) classified as epistemic level V.

Overall, in terms of criterion of integration of claims across the levels, Beste proposed evidenced claims at various levels except for epistemic level II. In particular, she did not referenced data recalled from her previous knowledge. Besides, in terms of the criterion of data statements to theoretical statements, she used four data references in proportion to six theoretical claims. Put more specifically, theoretical claims were sufficiently supported by data. Hence, epistemic quality of her arguments was relatively high.

4.1.2.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels for *Whales* Scenario

Table 4.37 illustrated how Beste justified her claims appealing to evolution conceptions documented at different epistemic levels for Whales scenario. In the first example, she referenced data embedded in scenario to justify the third explanation and then, she linked data and claim in the form of theoretical claim to justify placed in epistemic levels I-III.

In the second example, she explicitly referenced data from scenario in order to support the third explanation. Then, she used a general theoretical claim as a warrant regarding key concept, in particular variation classified as epistemic level V. Then, she backed up her claim through using three theoretical claims with respect to key concepts of evolution, in particular variation, differential survival and evolutionary notion regarding ancestral relation classified as epistemic levels III and IV.

Table 4. 37 Articulation of evolution conceptions and argumentation practices for *Whales* scenario

Beste's Excerpts	Argumentation Practices	Epistemic Levels
(3) Pakicetus' ear region in skull is not exactly similar to land mammals but it is somewhere between that of land mammals and aquatic mammals, which proves that it was a transition form.	**Claim:** Explanation 3 **Data:** similarity of ear region **Warrant:** Transition form	(Not coded) Epistemic Levels I-III
(4) Basilosaurus had small hind limbs that did not disappeared although it had been a long time. (5) Because, for instance, there is variation in populations; some people carry genes and organs appeared even if they (organs) atrophy or they are useless. (6) Therefore, Basilosaurus had it because of variation. (7) However, they (Basilosaurus) which do not have hind limbs become advantageous and they survive. (8) Nevertheless, appearing of small and useless hind limbs in whales indicates that they (have) inherited these genes from their ancestors.	**Claim:** Explanation 3 **Data:** small hind limbs **Warrant:** variation **Backing 1:** small hind limbs due to variation **Backing 2:** Differential survival **Backing 3:** Ancestral relation and Heritability of genes	(Not coded) Epistemic Level I Epistemic Level V Epistemic Level IV Epistemic Level IV Epistemic Level III

4.4.3. Scenario III: Lactose Intolerance

Lactose Intolerance scenario deals with gene-culture coevolution in humans (microevolution) (see Appendix A). Beste was provided with this scenario in which she was asked to several questions about how lactose tolerance developed in humans. Following subsections described the results on each phase.

4.4.3.1. Criteria for Evaluating Validity of Explanation for *Lactose Intolerance* Scenario

After reading scenario, Beste was asked to determine which of three alternative explanations was the most valid to explain how lactose tolerance developed in humans. The following dialogue took place after she decided:

> Beste: Explanation 1 is acceptable. (Since consuming milk is advantageous, the frequency of lactose tolerance allele increases in areas where dairy farming is common. As a result, digesting lactose becomes common in population. This process took placed in different geographical regions through change in the frequency of different allele which has same effects.)
>
> Researcher: Why did you say that?
>
> Beste: African people started dairy farming 9000 years ago and only 10 % of Africans cannot digest lactose, that is to say, ratio of digestion milk is high in Africans. Therefore, people can digest milk in areas where dairy farming is common, so alternative 1 is correct.

Beste evaluated validity of alternative explanations of *Lactose Intolerance* scenario through using rigorous criterion. Put more specifically, for the explanation 1, she used the criterion of how available data fits with the claim since she referenced the example of Africans to select alternative and she reached a conclusion based on this data.

In the following, Beste was asked to construct argument for *Lactose Intolerance* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.4.3.2. Conceptual Aspect of Argumentation Practices for *Lactose Intolerance* Scenario

For *Lactose Intolerance*, Beste chose the first explanation which includes evolutionary explanations. In line with her choice, she mostly applied key concepts of evolution regarding variation, heritability of genes and generational changes in the frequency of alleles in her arguments. The representative examples for these concepts were:

> If an individual carries this gene (lactose tolerance), its frequency of allele *increases* in population because they (people) *inherit* them (genes) from parents.
>
> There may be individuals who do not carry allele but this is because of *variation*. However, I do not think that individual carry active or passive genes randomly.

In the first example, she mentioned about heritability of genes and generational changes in allele frequency. In the second one, she used variation among individuals in population. In addition to key concepts, she also rejected Lamarck's theories regarding change due to use and disuse or habits and inheritance of acquired traits.

Overall, she used some key concepts of evolution and she did not hold misconceptions or cognitive biases. However, since she did not use all key concepts of evolution according to Nehm et al.'s (2010) framework, her conceptual level was placed in partial understanding (PU) according to Abraham et al.'s (1992) framework.

4.4.3.3. Structural Aspect of Argumentation Practices for *Lactose Intolerance* Scenario

Beste constructed four arguments at Levels 2 and 5 in order to support her claim and rebut the other alternative.

For the Level 2, she constructed two arguments to support the first explanation. One of the example quotations was presented in Table 4.38. In this example, explanation 1 was regarded as a claim. She used data regarding Africans' milk consumption. Then, she reached a conclusion from data and generated a new claim in which she constructed a relationship. For she supported her claim through data and there was no attempt to rebut the other alternatives, her argument was placed in Level 2.

For the Level 5, she generated two arguments which consist of more than one rebuttal for each. One of the example quotations was shown in Table 4.38. In this example, explanation 2 was regarded as a claim. She generated a counter-claim about the effects of habits on genes to oppose. Then she supported her counter-claim with data regarding rate experiment and she provided two warrants including rejections. Since she strongly rebutted the second explanation through two arguments, her argument was categorized in Level 5.

Table 4.38 Beste's excerpts at argumentation levels in *Lactose Intolerance* scenario

Argumentation Level	**Beste's excerpts**
Level 2	*African people started dairy farming 9000 years ago and only 10 % of Africans cannot digest lactose, that is to say, ratio of digestion milk is high in Africans. Therefore, people can digest milk in areas where dairy farming is common, so alternative 1 is correct*
Level 5	*In explanation 2, how habit of drinking milk influenced the genes? As I mentioned before, like rat experiment, I don't think that habits of drinking milk is directly related to genes. Besides, habits of drinking milk is a physical feature, that is to say, an individual who consume milk a change may occur but it does not mean that it (change) is passed to next generations.*

4.4.3.4. Epistemic Aspect of Argumentation Practices for *Lactose Intolerance* Scenario

Figure 4.24 represents the distribution of Beste's propositions across the epistemic levels for *Lactose Intolerance* scenario.

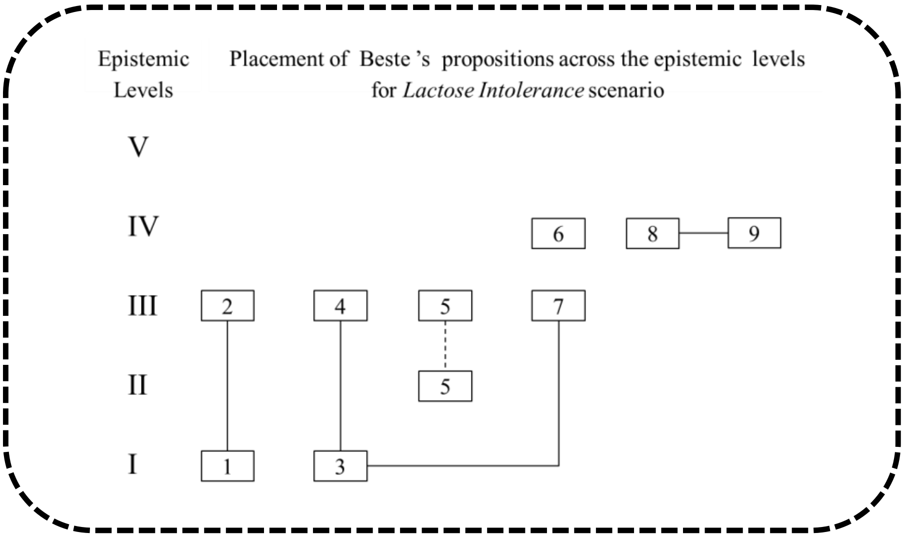

Figure 4.24 Beste's argumentation structure by epistemic levels for *Lactose Intolerance* scenario

Based on five epistemic level framework, she explicitly referenced data embedded in scenario in two propositions (1 and 3) classified as epistemic level I. She also referenced data recalled from previous knowledge in 5^{th} proposition placed in epistemic level II. A representative example for this proposition was:

> (5) As I mentioned before, like rat experiment, I don't think that habits of drinking milk is directly related to genes.

In this example, she used theoretical claim regarding change due to habits with identifying data regarding rat experiment from previous knowledge classified as epistemic levels II-III. In addition, she explained the processes regarding lactose tolerance with identifying data placed in epistemic level III in proposition 7. Besides, she also used theoretical claims regarding heritability of genes, generational changes and variation in three propositions (6, 8 and 9) classified as epistemic level IV.

Hence, based on criterion of integration of claims across the levels, Beste proposed evidenced claims at various levels except for the level V. In addition, in terms of the criterion of ratio of data statements to theoretical statements, she used three data references in proportion to seven theoretical claims. That is, theoretical claims were insufficiently supported by data. Hence, epistemic quality of her argument was relatively low for the *Lactose Intolerance* scenario.

4.4.3.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels for *Lactose Intolerance* Scenario

Table 4.39 illustrated how Beste justified her claims appealing to evolution conceptions documented at different epistemic levels for *Lactose Intolerance.* In the first example, explanation 1 was considered as a claim. She explicitly referenced data from scenario categorized as Level I and provided a warrant regarding the process of evolution of lactose tolerance classified as epistemic level III.

In the second example, explanation 3 was regarded as a claim. She generated two rebuttals to oppose the third explanation. Firstly, she generated a counter-claim as regard to relationship and then, she constructed a relationship based on data as to different allele in Africans referenced from scenario to justify her counter-claim categorized as epistemic level III. Then, she constructed another argument for the third explanation. She also generated a counter-claim and then, she appealed to key concepts of evolution, in particular heritability of genes and generational changes in allele frequency in order to support her counter-claim classified as epistemic level IV. Besides, she backed up her claim with theoretical claim regarding another key concept of evolution, in particular variation placed also in epistemic level IV.

Table 4. 39 Articulation of evolution conceptions and argumentation practices for *Lactose Intolerance* scenario

Beste's Excerpts	Argumentation Practices	Epistemic Levels
(3) Africans who carry different allele intolerance (of lactose) decreases (4) because the frequency of this particular allele increase in areas where dairy farming is common and thus, ability to digest lactose is common in population.	**Claim:** Explanation 1 **Data:** different allele **Warrant:** process of digestion of lactose in population	(Not coded) Epistemic Level I Epistemic Level III
(7) The third explanation mentioned about no relation milk consumption with lactose tolerance allele but here there is (Not coded). That is, 90 % Africans who carry different allele digest lactose.	**Claim:** Explanation 3	(Not coded)
	Rebuttal	
	Counter-claim: there is relationship **Data:** different allele **Warrant:** 90% of Africans digest	(Not coded) Epistemic Level III
(8) I do not think that people carry 50 % active and 50% passive genes randomly (Not coded). Because if an individual carries this gene (lactose tolerance), its frequency of allele increases in population because they (people) inherit them (genes) from parents. (9) There may be individuals who do not carry allele but this is because of variation.	**Counter-claim:** not 50% and 50% **Warrant:** Heritability of genes/ Generational changes **Backing:** Variation	(Not coded) Epistemic Level IV Epistemic Level IV

4.4.4. Scenario IV: Cambrian Explosion

Cambrian Explosion scenario deals with gaps in the fossil record (macroevolution) (see Appendix A). Beste was provided with this scenario in which she was asked to several questions about gaps in the fossil record as a consequence of gradual or rapid changes. Following subsections described the results on each phase.

4.4.4.1. Criteria for Evaluating Validity of Explanation for *Cambrian Explosion* Scenario

After reading scenario, Beste was asked to determine which of three alternative explanations was the most valid to explain the reason of gaps in fossil records. The following dialogue took place after she decided:

> Beste: I selected Explanation 1. (The lack of intermediate fossils is due to the fact that very few fossils from periods prior to 570 million years were formed or preserved. The evolution of multicellular organisms was a gradual process proceeding by little steps.)
>
> Researcher: Why did you say that?
>
> Beste: Because evolution of multicellular organisms is a gradual process. Besides, the reason of very fossils found or preserved is because of changes on Earth. Besides, if we considered the *forks*, they (species) differentiate each other and there are intermediate forms between them. In addition, for example, there are layers called sediments and because of this, reaching fossils may have been difficult.

Beste evaluated acceptability of alternative explanations of *Cambrian Explosion* scenario through using rigorous criterion. In particular, she evaluated the alternatives based on how well her scientific theoretical knowledge fits with the claim since she explained evolution through gradual process and also mentioned about phylogenetic pitchfork and sediments on Earth. Besides, she referenced the data embedded in scenario to confirm her choice.

In the following, Beste was asked to construct argument for *Cambrian Explosion* scenario. Her argumentation practices were analyzed in terms of conceptual, structural and epistemic aspects.

4.4.4.2. Conceptual Aspect of Argumentation Practices for *Cambrian Explosion* Scenario

She chose the first which is about evolution through gradual process. She used some key concepts of evolution in her argument based on Nehm et al.'s (2010) framework. The representative examples of these concepts were:

> Species which can live in that environment *survive* and others which cannot live *die*. Therefore, since species suit to environment survive, they are *common in population*.

In this example, she explained the process through differential survival and generational changes in the population. In addition to key concepts, she appealed to some evolutionary notions and the following excerpts indicated these notions:

> If we considered the *forks*, they (species) differentiate each other and there are intermediate forms between them.
>
> Evolution is a gradual process because it is not change within *population* rather than an *individual*.

In the first example, she used the term "forks" to mean phylogenetic pitchforks within evolutionary tree model. Besides, she explained evolution at population level.

Overall, although she used some key concepts and evolutionary notions and did not utilize any misconceptions or cognitive biases; she did not use all key concepts in her arguments. Hence, her conceptual level was placed in partial understanding (PU) according to Abraham et al.'s (1992).

4.4.4.3. Structural Aspect of Argumentation Practices for *Cambrian Explosion* Scenario

Beste constructed seven arguments at Levels 2 and 4 in order to support her claim and rebut the other alternative.

For the Level 2, she constructed six arguments to justify the first explanation. One of the example quotations was shown in Table 4.40. In this example, explanation 1 was considered as a claim. She gave example from layers and explained the reason of finding of few fossils. Then, she backed up her claim through explaining the relation of natural phenomena and finding them. As there was no attempt to rebut the other alternative, her argument was categorized in Level 2.

For the Level 4, she generated an argument to rebut the second explanation. The example of quotation was presented in Table 4.40. In this example, explanation 2 was regarded as a claim. She constructed a counter-claim regarding rate of speciation. Then, she used periods of changes on earth as a data and provided a warrant with regard to relation of rate of speciation and climatic changes. Since she used one strong rebuttal through justifying with data and warrant to oppose the second alternative, her argument was placed in Level 4.

Table 4.40 Beste's excerpts at argumentation levels in *Cambrian Explosion* scenario

Argumentation Level	**Beste's excerpts**
Level 2	*There are layers called sediments and because of this, reaching fossils may have been difficult. Since it is a very slow process, as time went on, different natural phenomena occurred and layers formed, increased and changed, for instance, lava formed and thus, it is getting more difficult to find them.*
Level 4	*Speciation does not occur rapidly. (...) Furthermore, Ice Age or other changes on Earth is not like raining, that is to say, they (changes on Earth) leading to it (speciation) does not last one or two years and so, it (speciation) also occurs slowly*

4.4.4.4. Epistemic Aspect of Argumentation Practices for *Cambrian Explosion* Scenario

Figure 4.25 represents the distribution of Beste's propositions across the epistemic levels for *Cambrian Explosion* scenario.

Based on five epistemic levels framework, she explicitly cited data regarding climatic changes from the scenario classified as epistemic level I. She also referenced data recalled from her previous knowledge in five propositions (4, 5, 7, 9 and 11). A representative example for proposition 7 was:

> (7) For instance, I read on a website that few fossils of intermediate forms between some species were found, such as an intermediate form between dinosaurs and birds

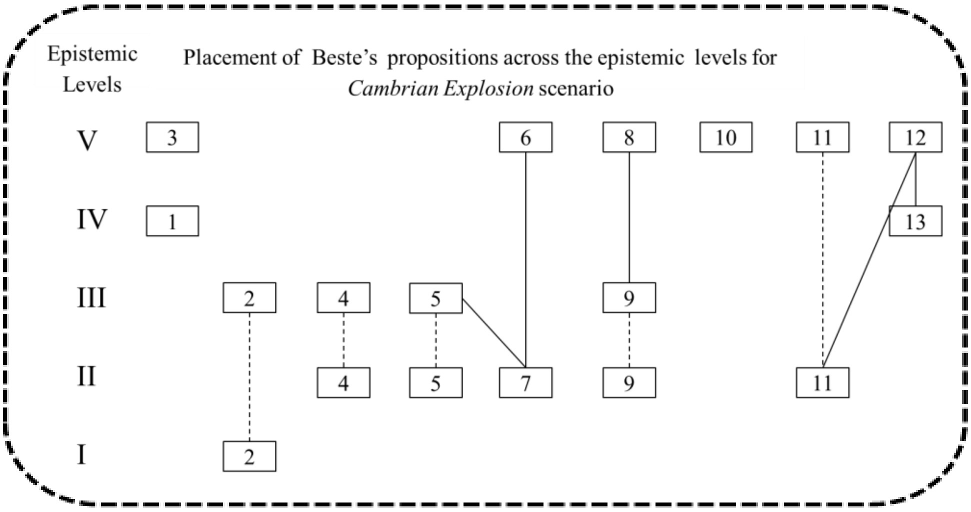

Figure 4.25 Beste's argumentation structure by epistemic levels for *Cambrian Explosion* scenario

In this example, she gave example as to intermediate form between dinosaurs and birds recalled from existing knowledge. In addition, she also used theoretical claims and explained processes regarding relation of climatic changes with gradual process and with existing of few fossils with identifying data placed in epistemic level III. Besides, she also used specific theoretical assertions regarding gradual process classified as epistemic level IV. She mostly used general theoretical statements regarding differential survival and generational changes placed in epistemic level V.

Based on criterion of integration of claims across the levels, Beste proposed evidenced claims at various levels. Besides, in term of the criterion of ratio of data statements to theoretical ones, she used six data references in proportion to eleven theoretical claims. Hence, theoretical claims were in sufficiently supported by data. Hence, her epistemic quality of argument was relatively low.

4.1.4.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels for *Cambrian Explosion* Scenario

Table 4.41 represented how Beste justified her claims appealing to evolution conceptions documented at different epistemic levels for *Cambrian Explosion* scenario. In the first example, explanation 2 was considered as a claim. She generated a counter-claim in the form of general theoretical claim regarding rate of speciation classified as epistemic level V. Then, she explained how rate of climate change is related to gradual process with identifying data recalled from previous knowledge in order to justify her counter-claim placed in epistemic levels II-III.

In the second example, explanation 1 was regarded as a claim. She provided a warrant through using general theoretical assertion with respect to evolution through using an evolutionary notion regarding change within population classified as epistemic level V. Then, she used a general theoretical claim regarding a key concept including differential survival by referencing data recalled from previous knowledge about climatic and environmental changes in order to support her claim placed in epistemic levels II-V. She backed up her claim through utilizing general theoretical statement with respect to another key concept of evolution, in particular generational changes in population classified as epistemic level V.

Table 4. 41 Articulation of evolution conceptions and argumentation practices for *Cambrian Explosion* scenario

Beste's Excerpts	Argumentation Practices	Epistemic Levels
(8) Speciation does not occur rapidly (not coded) because knowledge that I have learned so far is not consistent with this claim (the second one). (9) Furthermore, Ice Age or other changes on Earth is not like raining, that is to say, they (changes on Earth) leading to it (speciation) does not last one or two years and so, it (speciation) also occurs slowly.	**Claim:** Explanation 2 **Rebuttal** **Counter-claim:** not rapidly **Data:** climate does not change rapidly **Warrant:** relation slow climatic changes with gradual process	(Not coded) Epistemic Level V Epistemic Levels II-III
(10) Evolution is a gradual process because it is not change within population rather than an individual. (11) For instance, there was a plain under which lava erupted or an earthquake occurred and consequently, environment and climate change over time and after that species changed over time since they which can live in that environment survive and others which cannot live die. (12) Therefore, since species suit to environment survive, they are common in population	**Claim:** Explanation 1 **Warrant:** population level **Data:** climatic and environmental changes **Warrant:** Differential survival **Backing :** Generational changes	(Not coded) Epistemic Level V Epistemic Levels II-V Epistemic Level V

4.4.5. Beste's Result across Scenarios

Profile of Beste based on findings across the four scenarios in terms of criteria for evaluating alternatives, conceptual, structural and epistemic aspects of argumentation practices was presented in Table 4.42.

Table 4.42 Profile of Beste

Evolutionary Scenarios	**Criteria**	**Conceptual Aspects**	**Structural Aspects**	**Epistemic Aspects**
Venezuelan Guppies	Rigorous Criteria	Partial Understanding	Level 2 (Reason)-2 Level 5 (Rebuttal)-2	Coordination of 7 data statements with 9 theoretical statements
Whales	Rigorous Criteria	Partial Understanding	Level 2 (Reason)-3 Level 3 (Rebuttal)-1 Level 4 (Rebuttal)-1	Coordination of 4 data statements with 6 theoretical statements
Lactose Intolerance	Rigorous Criteria	Partial Understanding	Level 2 (Reason)-2 Level 5 (Rebuttal)-2	Coordination of 3 data statements with 7 theoretical statements
Cambrian Explosion	Rigorous Criteria	Partial Understanding	Level 2 (Reason)-6 Level 4 (Rebuttal)-1	Coordination of 6 data statements with 11 theoretical statements

In the following five subsections, Beste's results across the four scenarios were described in detail and discussed.

4.4.5.1. Criteria for Evaluating Validity of Explanation across Scenarios

She used several filters to evaluate alternative explanations based merely on rigorous criteria. Among them, she mostly appealed to the criterion of consistency with scientific theories. This means that she considered her previous theoretical knowledge during decision-making phase. The reason of this may be that she could distinguish misconceptions especially related to Lamarck's theory. Besides, she utilized the criterion of how well available data fits with the alternative explanation. She also expressed the importance of evidences for persuasive arguments such as "the use of scientifically valid evidence is the most important way to convince the others". Besides, she rarely criticized the line of reasoning of explanations, and she seemed to mostly focus on data and existing knowledge related to scientific theories. As a result, although she used scientifically appropriate criteria, she did not consider all criteria that scientists use such as adequacy and coherence of explanations.

4.4.5.2. Conceptual Aspect of Argumentation Practices across Scenarios

Beste explained the evolutionary theory: "some species' chance of survival and reproduction decreases due to change in environmental conditions. Some species' survival and reproduction chance increase because of their traits." And she stated the reason of acceptance as a valid theory:

> For instance, some people have pouch like structure upon thyroid gland. This structure resembles fish gills that indicated that we share a common ancestor with them (fish). In addition, our close cousins, chimpanzee, and we have many common characteristics. That's why I think that speciation occurred from a single ancestor.

In line with her evolutionary explanations, she appealed to some key concepts in her arguments for each scenario, namely differential survival, resource limitation, heritability of genes, variation and generational changes across the four scenarios. She was also aware of some misconceptions embedded in alternatives regarding Lamarck's theory of change due to inheritance of acquired traits and use and disuse and rejected both of them in related scenarios. Besides, she also used some evolutionary notions of common ancestor, phylogenetic pitchfork and evolution at population level. It has to be noted that she did not utilized any misconceptions and cognitive biases in her arguments across the four scenarios. In addition, in general sense, she mentioned about variation among individual within population. This indicated that she did not tend to consider species as sharing a common "essence". Therefore, she did not hold cognitive bias regarding essentialism. Examples of her evolution conceptions were given in Table 4.43.

Table 4.43 Beste's conceptions across the four scenarios

Conceptions		Examples
Key Concepts	Differential survival	"While genes that suit to environment are passed, others that do not suit to environment are lost."
	Heritability of genes	"If an individual carries this gene (lactose tolerance), its frequency of allele *increases* in population because they (people) *inherit* them (genes) from parents."
	Variation	"There is variation in populations; some people carry genes and organs appeared even if they (organs) atrophy or they are useless."
	Resource Limitation	" Cichlids may recognize bright ones and attacked them"
	Generational changes	"Therefore, since species suit to environment survive, they are common in population"

As seen in the figure 4.26, her conceptual understanding levels were partial understanding. This means that she had some basic knowledge regarding evolutionary theory but not all concepts. She utilized mostly differential survival and variation concepts. In particular, she appealed to differential survival concept in three scenarios, namely *Venezuelan Guppies, Whales* and *Cambrian Explosion* and variation concept in *Whales* and *Lactose Intolerance* scenarios. Her conceptions did not vary across microevolution and macroevolution.

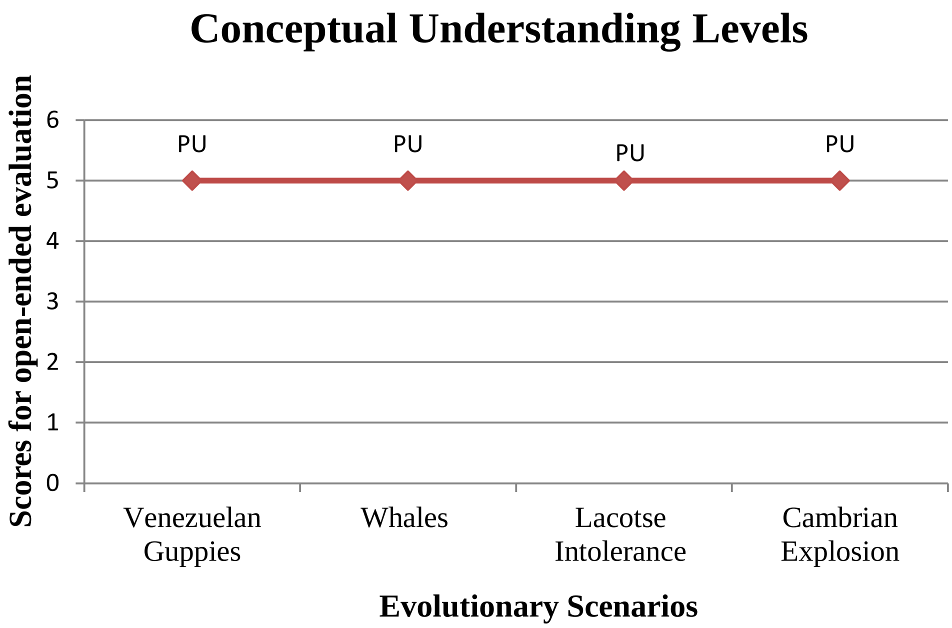

Figure 4.26 Beste's conceptual understanding levels across the scenarios

4.4.5.3. Structural Aspect of Argumentation Practices across Scenarios

Beste's argumentation levels were presented in Figure 4.27. As seen in the figure, she mostly constructed arguments at Level 2 which consists of justifications by either data, warrant or backing. She generated one weak rebuttal at Level 3 for *Whales* scenario. Besides, her argumentations were relatively higher for *Venezuelan Guppies* and *Lactose Intolerance* even if conceptual understanding level was same for these scenarios. It is most likely related to her familiarity with Lamarck' theory since she brought examples from her previous knowledge regarding change due to inheritance of acquired traits and use and disuse. Besides, she constructed six arguments to justify her claim in Cambrian Explosion scenario. This could be related to her familiarity with this concept, in particular evolution through gradual process because she gave five different examples based on her existing knowledge.

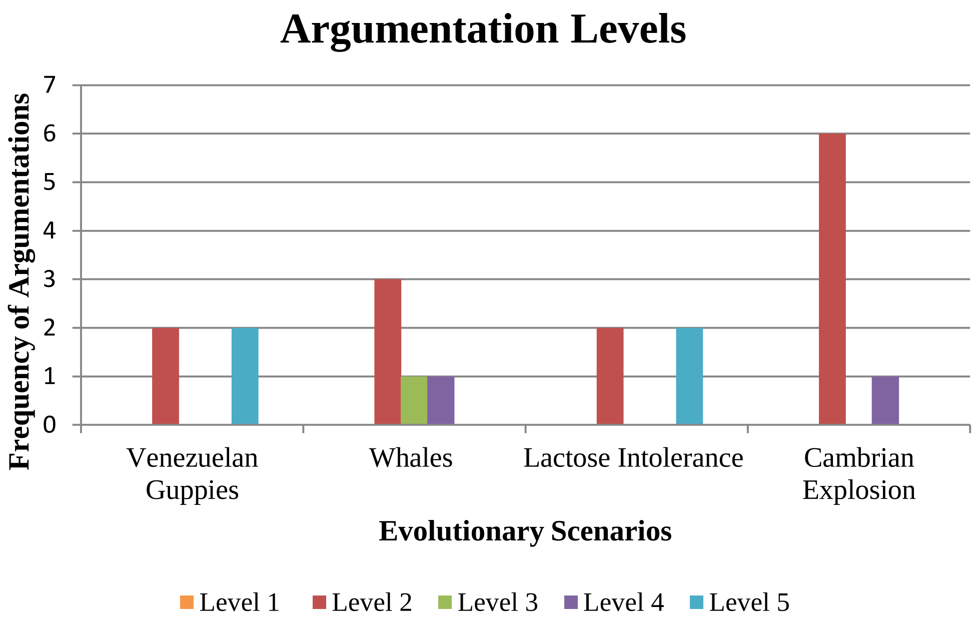

Figure 4.27 Beste's argumentation levels across the scenarios

4.4.5.4. Epistemic Aspects of Argumentation Practices across Scenarios

As seen in Table 4.44, most evidenced claim she utilized placed in epistemic level III. More specifically, she most frequently used theoretical claims with identifying data either from scenario or previous knowledge. However, in general, in terms of ratio of data and theoretical claims, she referenced 22 data statements for 35 theoretical claims. In general sense, she frequently used general or specific theoretical claim supported by insufficient use of data. Moreover, she also brought to bear examples from her previous knowledge and experiences at ten data statements in her argument.

Table 4.44 The distribution of Beste's propositions across the epistemic levels

Epistemic Levels	**N**	**Percent**
Epistemic Level V- General Theoretical Claims	11	19.3 %
Epistemic Level IV-Theoretical Claims	8	14 %
Epistemic Level III- Theoretical Claims with data	16	28.1 %
Epistemic Level II- Retrieved Data	8	17.5 %
Epistemic Level I-Provided Data	12	21.1 %

Figure 4.28 represented the evidenced claims across the evolutionary scenarios that Beste constructed. As seen in the figure, she developed evidenced claims at various epistemic levels except for *Whales* scenario. In particular, she did not brought data retrieved from her previous knowledge in this scenario. This may be related to her unfamiliarity with its content. She mostly appealed to her previous knowledge in Cambrian Explosion scenario since she mostly utilized general theoretical claims and examples not specific to issue discussed.

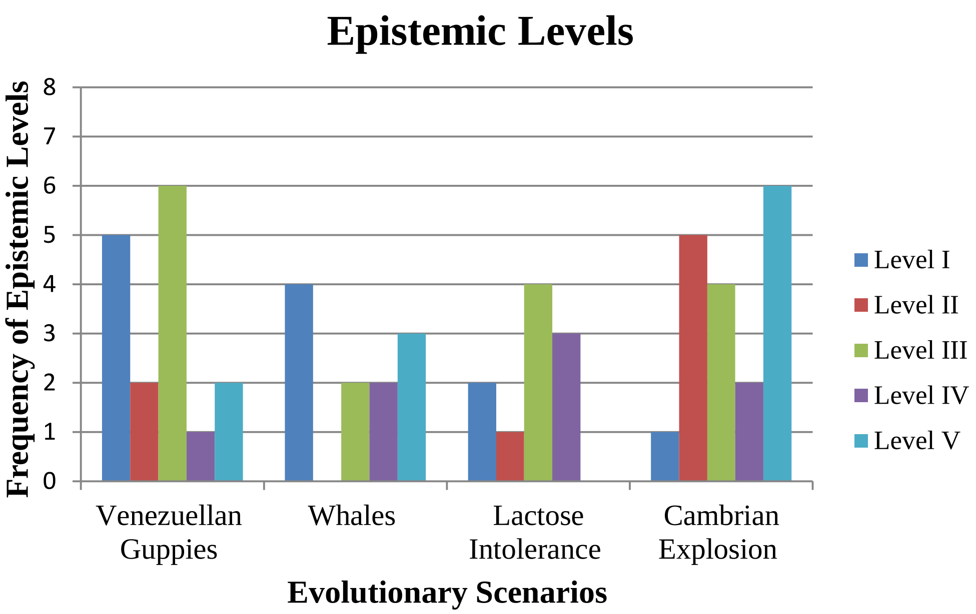

Figure 4.28 Beste's epistemic levels across the scenarios

Taken together, she mostly utilized theoretical assertions in proportion to data statements in each scenario. For some of them, *Venezuelan Guppies* and *Lactose Intolerance*, she mostly identified data with theoretical claims. For other scenarios, she did not sufficiently connect theory and data. The reason of this may be that she was unfamiliar with the use of data to connect theory.

4.4.5.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels across Scenarios

In general, she frequently appealed to key concepts of evolution in the form of theoretical claims in order to provide warrant and back up her claims and counter-claims. In addition to key concepts, she appealed to some evolutionary notions such as common ancestry, phylogenetic pitchfork and evolution at population level at in the forms of general theoretical claims or she connected them into specific issue discussed in scenarios. In addition to theoretical claims, she referenced data either from scenario or her previous knowledge and experiences. She brought to bear scientifically valid examples such as rat experiment, intermediate form between birds and dinosaurs and some geological information. Besides, she provided rebuttals in the form of either specific or general theoretical claims or empirical data in order to oppose to misconceptions related to inheritance of acquired traits and use and disuse.

4.5. Cross-Case Analysis

In this section, the comparisons of results of analysis across the four cases were presented. Accordingly, the similar and different results were discussed. The results were organized in terms of order of research questions.

4.5.1. Criteria for Evaluating Validity of Explanation across Cases

Rigorous criteria were mostly utilized by teachers during decision-making phase. Two teachers, Beste and Selin, mostly took into consideration of the criterion of consistency with scientific theories, in this case, evolutionary theory. Therefore, they mostly appealed to their previous knowledge. This may related to their conceptual understanding level. In particular, these two teachers' conceptual understanding levels were relatively high, so they could have applied their knowledge into this context when distinguishing between alternatives. The other two teachers, Leyla and Burcu, mostly utilized the criterion of how well data fits with the claims since they seemed to reach a conclusion form available data to evaluate alternatives.

More specifically, they rarely took into consideration of line of reasoning of alternatives. In addition, they scarcely evaluated explanations in the light of alternative explanations. This finding was consistent with the findings related to their argumentation levels. In particular, all teachers rarely attempted to rebut other explanations. Instead they mostly focused on justifying their claims through using data, warrant and backing. Hence, they utilized several filters based on three criteria but not all of them such as coherence and adequacy of explanation and sufficiency of evidence.

4.5.2. Conceptual Aspects of Argumentation Practices across Cases

In terms of evolutionary concepts, three teachers, Beste, Burcu and Selin, mostly appealed to key concepts of evolution in their explanations and the other, Leyla, appealed to one key concept. All teachers appealed to notion of heritability of genes. Besides, evolutionary concepts such as differential survival and resource limitation (prey/predator relationship) were most frequently used in their explanations. Other key concepts such as generational changes, variation, overproduction of offspring and competition were less frequently used. In addition to key concepts, some evolutionary notions were emerged. More specifically, the notion of common ancestry was most commonly used by teachers and also phylogenetic pitchfork, evolution at population level rather than individual, speciation, homolog organs and two mechanism of evolution: natural selection and genetic drift were also applied in their arguments. Besides, one teacher, Selin, frequently explicitly referred to Darwin's theory in three scenarios. In addition to key concepts and notions, some misconceptions and cognitive biases were also emerged. Lamarck's theory of inheritance of acquired traits and use and disuse, and also adaptation were utilized by the teachers. All teachers explained evolution phenomena through adaptation. However, mostly they used this notion inaccurately. In particular, they seemed to perceive adaptation as a goal-directed process rather than a process by the species become more suited to environment through change in a trait (Futuyma, 2009). One teacher, Leyla, explicitly referenced to Lamarck's theory as a valid explanation and explained some evolutionary phenomena through change due to inheritance of acquired trait and use and disuse. In addition, Leyla brought some irrelevant examples regarding development and color changing which was indicator of misconceptions regarding adaptation and speciation. As for cognitive biases, teleological and intentional reasoning were utilized by teachers except for Beste. In particular, these three teachers (Burcu, Selin and Leyla) seemed to perceive evolution as a goal or need-directed process (teleology) and as phenomena directed by mental agent (intentionality) and among them, teleology was commonly utilized. Two teachers, Leyla and Burcu, did not mention about variation among individual, so they underestimated the within-category variability. Hence, they had cognitive bias as to essentialism in general whereas others did not since they mentioned the variation within population.

The Figure 4.29 illustrated the conceptual understanding levels of four teachers across the evolutionary scenarios. Even if some teachers' levels were same in some scenarios, conceptual understandings varied across the cases. Based on the figure, while Beste did not use any misconceptions or cognitive biases, Leyla commonly appealed to them. In particular, Beste rejected Lamarck's theory but Leyla accepted them as a valid explanations. Besides, while Beste appealed to some key concepts of evolution in each scenario, Leyla appealed to one key concept in merely *Whales* scenario. Although Beste used some key concepts of evolution, she did not utilize all of them in each scenario. However, Burcu mostly appealed to various key concepts of evolution. On the other hand, Burcu utilized misconceptions and cognitive biases in each scenario. Selin's conceptual understanding level was relatively high. She appealed to various key concepts and other evolutionary notions such as genetic drift and natural selection. Although she utilized almost every key concepts of evolution in two scenarios, her conceptual understanding was not coherent among scenarios since she utilized cognitive biases and a misconception regarding adaptation in *Venezuelan Guppies* scenario. This may be related to context of scenario. These results indicated that conceptual understanding regarding evolutionary theory varied across the cases (teachers). It might be related to their teaching experiences on evolutionary theory or the integration of understandings from biology-related courses in their undergraduate programs and might be related other factors such as attitude toward or interest in evolutionary theory.

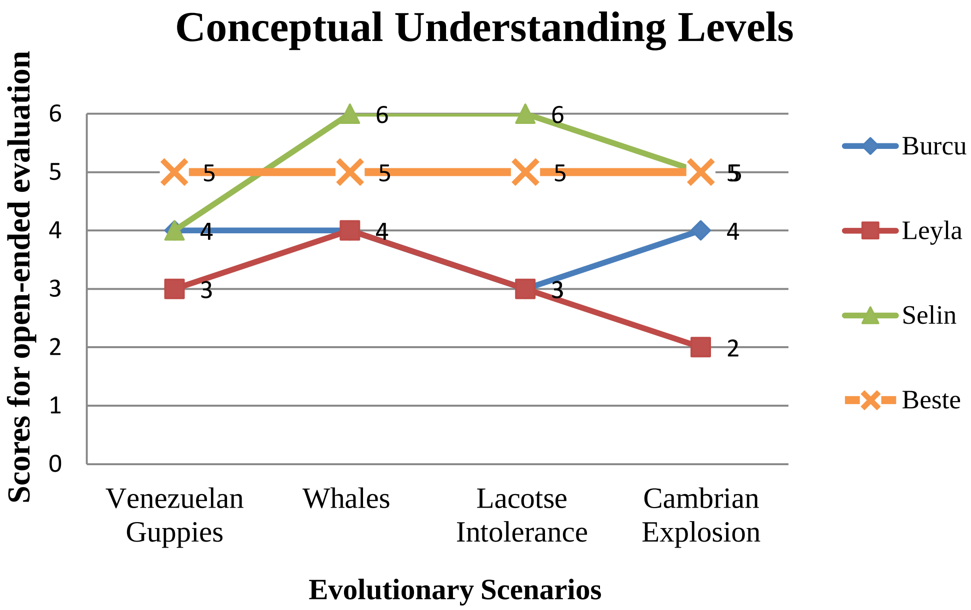

Figure 4.29 Conceptual understanding levels across the cases

4.5.3. Structural Aspects of Argumentation Practices across Cases

The figure 4.30 shows the argumentation levels across the cases. As seen in the figure, all of them mostly generated arguments at Level 2. This means that teachers mostly focused on justifying their claims through data, warrant or backing rather than rebutting the other alternatives. However, they provided rebuttals for each scenario even if some of them were weakly supported. Although Selin's conceptual understanding was relatively high, she generated merely one strong rebuttal. Even though Beste did not appeal to key concepts of evolution as Selin did, Beste constructed more rebuttals for her claims than the others did.

However, the reason of this might be that while Selin mostly chose two alternative explanations to explain an evolutionary phenomenon, Beste generally decided upon one explanation. Therefore, Selin provided one rebuttal for one explanation as Beste generated rebuttals twice for two alternative explanations. In addition, Leyla did not attempt to generate more than one rebuttal for alternative explanation. This might be related that she had a difficult to distinguish alternatives from each other because of her low level conceptual understanding.

Hence, these results indicated that they did not provide sophisticated arguments including more than one rebuttal in general. Besides, argumentation levels may be related to conceptual understanding levels.

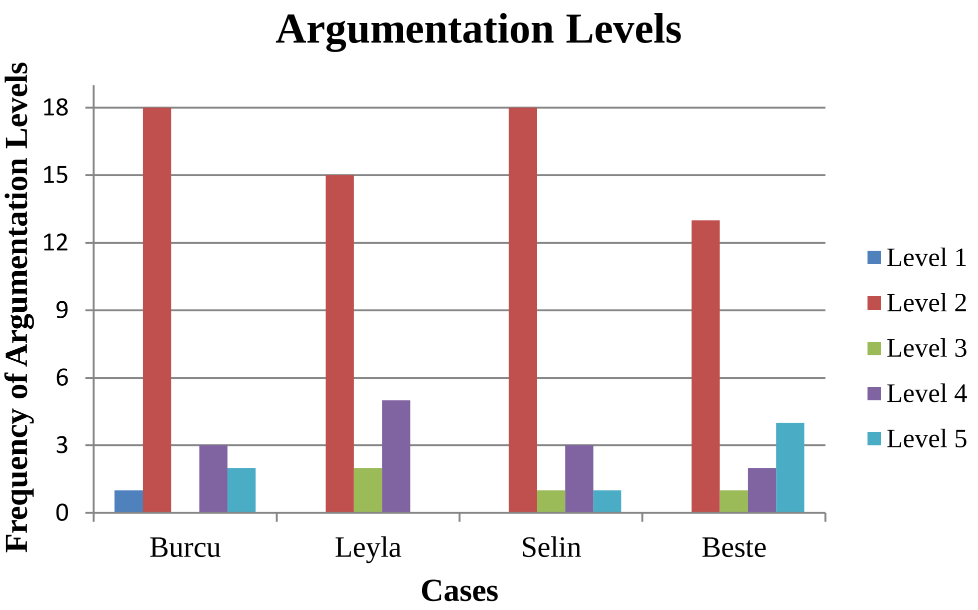

Figure 4.30 Frequency distribution of argumentation levels across the cases

4.5.4. Epistemic Aspects of Argumentation Practices across the Cases

As seen in the figure 4.31, all teachers utilized evidenced claims at various levels. All of them less frequently referenced data recalled from their previous knowledge and experiences. This may mean that their knowledge regarding examples of evolution was inadequate. As for the ratio of theoretical assertions (III-IV-V) and data statements (I-II) for each, they mostly utilized theoretical claims which were insufficiently supported by data. It seemed that they had difficulties for connecting data to theory. In addition, as seen in the figure, while Burcu and Leyla mostly mostly referenced to data from scenarios, Selin and Beste referenced data from scenarios relatively less frequently. This difference might be due to difference in conceptual understanding since Selin's and Beste's conceptual understandings were relatively higher than those of Burcu and Leyla. In particular, since Selin and Beste had high conceptual knowledge, they mostly appealed to their previous knowledge rather than using data from the scenario.

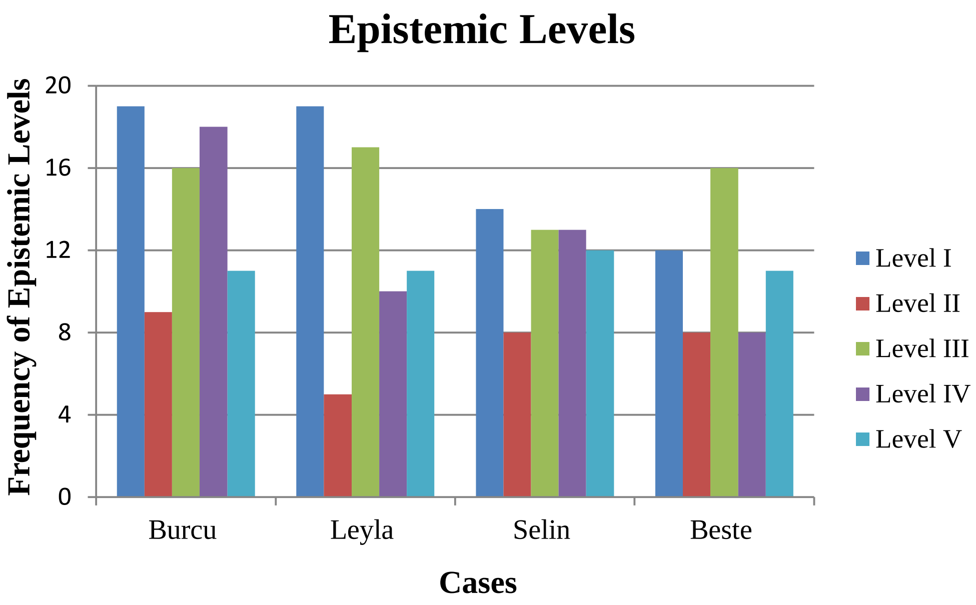

Figure 4.31 Frequency distribution of epistemic levels across the cases

4.5.5. Articulation of Argumentation Practices and Evolution Conceptions at Different Epistemic Levels across Cases

Articulation of conceptions and practices were summarized in following four tables (see in Table 4.45, Table 4.46, Table 4.47 and Table 4.48). As seen in the tables, all teachers brought their key concepts, evolutionary notions and also misconceptions and cognitive biases to their justifications across the different epistemic levels. Misconceptions and cognitive biases were mostly emerged in Leyla's justifications whereas key concepts and various evolutionary notions were most frequently arisen in other three teachers.

Table 4.45 Burcu's evolution conceptions used in justifications

Types of Justifications	**Conceptions**
Data (Retrieved from previous knowledge)	Differential Survival (Sexual selection): Birds
	Transition from water to land
	Natural Disaster
	Common Ancestor: chimpanzee and human
	Plant and Animal Cultivation
	Features of shell
	Few species in Ice Age Epoch
Theoretical Justifications with identifying data (Warrant and Backing)	Common ancestor with similarities
	Transition from water to land with natural disaster
	Theory of use and disuse with vital activities (misconception)
	Differential survival with animal cultivation (Teleological reasoning)
	Adaptation with features of shell
	Gaps in the fossil record with climatic changes
	Speciation with climatic change
Specific Theoretical Justifications	Adaptation due to protection (Intentional reasoning)
	Heritability of genes
	Differential Survival (Sexual selection)
	Resource Limitation (Prey/predator relationship)
	Differential Survival (Teleological reasoning)
	Adaptation (Teleological reasoning)
General Theoretical Justifications	Differential Survival (Sexual selection)
	Gradual Process
	Heritability of genes
	Common Ancestor
	Rejection of inheritance of acquired traits
	Overproduction of offspring
	Nature of science

Table 4.46 Leyla's evolution conceptions used in justifications

Types of Justifications	**Conceptions**
Data (Retrieved from previous knowledge)	Adaptation: Color change in chameleons (misconception) Adaptation: White color skin of Polar Bears Transition form: Frog's development (misconception) Theory of use and disuse: Ferocious animals' teeth (misconception) Theory of use and disuse: Bird's beaks (misconception) Theory of use and disuse: Queen bees' diet (misconception)
Theoretical Justifications with identifying data (Warrant and Backing)	Prey/Predator Relationship with numbers of bright and predators (Teleological Reasoning) Heritability of genes with useless hind limbs Rejection of inheritance of acquired traits with sudden transition Adaptation with abrupt changes
Specific Theoretical Justifications	Theory of use and disuse (misconception) Adaptation (teleological and intentional reasoning) Adaptation (misconception) Inheritance of acquired traits (misconception)
General Theoretical Justifications	Lamarck's theory (misconception) Relation of adaptation and evolution Existing of fossil forms Genetic change due to adaptation (misconception) Gradual process Microevolution Rapid evolution Modification (misconception)

Table 4.47 Selin's evolution conceptions used in justifications

Types of Justifications	**Conceptions**
Data (Retrieved from previous knowledge)	Differential Survival (Sexual selection): Birds Transition from land to water Her digestion problems "why monkeys are not evolving" Whale evolution Human evolution Intermediate forms: between human and ancestry
Theoretical Justifications with identifying data (Warrant and Backing)	Adaptation with numbers of bright and predators (Teleological reasoning) Resource Limitation (Prey/predator relationship) with number of predators Common ancestor with useless legs Variation (Change in genes) with useless legs Rejection of Lamarck's theory with its inaccuracy Differential survival with the frequency of allele Gaps in the fossil record with abrupt climatic changes
Specific Theoretical Justifications	Prey/predator relationship (Teleological reasoning) Heritability of genes Generational changes Natural selection Overproduction of offspring Genetic Drift
General Theoretical Justifications	Competition Natural selection Rejection of inheritance of acquired traits Homologous organs (Darwin's theory) Intermediate forms

Table 4.48 Beste’s evolution conceptions used in justifications

Types of Justifications	**Conceptions**
Data (Retrieved from previous knowledge)	Modification: Rat Experiment Modification: Iron shoes in China Sediments Volcanic Eruption Intermediate form: Dinosaurs and Birds Geographic Isolation
Theoretical Justifications with identifying data (Warrant and Backing)	Differential Survival (Sexual Selection) with number of bright males Resource Limitation (Prey/Predator Relationship) with number of drab males Rejection of inheritance of acquired traits with modification Transition form with similarity Ancestral Relation and Heritability of genes with existing of useless hind limbs Gradual Process with slow climatic changes Gaps in the fossil records with climatic changes on Earth
Specific Theoretical Justifications	Variation Differential Survival Heritability of genes Generational changes in allele frequency Gradual Process
General Theoretical Justifications	Rejection of inheritance of acquired traits with modification Phylogenetic Pitchfork Rejection of Rapid evolution Existing of intermediate forms Evolution at population level Differential Survival

CHAPTER 5

DISCUSSION

In this chapter, the findings collected through multiple cases of this research were discussed in accordance with the findings from the literature. In addition, suggestions for improving science education and recommendations for further research were also addressed.

5.1. Discussions

The purpose of this study was to investigate structural, epistemic and conceptual aspects of science teachers' argumentations in the context of evolutionary theory as well as how science teachers used conceptual knowledge to articulate their arguments at different epistemic levels. For this reason, four science teachers were interviewed based on four evolutionary scenarios to identify their argumentation levels in terms of structural aspects, epistemic levels of their propositions and conceptual understanding levels. In addition, articulation of components of argumentation and conceptual knowledge in epistemic levels were also presented to deepen understanding about justification process through multiple case study. In this section, five major issues including criteria used to evaluate alternative theories, structural, epistemic and conceptual aspects of argumentation and the articulation of aspects of argumentation practices were presented in detail.

First of all, the results of present study indicated that teachers appealed mostly to rigorous criteria to evaluate validity of alternative explanations. That is, their criteria were line with scientific reasons and standards. In particular, especially two teachers (Leyla and Burcu) mostly used the criterion of how well claims fit with available data. This criterion was included in empirical criteria (see in Sampson & Blanchard, 2012) and mostly used by scientists as shown in Hogan and Maglienti's (2001) study. More specifically, authors found that scientists mostly examined the coherence between evidence and conclusion when evaluating the alternative theories.

In the present study, teachers used available data embedded in scenarios to distinguish alternative explanations from each other. This finding was in parallel with Yalçınoğlu's (2007) findings. Specifically, author found that science teachers mostly used the criterion of coherence between evidence and conclusion. In addition, in the present study, other two teachers (Beste and Selin) mostly appealed to criterion of how claims fit with scientific theories, in the case of evolutionary theory. This criterion was included in theoretical criteria and taken into consideration by scientists (see in Sampson & Blanchard, 2012). For example, the following quote, which was provided by Selin for *Whales* scenario, indicated how to use the criterion of consistency with scientific theory, in this case genetic drift:

> It could be the third explanation because while some people may have active lactase gene, others do not. It was mentioned about genetic drift; Darwin's evidences that support evolution, and it (genetic drift) leads to variation because it (variation) occurred completely randomly.

This finding was in line with Sampson and Blanchard's (2012) findings for science teachers. Authors found that science teachers took into consideration of how the claim fits with accepted theories and laws.

Regarding above mentioned differences between teachers' criteria, Sampson and Blanchard (2012) argued that science teachers appealed to the criterion of how well data fits with claims to evaluate alternative explanations when they were unsure their knowledge about particular evolutionary phenomena. However, teachers who had relatively high conceptual understanding made their decisions based heavily on their content knowledge. Similarly, in the present study, Leyla and Burcu who had relatively low conceptual understanding used empirical criteria most frequently while Beste and Selin who had relatively high conceptual understanding regarding evolutionary theory used scarcely empirical criteria and mostly theoretical criteria. One can conclude from these findings that using empirical and theoretical criteria depend on degree of content knowledge.

Although all teachers mostly appealed to scientifically appropriate criteria, some of teachers also used informal criteria including personal views and existing knowledge. For instance, Burcu used an informal criterion of consistency with personal inference as “in the explanation 2, abrupt climatic changes took placed; Ice Age Epoch began and thus, different habitats developed, *so* species changed abruptly”. It was an informal criterion since she did not attempt to support her inference by any scientific theory.

Among informal criteria used by teachers, the criterion of how well previous knowledge fits with the claim was utilized by all teachers. More specifically, their decisions relied on their previous knowledge. In line with this finding of present study, Sampson and Blanchard (2012) also revealed that science teachers used the criterion of how previous knowledge fits with the claim aside from the criterion of how data fits with claim. This criterion could be included in either rigorous or informal criteria depend on the content. Put more specifically, only if previous knowledge was supported by scientific theory, this criterion was valued in science (Sampson & Blanchard, 2012). Otherwise, their criteria were no longer consistent with scientific standards since these criteria were based heavily on personal judgments. In this regard, Sampson et al. (2011) argued that the use previous knowledge in order to challenge alternative theories is valued in science but if it is coupled with the adequate content knowledge. Regarding this issue, there were two instances worth mentioning in the present study. Firstly, especially one teacher (Leyla), who had relatively low level of conceptual understanding about evolutionary theory, used the criterion of previous knowledge in some scenarios to determine the most valid alternative but she did not mostly attempt to support her existing knowledge by using scientific theories and she chose wrong alternatives containing series of misconceptions. This means that previous knowledge coupled with inadequate knowledge could lead to wrong decisions. Therefore, this type of criterion was included in informal criteria rather than rigorous one. This result was in parallel with Hogan and Maglienti’s (2001) findings for students. In particular, authors found that students focused heavily on previous knowledge. In another example, two teachers (Beste and Selin) who had relatively high level of conceptual understanding about evolutionary theory mostly tended to use scientific theories to explain the reason behind their choice. Besides, these two teachers ruled out inaccurate explanations more often and tended to modify and refine the alternative explanations, in other words, they attempted to transform inaccurate claims closer to the accepted view. This finding supported the Sampson and Clark's (2011) findings in that authors comparing criteria used by high and low performing groups in terms of conceptual understanding levels found that higher performing groups utilized rigorous criteria more frequently than the lower performing groups. In this sense, authors argued that higher performing groups could identify and distinguish explanations including misconceptions more effectively. Therefore, it could be concluded that conceptual understanding might be an indicator of the use of rigorous criteria.

The present study also showed that there was a variation among teachers' conceptual understandings regarding evolutionary theory based on the analysis of conceptions used in their arguments. In particular, this study provides four different profiles in terms of evolution conceptions. First of all, Leyla had relatively low level of conceptual understanding about evolutionary theory, that is, she scarcely used evolutionary concepts and held misconceptions and cognitive biases as well. Put more specifically, she appealed to one key concept of evolution (heritability of genes) across the four scenarios. As for cognitive biases, she seemed to consider that the driving force behind evolutionary change is purpose (teleology) and mental agent (intentionality), as well as she underestimated the variation within population (essentialism) and as for misconceptions; she attempted to explain evolutionary change by Lamarck's theory and used adaptation process as cause of evolutionary change. Therefore, Leyla's conceptual understanding levels for scenarios were mostly classified as specific misunderstanding or cognitive biases. Second, Burcu had relatively low level of conceptual understanding. However, there was something different in the case of Burcu. In particular, Burcu mostly used evolutionary concepts such as differential survival, heritability of genes and common ancestry; however, she also held misconceptions and cognitive biases regarding evolutionary theory. She used teleological, intentional and essentialist reasoning and she had misconceptions about adaptation and Lamarck's theory. For that reason, her conceptual understanding levels for scenarios were mostly placed in partial understanding with misconceptions and cognitive biases. Next, Beste had relatively high conceptual understanding. More specifically, she used evolutionary concepts such as variation, common ancestry and differential survival and did not use any misconceptions and cognitive biases; however, she did not utilize all evolutionary concepts according to Nehm et al.'s (2010) framework. For that reason, her conceptual understanding level for each scenario was placed in partial understanding category. Lastly, Selin had relatively highest conceptual understanding. That is, Selin mostly appealed to evolutionary concepts such as natural selection, genetic drift and homologous organs. That's why her conceptual understanding levels for scenarios were mostly placed in sound understanding. However, Selin also held cognitive biases such as teleology and intentionality for one scenario. Taken as a whole, these results showed that even if they had basic or sophisticated understanding of evolutionary theory, they mostly held cognitive biases.

In addition to these findings, four instances about the use evolutionary conceptions should be noted. Firstly, some evolutionary key concepts and notions such as differential survival, common ancestry and heritability of genes were appealed in different contexts by especially three teachers (Burcu, Beste and Selin). In this regard, Tavares et al.'s (2010) claimed based on their findings that connecting same evolutionary conceptions to other contexts is an indicator of sound evolutionary explanation. Therefore, these three teachers seemed to have sound understanding with respect to aforementioned evolutionary conceptions. Next, three teachers employed teleological reasoning among three cognitive biases, in particular they perceived evolutionary process as a goal-or need-directed process even if some of them had high conceptual understanding about evolution. In this study, science mostly applied this type of reasoning especially when explaining survival of species as Gregory (2009) specified it. For instance, following quote which provided by Burcu for Whale scenario illustrated this type reasoning clearly:

> When the environment changed, living thing had to change *in order to* suite environment or died and became extinct

This relative prominence of teleological reasoning in this study was not surprising when taking into account of previous studies studying with biology teachers and experts (Ha & Nehm, 2014; Jensen & Finley, 1996; Nehm & Schonfeld, 2007).

For example, Jensen and Finley (1996) argued that the most common misconception regarding evolutionary theory is related to teleological reasoning. In this regard, Gregory (2009) argued that teleological reasoning is suppressed rather than replaced with the correct one by scientific training. In addition, author also discussed the possible reason behind bringing teleological reasoning to evolutionary context such that human experience includes purposeful and need-driven activities, so one easily interprets evolutionary process through goal-or need-driven process. In addition, Kelemen (2003) argued that this type of reasoning develops during early ages. Therefore, teleological reasoning is most probably deeply rooted since most of teachers in this study interpreted evolutionary process by using this type of reasoning (Stover & Mabry, 2007). Regarding the use of another cognitive bias, in particular essentialism, two teachers (Beste and Selin) who had high conceptual understanding level did not employ essentialist reasoning. In particular, they mentioned about variation within population. On the other hand, the other teachers (Leyla and Burcu) who had relatively low level of conceptual understanding employed this reasoning in their arguments. More specifically, they tended to consider species as sharing common "essence". This was probably due to poor understanding of genetics as well as inability to distinguish the evolution at population and individual level (Stover & Mabry, 2007). The following quote which was provided by Leyla showed how she employ this type of reasoning by explaining transformation of bright males into drab one :

> Bright males are few, that is, in order not to attract attention and not to be hunted by predator, *they* (bright males) *turn* into drab.

Lastly, one of the most commonly used evolutionary conceptions by teachers was the concept of adaptation. On the other hand, most of teachers applied this notion inaccurately. In particular, they perceived adaptation as a goal-driven process (teleology) and process directed by mental agent (intentionality) and these perceptions lead to common misconception that is related to adaptation due to environmental changes. For instance, Burcu explained adaptation process of Venezuelan Guppies by two aforementioned reasoning as "They (species) *adjust* their colors depend on particular environment in order not to be hunted by predators". This finding was in parallel with Bishop and Anderson's (1990) findings. For instance, Bishop and

Anderson argued that everyday meanings of adaptation lead to interpret this process in an inaccurate way. That is, everyday meanings of this notion imply altering by own effort or behavior and purpose. Therefore, this misinterpretation causes perceiving appearance of a trait due to influence of environment. In addition, there was another instance that is related to cognitive biases. The perceptions about goal-driven process and process directed by mental agent are related to teleological and intentional reasoning. As mentioned above, these cognitive biases could cause misconceptions. This finding was consistent with Moore et al.'s (2002) and Evans's (2008) results. For instance, Moore et al. found that students tended to ascribe agency in evolutionary explanations that results in misconceptions. In this regard, authors argued that one that did not adequate knowledge about the context tended to apply agency concepts to explain evolutionary process easily. In this sense, in the present study, Leyla who had low conceptual understanding about evolutionary theory, mostly employed teleological, essentialist, intentional reasoning. However, although Burcu appealed mostly to evolutionary concepts, she held cognitive biases. This co-existence of key concepts (normative concepts) and cognitive biases (non-normative concepts) was also found by Opfer et al. (2012). Opfer et al. argued that the use of cognitive biases with key concepts may be related to our cognitive structure, that is, especially essentialist and teleological biases are so fundamental that could influence our thinking and reasoning about the cause of evolutionary change.

The last issue for conceptual understanding was related to variations among scenarios. In the present study, there were four evolutionary scenarios discussing four distinct evolutionary phenomena. In particular, two scenarios (*Venezuelan Guppies* and *Lactose Intolerance*) were related to microevolution and other two (*Whales* and *Cambrian Explosion*) were related to macroevolution. In four cases (teachers), significant difference in conceptual understandings for microevolution and macroevolution was not found. However, there were three instances worth mentioning. First of all, although macroevolution includes evolutionary change at or above the level of species, most of teachers did not attempt to explain Cambrian explosion through applying microevolution concepts such as change in allele frequency or genetic variations. They mostly applied an evolutionary notion of common ancestry for this scenario. Another instance was related to human and other species evolution. In related literature, Sinatra et al. (2003) and Evans (2008) found in their studies, students and even adults perceived human evolution and other species evolution differently. Put more specifically, they accepted animal evolution but rejected human evolution. In the present study, there was not such an instance; however regarding this issue, there was a difference in some of teachers' explanations. Some of teachers applied intentional and teleological reasoning to *Lactose Intolerance* scenario dealing with human evolution relatively more frequently. This result was consistent with that of Evans. Last instance was related to trait gain and loss concepts. In this study, *Whales* scenario deals with trait loss while *Lactose Intolerance* scenario deals with trait gain. In this sense, Burcu applied Lamarck's theory of use and disuse for Lactose Intolerance while Leyla used this theory for both scenarios. In this regard, in the trait lose and gain contexts, students tended to use Lamarck's theory (Ha & Nehm, 2014). Ha and Nehm (2014) found that students and even experts applied this theory for especially in trait loss context.

In addition to conceptual aspect of argumentation practices, the present study provided structural aspects of them. Based on the findings, all teachers focused heavily on justifying their claims rather than opposing counter-claims, that is to say, they did not mostly challenge the merits of other viewpoints. This result was similar to results obtained by previous studies (Bell & Linn, 2000; Jiménez-Aleixandre et al., 2000; Sampson et al., 2011; Schwarz et al., 2003). For instance, Sampson et al. (2011) found that students did not attempt to evaluate and discuss other ideas; instead, they mostly tended to justify their claims. Authors argued that this tendency of students was due to confirmation bias. In particular, students tended to only look for information that confirms their existing knowledge or beliefs (Zeidler, 1997). In this regard, in the present study, science teachers' were firstly asked to construct an argument and then, question prompts were used to guide their argumentation practices. Before using question prompts, most of them did not attempt to think in the light of alternative explanations. Therefore, one can conclude that science teachers, in this study, had confirmation bias. Another significant finding of this study was related to science teachers' oppositions. Although they scarcely opposed alternative explanations, they generated strong rebuttals. This means that they attempted to justify their counter-claims through using data, warrant of backings. However, some of their rebuttals were weak since these rebuttals were not sufficiently supported. The similar finding was reached by Sandoval and Millwood (2003). More specifically, authors found that students struggled to interpret data in their arguments. In this sense, they concluded that students perceived data as self-evident. The reason of this might be that they thought that evidence has only one possible meaning. Therefore, science teachers, in the present study, might regarded that some of data mean the same thing to everyone. The last issue has to be noted that even though each teacher had distinct profile in their conceptual knowledge regarding evolutionary theory, there was not great difference in their argumentation quality in terms of structural aspect. In particular, all generated arguments at Level 2, that is, they justified their arguments; however, they rarely provided rebuttal for alternative explanations. This result was consistent with the results of previous studies (Clark & Sampson, 2008; Sadler & Donnelly, 2006). For instance, Clark and Sampson (2007) found that sophisticated arguments were not always accompanied by sophisticated content knowledge. In another study, Sadler and Donnelly (2006) revealed that argumentation practices need to threshold understanding of concept, however, further knowledge is not required for high quality of it.

Regarding above mentioned issue, several instances should be noted. One of teachers (Leyla) who held low conceptual understanding regarding evolutionary theory did not generate any argument including more than one rebuttal. This might be related to struggling to distinguish alternative explanations from each other. However, two teachers (Burcu and Beste) who appealed to evolutionary conceptions in their arguments provided more than one rebuttal for their arguments relatively more frequently. On the other hand, one teacher (Selin) who had relatively sound understanding generated more than one rebuttal relatively less frequently. At first glance, it seemed that high conceptual understanding was not associated with high level of argumentation structure. However, there might be an exception for Selin's case. In particular, Selin usually chose two alternatives for an evolutionary phenomenon as a valid while other teachers usually chose one alternative. Therefore, Selin mostly provided rebuttal for one alternative explanation. Therefore, these instances might indicate that high conceptual understanding provides relatively high level of argumentation. Some results from previous studies indicated this relation (Acar, 2008; von Aufschnaiter et al., 2008). For instance, Sampson and Clark (2011) argued based on their findings that higher performing groups took into consideration of other alternatives and provided more counter-arguments more often as compared to low performing groups. When taking into account of findings of previous research and present study, it could be concluded that conceptual understanding contributes to providing more oppositional comments but further understanding was not need to generate more sophisticated arguments.

Another aspect of argumentation practices analyzed in the present study was epistemic one. The findings related to this aspect illustrated that although all teachers generated arguments at different epistemic levels, they used more theoretical statements than data statements. This means that they did not sufficiently support their theoretical assertions by data. Although the contexts were different, this result was similar to those of Jiménez-Aleixandre and Bravo (2009), Kelly and Takao (2002), Maloney (2007), Tavares et al.'s (2010). For instance, Maloney found that students mostly tended to use single piece of evidence rather than multiple evidences to support their arguments. In the present study, all teachers used multiple evidences; however, they did not reference sufficient evidences for their theoretical statements. In another study, Jiménez-Aleixandre and Bravo also found that students tended to use theoretical claims rather than data statements. Author argued the possible reasons of this result such that one reason might be related to conceptual understanding and the other one might be unfamiliarity the use of data and coordinating data to theoretical claims. For former reason, authors explored the relationship between the use of evidence at different epistemic levels and conceptual understanding regarding ecology. They concluded that basic understanding was needed to use relevant evidenced claims but high level understanding was not related to the use of multiple types of evidences. This conclusion was in parallel with findings of the present study such that one of teachers (Leyla) who had low conceptual knowledge and held misconceptions regarding evolutionary theory used irrelevant evidences in her arguments. In addition, although relationship between the use of evidence and conceptual understanding was not systematically analyzed in the present study, there was a significant instance regarding this issue worth mentioning. Although all teachers used theoretical assertions more frequently, one of the teachers (Leyla) who had low conceptual knowledge about evolutionary theory used data statements to support her theoretical assertions relatively most frequently. Selin and Beste especially who had relatively high conceptual knowledge used theoretical statements to justify their claims. Thus, high conceptual understanding might be related to tendency of the use of more theoretical assertions. This result was in line with the result found in prior analysis for science teachers' criteria to evaluate the alternative explanations in that high conceptual understanding was mostly associated with the use of theoretical criteria, in particular how well scientific theories fit with the claims. Hence, ability of coordinating evidence to theoretical claims may be related to conceptual understanding in some degree; however all teachers generated theoretical assertions relatively more frequently regardless of their levels of conceptual understanding. Thus, it can be said that this ability is more probably related to unfamiliarity of the use data.

The present study also provided integration three aspects of argumentation practices such as the articulation of conceptual knowledge and structural aspect of argumentation practices at different epistemic levels. Based on these findings, three teachers (Selin, Burcu and Beste) generally chose accurate explanations as to evolutionary theory. In line with their choices, they justified their claims by referencing relevant data from either scenario or their previous knowledge and appealing to wide range of evolutionary conceptions in the forms of specific and general theoretical claims such as differential survival, heritability of genes, common ancestry and genetic drift. This finding was in parallel with that of Tavares et al. (2010). In particular, authors investigating students' articulations of evolution conceptions and argumentation practices found that they also appealed to evolutionary conceptions such as common ancestry, speciation and chance in their arguments. For alternative explanations, in the present study, they rebutted them by appealing mostly to conceptions specific and general theoretical claims. In particular, most of them were aware of provided misconceptions about Lamarck's theory of use and disuse and inheritance of acquired traits and rejected them. On the other hand, although some of the alternative explanations also included cognitive biases, teachers did not reject them. This finding was inconsistent with Tavares et al.'s findings since authors found that students denied intentionality and teleological explanations. In addition to evolutionary conceptions, in this study, the articulation of misconceptions and cognitive biases were also documented. One teacher (Leyla) especially used irrelevant data and misconceptions align with cognitive biases in her arguments. For instance, she used Lamarck's theory of use and disuse to support her claim and used frog's development as data to support claim regarding transition form. Moreover, in Leyla's and Burcu's arguments teleological, intentional and essentialist reasoning were appeared. These findings were in line with Zembal-Saul et al.'s (2002) findings. Authors revealed that pre-service science teachers struggled to apply differential survival and variation to support their arguments. In addition, Lamarckian evolution and teleological reasoning were also used to articulate their arguments. These findings supported the Sampson and Clark's (2011) results which indicated that those who possess adequate knowledge utilized more appropriate and relevant evidences, reasoning and oppositions as opposed to lower performing group. Therefore, it could be concluded that conceptual understanding, the use of relevant evidence and generating appropriate justification and rebuttals were interrelated. Put it differently, the use of relevant and appropriate justifications and coordinating them in a scientifically appropriate way to generate scientific arguments require conceptual understanding.

5.2. Conclusions

The focus of this study was on science teachers' argumentation practices. In related literature, previous studies mostly investigated structural aspects of argumentation. Although structural analysis of argumentation provided a template to seek out participants' components of argumentations, as Sampson and Clark (2008) voiced, there need to provide additional insights of argumentation practices to deepen our understanding. From this perspective, scientific activity consists of moving between theoretical assertions and data statements and in parallel with this, scientific argumentation involve connecting the two together. Therefore, there is a need an epistemological focus examining relative epistemic status for argumentation practices. This additional focus provides consideration of knowledge claims at various levels of theoretical generality. In line with this, the current study explored degree of abstractness of knowledge claims and how science teachers coordinate these knowledge claims with each other. In addition to these aspects, analysis of conceptual aspects of argumentation is also required to understand how teachers and students used their conceptual knowledge to articulate their arguments. It is important for scientific argumentation since argumentation practices in science education should be articulated with relevant and accurate scientific knowledge (Kelly et al., 1998; Sampson & Clark, 2008).

In the present study, in line with the above mentioned issues, qualitative data gathered to illuminate the detailed aspects of argumentation practices through lens of four different science teachers. Based on the findings, the current study provided four cases differing in terms of conceptual aspects. Accordingly, different argumentation practices in terms of structural and epistemic aspects were reported. According to the findings of the present study, some of the science teachers brought to bear evolutionary concepts and notions in their arguments, however, others were unable to use evolutionary theories and models as a tool to construct scientific arguments. In addition, some of them utilized non-normative concepts that are not consistent with current scientific understanding in their arguments. Further, although conceptual aspects of science teachers' argumentation practices varied, their argumentation practices in terms of epistemic and structural aspects were not quite different from each other. In particular, all teachers struggled to generate sophisticated arguments and coordinate evidence with theory. These result indicated that science teachers, in this study, had confirmation bias and they were unfamiliar with the use of data. These results might provide insight to science educators looking for ways to improve scientific argumentations while making instructional decisions in teacher education since as Simon et al. (2006) stressed, developing teacher's argumentation practices is more important than students' trainings to cultivate argumentation practices inside the classrooms. Besides, these findings might provide insight for science education researchers in terms of different aspects of argumentation practices.

Furthermore, argumentation is a valuable tool to understand how students and teachers construct and evaluate the scientific knowledge claims (Duschl, 2008). In parallel of this, the present study also attempted to analyze science teachers' conceptual understanding regarding evolutionary theory through examining contents of their arguments. As a unifying theme, theory of evolution is central to science education. Therefore, science teachers need to have comprehensive understanding of it. However, the findings of the present study revealed that science teachers' conceptual understanding of evolutionary theory was inadequate in general even if some of them had relatively high conceptual knowledge. Various misconceptions and cognitive biases regarding evolutionary theory were brought to bear upon evolutionary problems. Even if some of them applied evolutionary theory to explain natural phenomena, they still had misconceptions and used cognitive biases to explain evolutionary change. Along with these findings, another remarkable finding was that conceptual biases about evolutionary change could lead to misconceptions. Therefore, the co-existence of normative and non-normative concepts regarding evolutionary theory and existence of cognitive biases as a potential barrier to understand evolutionary theory suggested that pedagogical efforts or interventions were needed for science teachers to address not only causes of evolutionary change but also cognitive biases since as several researchers voiced, teaching evolution improperly could affect students' biological reasoning (Smith, 2010).

The findings of the present study are generally similar with the findings of previous studies in related literature. However, these comparisons with previous works were limited because there are apparent deficiencies on research that explore science teachers' argumentation practices, that is, how science teachers construct scientific arguments. Therefore, it is difficult to make well-grounded conclusions.

5.3. Implications and Recommendations for Further Studies

The current study has several implications and recommendations for science teacher educators and science education researchers based on results of this study and discussions made.

The present study investigated different aspects of argumentation practices, namely conceptual, epistemic and structural aspects. These analyses provided different insights into argumentation practices. In particular, how science teachers assimilate the argumentation practices, their types of reasoning, how they coordinate evidence to theoretical claims and how they utilized conceptual understandings in their argumentations as well. In addition, the investigation of the articulation of conceptual knowledge and argumentation practices at different epistemic levels indicated that these three aspects of argumentation practices were intimately linked. More specifically, in order to generate persuasive and scientific arguments, justification in the light of alternative theories is necessary to challenge opponents' ideas including inaccurate or inappropriate notions, conceptual knowledge is required to decide relevant evidence and provided appropriate justifications and the ability of the use of evidence are required to adequately coordinate it to relevant theory. This interrelation can be interpreted as two ways. One way is that argumentation could be used as a tool to develop conceptual and epistemological understanding. Another way is that conceptual and epistemic aspects could be used as a tool to improve quality of scientific arguments. Put more specifically, argumentation practices, with its emphasis on justifications of scientifically appropriate knowledge claims and on the coordination of relevant evidence with scientific theory supports the development of epistemological criteria and conceptual understanding within a specific domain. At the same time, emphasis on the ability to coordinate relevant evidence with scientific theory and to apply normative scientific concepts in arguments has potential to improve scientific argumentation quality. Therefore, based on the findings, it was suggested that argumentation practices should be carried out and designed by taking into consideration of this interrelationship. This finding may be useful for curriculum developers and science educators while designing argumentation practices. More specifically, students' or teachers' argumentation practices should be analyzed and guided based not only on structural but also on conceptual and epistemic aspects in order to develop conceptual and epistemological understanding and in turn, scientific argumentation practices.

In related to above mentioned issues, evolutionary theory was chosen as a theme for the present study. Thus, science teachers' argumentation practices about evolutionary theory were analyzed. The findings based on this analysis suggested that understanding of evolutionary theory was required for justifying claims with relevant and appropriate evidences, coordinating theoretical assertions regarding evolutionary theory with relevant data statements and by considering wide range of ideas, generating strong counter-arguments to disprove others' ideas including misconceptions. In parallel with these practices, argumentation could promote understanding of evolutionary theory, that is, as individuals considered and evaluated alternative explanations or theories and generated reasons by coordinating data with evolutionary theory, they were required to evaluate their existing knowledge regarding evolutionary theory and articulate them at multiple levels of abstraction in arguments. For example, they could need to integrate inferences made from provided evidences and appropriate theories recalled from previous knowledge regarding the concept of differential survival to explain evolutionary problems and to discuss the alternative explanations related to use and disuse theory. Thus, this process leads to promoting knowledge construction process. Hence, the process necessary for concept learning are naturally engage in the argumentation context. From this perspective, one can say that if teachers have required skills to generate arguments about evolutionary theory, they develop sophisticated understanding about this theory which in turn, improves their teaching skills while sophisticated understanding regarding evolutionary theory also promote scientific argumentation practices. Therefore, the aforementioned results might have two implications. First, argumentation practices could serve as a tool to teaching and learning evolutionary theory in science classrooms. Several previous works supported this in such a way that they found that traditional teaching methods were insufficient to teach evolutionary theory, however, engagement in knowledge construction process might provide effective learning about this topic (Asterhan et al., 2007; Jensen & Finley, 1996). Second, evolutionary theory as a unifying theme could be valuable topic to analyze and develop scientific argumentation skills since individuals are required to evaluate and integrate different scientific principles and evidences from different scientific domain to articulate their arguments.

The present study also recommended that future research explore above mentioned articulation in depth to gain broader view of argumentation practices. In addition to this, further research should pay attention to social aspect of argumentation practices. More specifically, argumentation practices could be carried out in social processes in which participants engage in justifying their claims and providing rebuttals for opponents' ideas. Therefore, it provides the analysis of practices based on whether the process consists of cooperation in the generating arguments and dialectics between counter-arguments.

Further, in the present study, science teachers' argumentation practices in terms of conceptual aspects with respect to evolutionary theory were inadequate in general since their arguments included various misconceptions and cognitive biases regarding this theory. In addition to this aspect, science teachers' argumentation practices were also inadequate in terms of structural and epistemic aspects. That is, they inadequately challenged the alternative theories and struggled to coordinate evidence with theory. Therefore, this study indicated that science teachers need to learn more about evolutionary theory and nature of argumentation. As Sampson and Blanchard (2012) suggested, one way to help science teachers gain insight into process of generating arguments is to engage them into scenario-based argumentation activities. Then, science educators could utilize these experiences as a base for developing their understandings about nature of argumentation. As Jiménez-Aleixandre and Bravo (2009) constructed analogy between riding a bicycle and the use of evidence to explain that the use of evidence and tying it to theory in that both of them need practices since previous studies provided evidences that practice provides development of argumentation skills (e.g., Erduran et al., 2004; Sampson et al, 2011). Therefore, professional development and research programs should be designed in such a way that science teachers can engage in argumentation practices. However, more studies of how science teachers construct scientific arguments and what they know about scientific argumentation are still needed. Regarding this issue, future researchers could make observations and analysis of teachers' argumentation practices in the classroom context in order to get broader view about teachers' knowledge and skills about scientific argumentation. In addition, they could employ different frameworks and tests to reveal science teachers' misconceptions and cognitive biases more precisely.

Along with the above mentioned issues, the present study underlined the required skills to generate sophisticated and persuasive arguments by examining scientific argumentation practices from different aspects and by revealing the inadequacy of science teachers' skills and knowledge about argumentation practices in terms of these aspects. These skills included the ability of coordination of appropriate data with relevant scientific theory, the use of scientifically appropriate conceptual knowledge to articulate scientific arguments and generating relevant counter-arguments. Therefore, such skills are necessary to support more productive scientific argumentation practices in science lessons since emphasis on structural aspect of argumentation practices alone is not sufficient to generate and develop scientific argumentations. From this point of view, it is essential (1) to inform science educators to become aware of such skills when designing educational intervention or workshops for in-service science teachers and teacher education programs for pre-service science teachers to improve quality of argumentation practices; (2) to inform curriculum developers about such argumentation skills to address them in programs to enhance the argumentation practices in science classrooms.

For the above mentioned aspects of argumentation practices, several frameworks were employed to analyze them. First of all, Nehm et al.'s (2010) framework provided in-depth analysis of conceptual knowledge regarding evolutionary theory. Put more specifically, this framework is quite different from other frameworks in that it distinguishes cognitive biases and misconceptions from each other. It is important to identify cognitive biases since both previous studies (Moore, 2002; Sinatra et al., 2008) and the present study showed that cognitive biases could lead to misconceptions about evolutionary theory. In addition, cognitive biases could preclude understanding of evolutionary theory. For those reasons, the use of Nehm et al.'s framework is suggested for the analysis of evolution conceptions to reveal students' and teachers' conceptions more comprehensively and if any, misconceptions along with cognitive biases and even, the source of misconceptions. Another framework used to analyze structural aspects of argumentation in this study was Erduran et al.'s (2004) framework. Author developed this framework to overcome the methodological issues associated with the Toulmin's (1958) layout. They distinguished argumentation components in two categories, namely reason and rebuttal. Therefore, by using this framework, the analysis of argumentation levels provides more reliable results. Besides, Tavares et al.'s (2010) framework was used to identify relative epistemic status of science teachers' propositions. This framework also provides promising approach for the analysis of epistemic nature of justifications. Hence, this framework enables to understand degree of abstractness of propositions and how students and teachers connect these propositions. Lastly, Tavares et al.'s rubric used in the present study enable to explore how these three aspects of argumentation practices integrated. More specifically, this rubric provides to examine the articulation of conceptual knowledge and argumentation practices at different epistemic levels and this analysis enables researchers to understand argumentation practices more comprehensively. Therefore, these conceptual, structural and epistemic frameworks enable science teachers and program developers to guide their instructional decisions and analyzing students' argumentation practices. However, there is still need to develop a framework that includes all of these aspects to make analysis more effective and easier. Moreover, future research should also focus on developing new frameworks to analyze argumentation practices in a broader view.

Final issue was related to context of the study. In this study, four different evolutionary scenarios designed based on problem solving approach to analyze science teachers' conceptual understanding and argumentation practices. This approach enables to reveal science teachers' practices more effectively rather than only asking questions. Therefore, this research suggested the analysis of conceptual knowledge and argumentation practices through using scenarios based on problem solving approach. In this sense, future research should pay attention to components of the scenario in order to enhance the argumentative practices. Also, scenarios related to chemistry and physics topics could be also developed to analyze conceptual understanding and argumentation.

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APPENDICES

APPENDIX A

TURKISH AND ENGLISH VERSION OF SCENARIOS

SCENARIO I: VENEZUELLA LEPİSTESLERİ

Lepistesler Venezuella'da akarsularda bulunan küçük balıklardır. 70'li yıllarda Biyolog John Endler yabani lepistes (Poecilla reiculata) popülasyonları üzerinde çalışırken, yerel popülasyonların birbirlerinden çarpıcı şekilde farklı olduklarını fark etmiştir. Bazı popülasyondaki ergin erkekler parlak, gökkuşağı renklerine sahipken, diğer popülasyondaki erkekler ise daha mat renklere sahiptir. Endler çektiği yüzlerce fotoğraf ve lepisteslerin büyüklük, renk ve benekleri üzerine yaptığı ölçümler sonucunda lepisteslerin yaşadığı yerler ve parlak veya donuk renkte olmaları arasında bir ilişki olduğunu keşfetmiştir. Endler'in, farklı akarsularda topladığı veriler aşağıda gösterilmiştir;

Dört Farklı Akarsuda Bulunan Venezuella Lepistesleri

Akarsu Özellikleri		Akarsular Akarsu 1	Akarsu 2	Akarsu 3	Akarsu 4
Akarsu derinlikleri		Derin	Derin	Sığ	Derin
Akarsuda Bulunan Avcı Balıklar	Cichlid	%44	%0	%0	%0
	Rivilus	%20	%66	%100	%0
	Acara	%36	%34	%0	%0
Toplam Avcı Balıklar		28	14	6	0
Akarsuda Bulunan Lepistesler	Parlak Erkekler	%3	%30	%42	%47
	Mat Erkekler	%41	%12	%5	%2
	Parlak Dişiler	%0	%0	%0	%0
	Mat Dişiler	%56	%58	%54	%51
Toplam Lepisteler		100	165	187	231

Bu verilere göre, Lepisteslerdeki renk dağılımını nasıl açıklarsınız?

Aşağıda yukarıdaki soruya yönelik 3 alternatif açıklama verilmiştir…

Açıklama #1 Lepistesler belirli bir yaşam alanında hayatta kalmaları için parlak veya donuk renkli olarak yaratılmışlardır

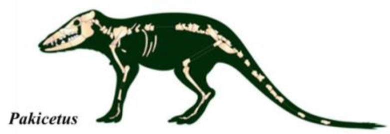
Açıklama #2 Dişi lepistesler çiftleşmek için parlak renkli erkekleri tercih ederler. Sonuç olarak, parlak erkekler eşleri cezbetme ve daha fazla döl üretme eğilimindedir. Yaşam alanında avcılar sayıca çok olduğu zaman, bu sefer parlak renkli erkekler üreyebilmek için yeterince uzun süre hayatta kalamamaktadır.

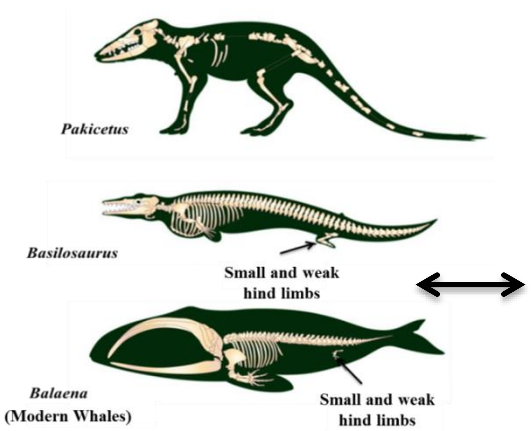
Açıklama #3 Lepistes türü balıklar diğer balıklar gibi gösterişli olmaya çalışmaktadırlar. Fakat bireyler farklı akarsulara göç ettikleri zaman, avcılardan korunmak için renklerini ayarlamaları gerekir. Sonuç olarak, bazıları yeni yaşam alanına daha iyi uyum sağlayabilmek için donuk renkli olmaya başlarlar. Bu yeni özellik sonra yavrularına aktarılır çünkü yararlıdır.

Yukarıdaki 3 alternatiften farklı bir açıklamanız var ise lütfen belirtiniz:
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

SCENARIO II: BALİNALAR

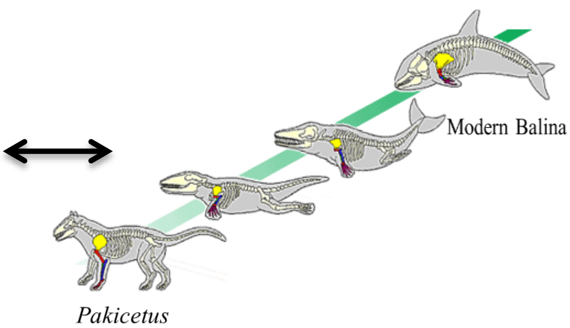
Balinalar dünyanın en büyük memeli hayvanlarıdır. 1978 yılında, Pakistan'da Creodonts fosilini (60 - 37 milyon yıl önce yaşamış kurt büyüklüğünde etoburlar) andıran bir kafatası fosili bulundu. Yeni bulunan kemik fosilleri *Pakicetus* olarak adlandırıldı. *Pakicetus*'a ait kafatasının, balinaların bilinen eski formlarıyla, sadece balinalara has olan, ortak özellikleri olduğu saptandı: *Pakicetus* kafatasındaki kulak bölgesi kara memelilerinkiyle tam benzer değildir ama kara memeliler ile sucul memelilerin arasında bir yerlerdedir. Sonrasında yapılan çalışmalar yeni keşifleri daha ortaya çıkardı;



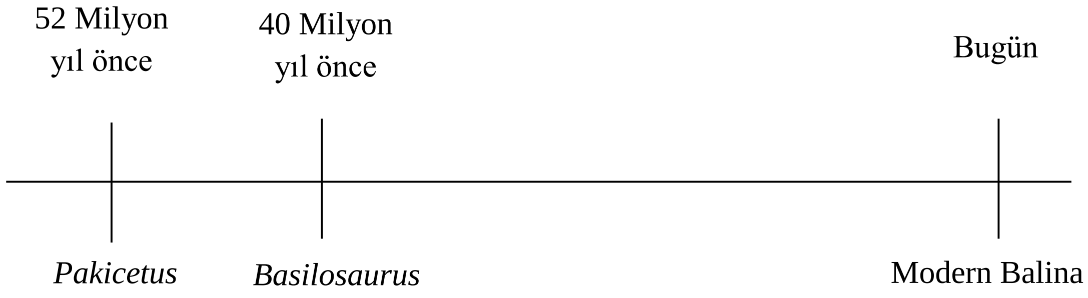


Bulunan diğer sucul balinaların atası, *Basilosaurus*, bacaklara sahipti (yandaki şekilde verildiği üzere). *Basilosaurus* su ortamına tam adapte olmuş ve 40 milyon yıl önce eski denizlerde yaşayan bir hayvandı. *Basilosaurus* karada yürüyememesine rağmen, zayıf arka bacaklara sahipti. Bugün modern balinaların bacakları yoktur fakat bazıları hala çok küçük arka bacak kemiklerine sahiptir.

Ayrıca yandaki şekilde görüldüğü üzere *Pakicetus*'un yürüme amaçlı kullandığı ön üyelerinin diğer türlerde bulunan yüzgeçlere anatomik olarak benzerliği gösterilmiştir.



Aşağıdaki zaman çizelgesi 3 türün yaşadığı zamanları göstermektedir;



Fosil kayıtlarına göre *Pakicetus*, *Basilosaurus* ve Modern Balina arasında nasıl bir ilişki vardır?

Aşağıda yukarıdaki soruya yönelik 3 alternatif açıklama verilmiştir…

Açıklama #1 *Pakicetus* karada yaşayabilen ilkel bir memeliydi. Sonrasında bu ilkel memeliler, çevrelerinin değişmesiyle birlikte suya taşındılar. Suda yaşamaya başladıktan sonra, bacaklarını kullanmaya ihtiyaçları kalmadı ve bacaklarını kullanmadıkları için zamanla farklılaşarak küçük ve zayıf arka bacaklara sahip olan *Basilosaurus*'a dönüştüler. Daha sonra yeni nesiller (modern balinalar) bacakları olmadan doğmaya başladı.

Açıklama #2 *Pakicetus*'un balinalarla herhangi bir ilişkisi yoktur. *Pakicetus* bir kara memelisi, *Basilosaurus* ise bir deniz memelisidir. Modern memeliler sadece, nesilleri tükenmiş olan *Basilosaurus* ve *Pakicetus* türlerine ait benzer yapılara sahiptir. *Basilosaurus* omurgasından bağımsız arka küçük kemiklere sahiptir fakat bu kemiklerin körelmiş kemikler olduğunu göstermez, farklı bir işleve sahip olabilir. Sonuç olarak *Pakicetus*, *Basilosaurus* ve modern balinaların arasında akrabalık ilişkisi yoktur. Onlar tamamen farklı türlerdir.

Açıklama #3 *Pakicetus* hem karada hem de denizde yaşayabilen bir memeliydi. Bu nedenle, *Pakicetus* bir geçiş formu olabilir. Balinaların ataları önce karada yaşıyorlardı ve bacaklara sahiplerdi. Popülasyonda, genlerinin değişmesi sonucunda bazı balinalar küçük ve zayıf arka bacaklara sahip olarak doğdu ve ortamları değiştiği zaman küçük ve zayıf arka bacaklara sahip olan balinalar (*Basilosaurus*) daha avantajlı konuma geldi ve daha fazla döl vererek çoğaldılar. Zamanla küçük ya da hiç arka bacağı olmayan modern balinalar popülasyona hakim oldu.

Yukarıdaki 3 alternatiften farklı bir açıklamanız var ise lütfen belirtiniz:

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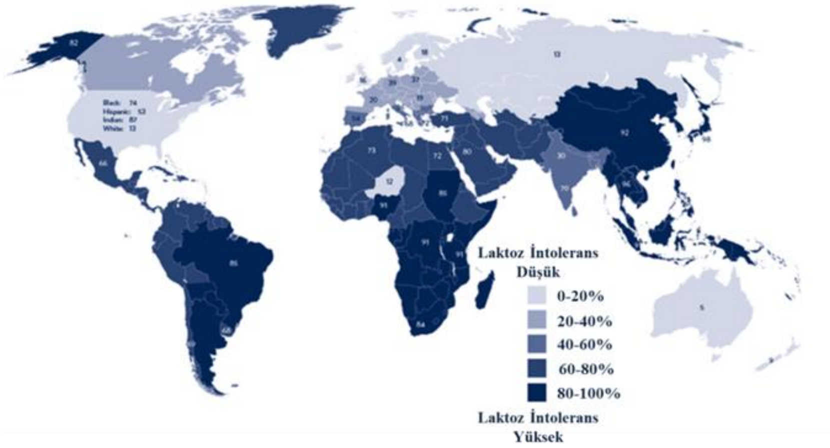
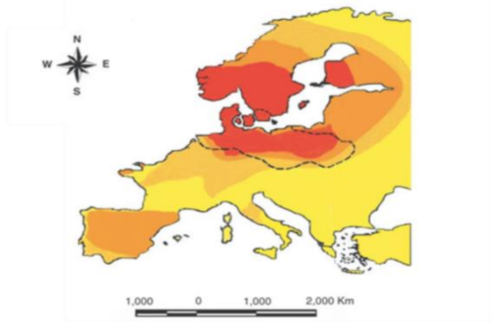
SCENARIO III: LAKTOZ DUYARSIZLIĞI



İnsanlarda Laktoz Duyarlılığı (İntolerans) Küresel Dağılımı

Türkiye ve pek çok diğer ülkede "süt" tüketiliyor, ancak bazıları bundan zevk alamıyor. Ek besin kaynağı olması ve kuraklık döneminde su ihtiyacını giderebilmesi açısından insanlar için avantajlı olan süt, Amerikalı'ların %10'u, Afrika'daki tutsi kabilesinin %10'u, İspanyol ve Fransızların %50'si ve Çinlilerin %99'u için hazım problemleri demek. Peki bu toplumlardaki laktoz tolerans çeşitliliği nereden kaynaklanıyor olabilir? Süt, içeriğindeki laktoz şekeri nedeniyle birçok yetişkin için sindirilebilir bir besin değildir. Laktoz şekerini, sindirimi kolay glikoz ve galaktoza indirgeyen "laktaz" genin aktivitesine bağlı olarak sindirebilme gerçekleşmektedir. Yapılan arkeolojik ve genetik çalışmalar, 8000 yıl öncesinde yetişkinlerde laktoz tolerans allelinin bulunmadığını ve yandaki şekilde verildiği üzere, yaklaşık 8000 yıl içerisinde Avrupa'da yetişkin popülasyonda laktoz tolerans allelinindeki değişikliği ortaya koymuştur (Burger vd., 2007).



Modern Avrupalılarda Laktoz Tolerans Alleli Coğrafi Dağılımı. Koyu turuncu rengi, yüksek frekanslı laktoz tolerans allelinin dağılımını göstermektedir. Kesikli siyah çizgiler, arkeolojik verilere göre, 7500-9000 yıl öncesi erken Neolitik dönemde süt hayvancılığının yapıldığı sınırlı coğrafi dağılımı temsil etmektedir.

Sahra altı Afrika'sında yapılan başka bir çalışma, 9000 yıl önce hayvan yetiştiriciliğine başlayan Afrikalı insanların bugün sütü sindirebildikleri fakat Avrupalılarda görülen laktaz genin aktif olmasını sağlayan allelden farklı bir çift allel taşıdıkları ortaya konmuştur (Tishkoff vd., 2009).

Bu verilere göre, insanlarda laktoz toleransı nasıl gelişmiştir?

Aşağıda yukarıdaki soruya yönelik 3 alternatif açıklama verilmiştir…

Açıklama #1 Süt elde edilebilen yerlerde, süt tüketim avantajlı olduğu için laktaz geninin aktif olmasını sağlayan allelin frekansı artmıştır. Sonuç olarak, laktozu sindirebilme popülasyona hakim olmuştur. Bu olay farklı coğrafik toplumlarda aynı etkiyi oluşturan farklı allel frekanslarının değişmesiyle meydana gelmiştir.

Açıklama #2 Süt elde edilebilen yerlerde, insanlar süt tüketmeye başlamış ve zamanla süt içme alışkanlığının artması sonucunda bu durum genomlara yansımış ve laktaz geninin aktif olmasını sağlayan allelin frekansını artırmaya başlamıştır. Sonuç olarak, süt tüketim alışkanlığı çok olan bireyler sütü sindirebilmeye başlamışlardır. Bu gelişme farklı toplumlarda farklı bir şekilde genomlara yansımıştır.

Açıklama #3 Toplumlar arası ve toplum içindeki sütü sindirebilme çeşitliliği, yani laktaz genin aktif olmasının süt tüketimiyle bir ilişkisi yoktur. Bu daha çok süt hayvancılığına başlanmadan önce rastgele bir şekilde bazı insanların laktaz genin aktif bazılarınınsa pasif olmasından kaynaklıdır. Mesela, süt hayvancılığının başladığı Avrupa'da hala sütü tüketemeyen insanlar vardır. Bu yüzden her insanın laktaz ilişkili allel çifti farklıdır.

Yukarıdaki 3 alternatiften farklı bir açıklamanız var ise lütfen belirtiniz:

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…………………………………………………………………………………………

SCENARIO IV: KAMBRİYEN PATLAMASI

Dünya 4.6 milyar yaşındadır fakat yaşam yaklaşık olarak 3.5 milyar yıl önce ortaya çıkmıştır. İlk yaşam kayıtları, 2 milyar yıldan fazla Dünya'ya hakim olan tek hücreli canlılara, prokaryotlara aittir. Yaklaşık 700-900 milyon yıl önce ilk çok hücreli canlılar yumuşak vücut formlarına sahiptir. Paleontolojik kayıtlar, sert kabuklu canlılara ait fosillerin ise yaklaşık 570 milyon yıl önce ilk defa Kambriyen adı verilen dönemde ortaya çıktığını göstermiştir. Kambriyen döneminde, çok hücreli canlı türleri büyük bir çeşitlilik göstermektedirler; annelidler, eklembacaklılar, derisidikenliler, yumuşakçalar veya sürüngenler ve hatta Chordata gibi karmaşık yapılı çok hücreli canlılar ilk defa bu dönemde ortaya çıkmıştır. Ayrıca, yapılan çalışmalarda Kambriyen döneminde, oksijen miktarının artması, sıcaklığın düşerek Dünya'nın buzul çağına girmesi ve koşulları birbirinden farklı habitatların oluşu gibi ani çevresel değişimler tespit edilmiştir. Fakat tek hücrelilerden çok hücrelilere geçişte enteresan bir şey vardır; kambriyen dönemindeki karmaşık yapılı çok hücreli canlıların fosil kayıtları ile kambriyen öncesinde yaşayan canlılar arasında ara form bulunmamaktadır.

Fosil kayıtlarının doğadaki canlı çeşitliliğini yansıttığı göz önüne alınırsa, bu verileri nasıl yorumlarsınız?

Açıklama #1 Ara fosillerin olmaması, 570 milyon yıl önceki dönemlerde çok az fosilin oluşmuş veya korunmuş olduğu gerçeğinden kaynaklanmaktadır. Çok hücreli organizmaların evrimi küçük adımlarla ilerleyen yavaş ve kademeli bir süreçtir.

Açıklama #2 Ara fosillerin olmaması, bu formların hiçbir zaman var olmadığı gerçeğinden kaynaklanmaktadır. Canlılardaki türleşme ara fosil oluşmasına imkan vermeyecek kadar hızlı olmuştur. Çok hücreli canlılar, ani değişimler sonucunda ortaya çıkmıştır.

SCENARIO I: VENEZUELAN GUPPIES

Guppies that live in Venezuelan streams are small fishes. When biologist John Endler began studying a species of wild guppies (called Poecilla reiculata) in the 1970s, he was struck by the wide color variation among guppies from different streams and sometimes even among guppies living in different parts of the same stream. Guppies from one pool sported vivid blue and orange splotches along their sides, while those further downstream carried only modest dots of color near their tails. Endler photographed hundreds of guppies and carefully measured their size color and the placement of their spots. He began to see pattern between where guppies lived in a particular stream and whether the fish were bright or drab. Data Endler collected from different streams is presented as follow;

Venezuelan Guppies four different streams

Characteristic of Streams		Streams Stream 1	Stream 2	Stream 3	Stream 4
Type		Deep	Deep	Shallow	Deep
Predator fish found in streams	Cichlid	%44	%0	%0	%0
	Rivilus	%20	%66	%100	%0
	Acara	%36	%34	%0	%0
Total Number of Predators		28	14	6	0
Guppies found in streams	Bright Males	%3	%30	%42	%47
	Drab Males	%41	%12	%5	%2
	Bright Females	%0	%0	%0	%0
	Drab Females	%56	%58	%54	%51
Total Number of Guppies		100	165	187	231

So, what caused these trends in coloration?

Three possible alternative explanations were presented as follow;

Explanation #1 These Guppies were created to either be drab or bright so they would be able to survive in a specific habitat.

Explanation #2 Female guppies prefer to mate with brightly colored males. As a result, bright males tend to attract more mates and produce more offspring. When there are lots of predators in a habitat, however, brightly colored males do not survive long enough to reproduce.

Explanation #3: The species of guppy try to appear very flashy like many other types of fish. However, when individual migrate into different pools, they need to adjust their coloration in order to avoid predators. As a result, some become drab in order to better fit in with a new habitat. This new trait is then passed down to their offspring because it is useful

If you have another explanation other than above explanations, please explain:
……………………………………………………………………………………………
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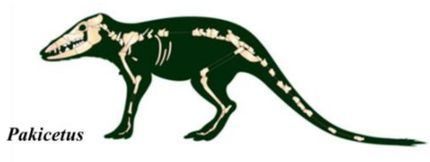
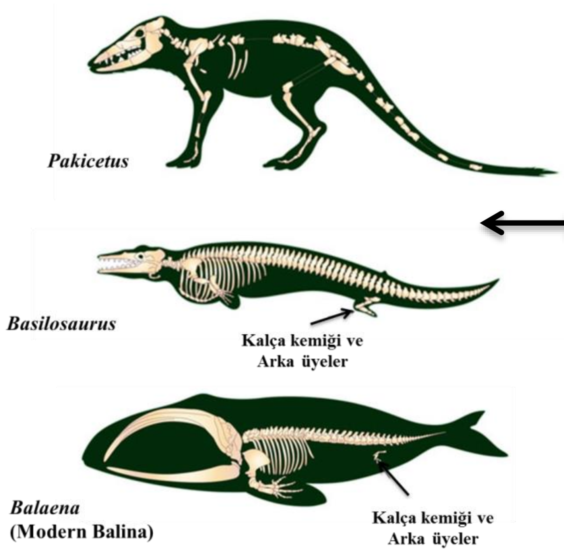
SCENARIO II: WHALES

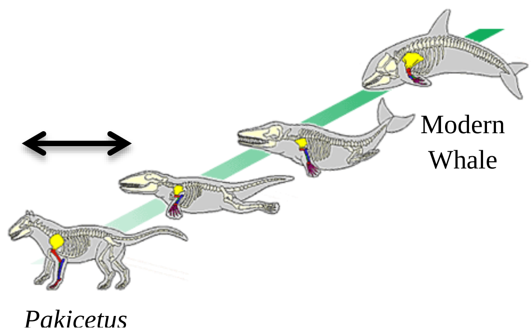
Whales are the largest mammals on earth. In 1978, a fossil form of a skull that resembled fossils of creodonts- wolf sized carnivores lived between 60 and 37 million years ago, has been found in Pakistan. The newly found bones are named *Pakicetus*. Skull from *Pakicetus* has common characteristics with oldest known forms of whales. Ear region of the skull of *Pakicetus* is not exactly similar to land mammals but it is somewhere between that of land mammals and fully aquatic mammals. Additional studies revealed another discovery;



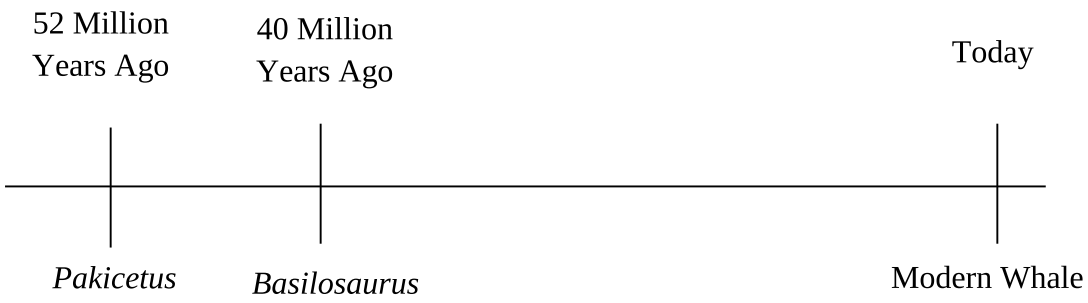


A known newer form of an aquatic whale ancestor, Basilosaurus, had legs. *Basilosaurus* was an animal fully adapted to an aquatic environment and living in ancient seas 40 million years ago. Yet *Basilosaurus* still retained small, weak hind legs even though it could not walk on land as shown in figure by side.

In addition, the figure shows anatomic similarities in forelimbs among Pakicetus and other species as shown in figure by side.



<u>Here is a timeline including times when they lived;</u>



According to fossil records, how are *Pakicetus*, *Basilosaurus* and Modern Whales related to each other?

Three possible alternative explanations were presented as follow;

Explanation #1 *Pakicetus* were some sort of primitive mammal that can live in land. Then, these mammals moved to water after environment changed. After they started to live in water, they did not need to use their legs and because they did not use their legs, they transformed into *Basilosaurus* that had small and weak legs over time. Then, next generations were born without legs.

Explanation #2 Pakicetus is not related to whales. Pakicetus was some sort of wolf and Basilosaurus was a sea mammal. Modern Whales have similar structures to those of extinct species; Basilosaurus and Pakicetus. Basilosaurus had small hind limb but it does not indicate that they were vestigial organs. They might have had different function. Hence, they were totally different species

Explanation #3 Pakicetus were some sort of mammal that can live both in land and in water. For this reason, it can be a transitional form. The ancestors of whales were living in land once and they had legs. As a result of changes of genes in the population, whales were born with small or no legs and when their environment changed, these whales with small or no legs became more advantageous and reproduced more.

If you have another explanation other than above explanations, please explain:
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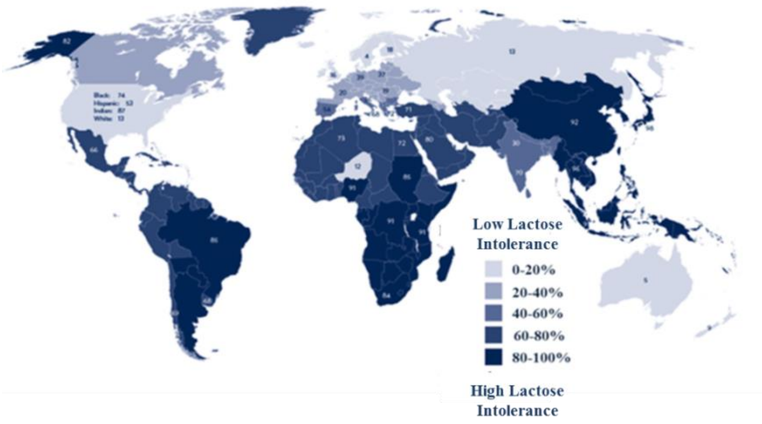
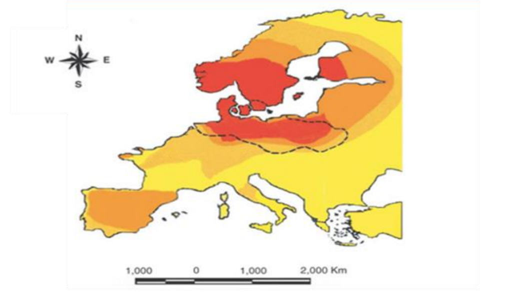
SCENARIO III: LACTOSE INTOLERANCE



Geographical Distribution Lactose Intolerance

In many countries including Turkey, people consume milk; however some of them cannot digest it. Drinking milk is advantageous for humans in that it is an additional nutrition source and meets the needs of water during drought. 10 % of Americans, 10 % of Africa's Tutsi tribe, %50 of Spanish and French people and 99% Chinese have digestion problems with milk. So, where does this variation in lactose tolerance come from? Most adults are lactose intolerant because of lactose sugar in milk. Digestion lactose sugar is dependent on the activity of lactase enzyme that breaks down lactose into glucose and galactose. According to archeological and genetic studies, adults did not carry lactose tolerance allele 8000 years ago. The figure by side indicates the changes in frequency of lactose tolerance allele in adult population in Europe within 8000 years (Burger et al., 2007).



Geographical distribution of lactose tolerance allele in contemporary Europeans The darker the orange color, the higher is the frequency of the lactase tolerance allele. The dashed black line illustrates the limits of geographic distribution of early Neolithic cattle pastoralist based on archeological data.

A study on sub-Saharan African population indicated that Africans people who started to dairy farming 9000 years ago digest milk in the present days. However, they carry lactose tolerance allele that is different from that of Europeans (Tishkoff et al., 2009).

According to this information, how does lactose tolerance develop in humans?

Three possible alternative explanations were presented as follow

Explanation #1 Since consuming milk is advantageous, the frequency of lactose tolerance allele increases in areas where dairy farming is common. As a result, digesting lactose becomes common in population. This process took placed in different geographical regions through change in the frequency of different allele which has same effects.

Explanation #2 People started to consume milk and over time, in consequence of increasing the habit of drinking milk, this situation affects genes and increases the frequency of allele that causes lactase gene to be active in areas where milk is available. As a result, people who have high consumption of milk started to digest lactose. This development affects genes disparately at different population.

Explanation #3 Variation of digestion of lactose between communities and within communities is not related to consumption of milk. This is mostly based on whether randomly carrying lactose tolerance allele or not before dairy farming started. For instance, there are still people who do not digest milk in Europe where dairy farming started. That's why each person carries different lactose allele

If you have another explanation other than above explanations, please explain:
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SCENARIO IV: CAMBRIEN EXPLOSION

The Earth is 4.6 billion year-old, but life originated about 3.5 billion years ago. The first life records belong to prokaryotes, that is, unicellular organisms that dominate the fossil record for more than 2 billion years. 700-900 million years ago, the first multicellular organisms were soft bodied. Paleontological records revealed that the first fossils belong to hard-shelled organisms appeared for the first time about 542 million years ago in Cambrian Period. In this period, we find a diversity of multicellular organisms, annelids, arthropods, echinoderms, molluscs or sponges, and even chordata. In addition, studies also revealed that abrupt environmental and climatic changes such as increasing oxygen level, beginning of Ice Age Epoch by decreasing of temperature and forming new different habitats. However, it has to be noted that between this fossil records of multicellular organisms and the earlier records of living organisms, no fossils of intermediate forms are found.

Considering that the fossil records may reflect the diversification of living beings in nature: How can we interpret these data?

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Explanation #1 The lack of intermediate fossils is due to the fact that very few fossils from periods prior to 570 million years were formed or preserved. The evolution of multicellular organisms was a slow process proceeding by little steps.

Explanation #2 The lack of intermediate fossils is due to the fact that these forms never existed. Multicellular organisms appeared as a consequence of abrupt changes.

APPENDIX B

TURKISH VERSION OF INTERVIEW QUESTIONS

1. Verilen alternatiflerden sizce hangisi kabul edilebilir bir açıklamadır?

2. Neden?

3. Seçtiğiniz açıklamayı desteklemek için bir argüman oluşturur musunuz? (geçmiş bilgilerinizi ve bilimsel teorileri kullanabilirsiniz).

4. Neden diğer alternatif açıklamalar düşüncelerinizi desteklemek için yetersizdi?

5. Size inanmayan veya diğer alternatifleri destekleyenleri ikna etmek bir argüman oluşturur musunuz?

6. Bilimsel bir argümanı daha ikna edici yapan faktörler nelerdir?

7. Evrim nedir?

8. Evrim sizce bilimsel olarak geçerli bir teori midir? Neden? Bunun için kanıtlarınız var mı?

ENGLISH VERSION OF INTERVIEW QUESTIONS

1. Which is the most acceptable explanation?
2. Why do you say that?
3. Do you construct an argument to support your explanation?
4. Why were other alternative explanations insufficient to support your claim?
5. Do you construct an argument to persuasive the others who have different opinions?
6. What do you think about what makes an argument more persuasive?
7. What is evolution?
8. Is evolutionary theory scientifically valid? Why? What are your evidences for this?

APPENDIX C

Sample Pages of the Evolution Open Response Scoring Rubrics

Key Concept (and Core Concept) 1: The presence and/or causes of variation among individuals

Scoring: A score of 1 indicates the presence of a key concept in the response. A score of 0 indicates the lack of a key concept in the response.

Score	Description	Key words	Example 1	Example 2
1	**Mutation** the random change of genetic information; may produce different phenotypes from parent's traits	mutation/mutated gene/ change of gene/genetic information/DNA/genome genetic defect/error/ deformity/anomaly/make-up/etc. random change/randomly/by chance/etc.	The long tarsi enabled the prosimian to survive longer, so the ones with the long tarsi **mutation** survived longer.	Biologists would…Next they would need to show that as time goes on, each generation of prosimian is slightly different than the last and that **these changes in DNA** eventually cause a major change in structure of the prosimian.
1	**Variation** diversity of genotypic or phenotypic Attributes; each individual genotype or phenotype is different	variation in genetics a few/some species/organism/ had X gene/trait genetic difference/variation gene pool	Animals may have adapted to their environment or **different genes** are replicated.	The species of pro simian probably all had short tarsi at one point in history. There must have been some genetic variation so that some of the species had slightly longer tarsi. The environment must have changed and therefore the species with the longer tarsi were better equiped and they survived and reproduced more efficiently therefore increasing the number of prosimian with long tarsi.
1	**Recombination** mixed characters, cross breeding, genetic recombination	hybrid cross breeding/pollination/fertilized/ allele, dominant/recessive gene interacted/mated different species	Through selective breeding, prosimians could **choose to breed with others** that have longer than average tarsi. After time, only longer tarsi would exist.	Bees and other animals spread pollen to fertilize seeds. Therefore, pollen (or a similar substance) from a tree with winged seeds could have crossed with the elm without winged seeds. A new species of elm tree which produced winged seeds eventually emerged.
1	**Particular genotype** special genes are associated with particular traits	the/this/that gene/trait gene for X function	the ancestral prosimian species with short tails may have used the tails in mating rituals. This could mean that the females picked **the males with the longer tails** and as each generation after that the same process would occur. The choosing of **this genetic trait** made each generation of the species have longer and longer tails.	the ancestral prosimian species with short tails may have used the tails in mating rituals. This could mean that the females picked the males with the longer tails and as each generation after that the same process would occur. The choosing of this genetic trait made each generation of the species have longer and longer tails.

Essentialism

Scoring:

A score of 1 indicates the presence of a cognitive bias in the response. A score of 0 indicates the lack of a cognitive bias in the response.

Score	Description	Example 1	Example 2	Example 3
1	Response explains change at a level higher than the individual (e.g. the entire species changes, reifying the species; highlighted in **bold**) and fails to mention within species variability (e.g. some individuals have a specific trait while others do not)	*A biologist would explain this by saying that this **species of elm** had a mutation that was advantageous and saw that it was more effecting in seed dispersal which caused it to continue into this line of **species**.*	*Predation is a major selective pressure acting on animals. Their was most likely a gene mutation that caused **the snails** to become poisonous and as a result it allows **them** to be able to defend **themselves** more efficiently.*	***It** underwent a mutation the resulted in a long tarsi which increased **the prosimian's** fitness.*
0	Response explains change at a level higher than the individual but mentions within species variability (variability highlighted in **bold**).	*Winged seeds developed from selective pressures. Random mutation created an elm tree species with winged seeds. Natural selection occurred to the ancestral elm trees that produced winged seeds. The **winged seeds produced more offspring than the elm trees that did not produce winged seeds**. The improved fitness of the elm trees with winged seeds produced more offspring, eventually forcing the ancestral elm tree into extinction.*	*For some reason, the plant needed pulegone to survive and eventually the plant evolved to contain pulegone. **The plants with pulegone survived better** and reproduced to produce plants with pulegone.*	*Long ago, one of the ancestral snail species developed poison and was unique to the other snail species. In the environment where the snail species inhabited, the poison showed to be beneficial to the snail because it prevented the snail from being predated on. This **allowed the poisonous snail to better survive and outlive the non poisonous snails**, and were better able to pass on this trait to more offspring.*
0	Response does not explain change at a level higher than the individual.	*The condition of being poisonous was beneficial to the individual and those individuals that were poisonous were likely to survive and reproduce than those individuals that were not poisonous.*	*At some point, an ancestral prosimian had a genetic mutation that caused it to have a longer tarsi than others. This allowed it and its descendants to survive and reproduce better than ones with shorter tarsis. Over time, through breeding long tarsis with long tarsis, the tarsi became the length it is now.*	*Elm trees which produced seeds with more around the edge that could catch the wind could spread their seeds further, thus having less competition with other elms. Natural selection led to the expansion to create the wings over several generations. The winged seeds were an advantage, thus allowing those trees to produce more offspring.*

Use and disuse

Scoring:

A score of 1 indicates the presence of a misconception in the response. A score of 0 indicates the lack of a misconception in the response.

Score	Description	Key words	Example 1	Example 2
1	Species use a particular trait. The word 'use' can be substituted for 'run', 'swim.' Sometimes 'use' can be connected with 'need'	use(s) traits the use of trait run/swim/walk/fly more and more trait was used	The species **used the tarsi more and more** as time when on causing them to become longer to suit the needs of the prosimian.	The species of ancestral penguins likely encountered arctic temperatures and conditions and **began to walk more and fly less** because of the frigid temperatures and difficulty flying. As the need to swim to retreive food became pressing the penguins may have began to use their wings for swimming.
1	Species did not use a particular trait. The word 'did not use' can be substituted for 'did not run', 'did not swim.' Sometimes 'did not use' can be connected with 'did not need'	did not use traits lack of use have no use no longer use was not used no longer being used use less stopped/ceased using	The penguin could have developed alternative ways to travel and **did not use his wings as much.** Therefore, he lost his wings throughout the course of evolution.	This could have many factors affecting this. If the environment or land mass was different millions of years ago it may have caused penguins to need to be able to fly to get there food. As time went on the land and ecology changes and the penguins no longer needed their wings to survive. **The less that they used them the more they were no longer used to fly.**
1	Energy should be allocated in other trait instead of particular trait which is not helpful.	better use of energy invest more resources saved by not having trait in other trait resource allocated to trait could be used elsewhere	Without the need to fly to be successful, **resources allocated to wings could be used elsewhere**, increasing reproductive success	If thorns are costly to produce, which seems likely, there would also be selection for thornlessness, since **those individuals would be able to invest more resources (that they came by not making thorns) in offspring.**

The rest of the rubrics can be downloaded from http://evolutionassessment.org/Evo_Assessment/Scoring.html

APPENDIX D

TURKISH SUMMARY

Evrim Teorisi Bağlamında Fen Bilimleri Öğretmenlerinin Argümantasyon Uygulamalarının Kavramsal, Yapısal ve Epistemik Boyutları

1. Giriş

Argümantasyon, iddiaların gerekçe ve veriler ile ilişkilendirilmesi ve karşıt iddiaların veya argümanların kanıtlarla çürütülmesi süreci olarak tanımlanabilir (Toulmin, 1958). Argümantasyon teorisi ise Aristoteles'in çalışmalarından günümüze kadar gelişen, argümanların nasıl analiz edildiğini ve değerlendirildiğini ortaya koymaya çalışan bir alandır. Aristoteles mantık teorisine göre Analitik, Diyalektik ve Retorik olmak üzere 3 farklı argüman yapısı geliştirmiştir. Analitik argüman mutlak gerçeklere ve kabul edilmiş görüşlere dayanarak bir dizi varsayımdan sonuca ulaşmayı hedeflerken, Diyalektik argüman tartışma yolu ile fikirlerin değişmesini amaçlar ve Retorik argüman tartışma esnasında ortaya çıkan tutarsızlıklar konusunda karşı tarafı ikna etmeyi hedeflemektedir (Puvirajah, 2007). Klasik ya da diğer bir deyişle formal mantığı temel alan argüman yapıları 2000 yıl geçerliliğini sürdürürken, 20. Yüzyılda informal mantığın ön plana çıkmasıyla birlikte farklı argümantasyon teorileri geliştirilmiştir. Formal mantık temelindeki argümanlar herkes tarafından kabul gören önermelerden yola çıkarak geçerli sonuçlar çıkarmaya dayalı iken, informal mantık temelindekiler ise daha çok günlük hayat bağlamında gerçekleşen, kurallara ve ilkelere bağlı kalmaksızın yapılan tartışmaları kapsamaktadır. Bu kapsamda, Toulmin (1958) ve Perelman ve Olbrechts-Tyteca (1958) sosyal hayat bağlamında, gerçeklerin insanların deneyim ve yorumlarına göre şekillenen tartışmaları analiz etmeyi hedefleyen argümantasyon teorileri ortaya koymuşlardır. Toulmin geleneksel çıkarım tekniklerine karşı çıkarak argümantasyona geriye dönük akıl yürütme temelinde gerekçelenen iddialar bütünü anlayışını getirmeye çalışmıştır. Bu bağlamda, Toulmin, *The Uses of Argument* adlı kitabında bir argümantasyon modeli önermiştir. Bu modelde argümanın temel bileşenlerini ve bu bileşenler arasındaki fonksiyonel ilişkiyi tanımlamıştır. Modeldeki bileşenler veri, iddia, gerekçe, nitelendirici, destek, ve çürütmeleri kapsamaktadır. Bu modele göre, iddialar bir probleme ya da bir soruya çözüm olarak öne sürülen açıklamalardır ve iddialar verilerle desteklenir. İddialar ve verilerin arasındaki ilişki gerekçeler sunularak ortaya konulur. İddiaları güçlendirmek için temel bilgiler ve genellemelerden yararlanılarak destekler sunulur. Ayrıca, argümanlar karşıt görüşte olanların iddialarını kanıtlarla çürütmek veya kendi iddiasının geçerli olmayacağı durumları açıklamak için reddedicileri de kapsamaktadır. Toulmin modeline göre, iyi bir argüman iyi belirlenmiş bir iddia ve bu iddianın dayandırıldığı sağlam kanıtlardan oluşmaktadır. Aynı yıl içinde, Perelman ve Olbrechts-Tyteca *New Rhetoric* adlı kitaplarında sosyal bağlamda yapılandırılan argümanları incelemiş ve argümanın amacının dinleyicileri etkileme ve ikna süreci olarak belirtmişlerdir. Ancak, Toulmin ve Perelman ve Olbrechts-Tyteca'nın teorileri durumsal ve bağlamsal faktörleri göz önünde bulundurmadığı doğrultusunda birçok eleştiriye maruz kalmış ve formal mantığa, alternatif olmadıkları tartışılmıştır (Van Eemeren, 2002). Bu eleştirilere cevap olarak informal mantık hareketi ortaya çıkmıştır. Bu alanda, Johnson ve Blair (1994) önermeler ve sonuçlar arasındaki ilişkiye odaklanırken, Walton (1996) meşru akıl yürütmeye dayalı tartışma şemaları geliştirmiştir. Her iki modelde günlük hayatta kurgulanan argümanları incelemek ve değerlendirmek için araştırmacılar tarafından kullanılmaktadır.

Argümantasyon, kanıtların yorumlanması ve var olan teoriler ışığında teorik önermeleri verilerle ilişkilendirme kapsamında bilim insanlarının tartışmalarının temelini oluşturmaktadır. Bu bağlamda, argümantasyon uygulamaları bilim eğitiminin önemli bir parçası olarak düşünülmektedir (Driver, Newton & Osborne, 2000). Bu nedenle, bilim eğitimi araştırmacıları ve ulusal ve uluslararası eğitim kurumları bilim eğitiminde argümantasyonun önemini belirtmiş ve bilim eğitimi programlarına dahil edilmesini önemle önermiştir (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996; Driver vd., 2000; Duschl, 2008; Jiménez-Aleixandre, & Erduran, 2008; Kuhn, 2005; Milli Eğitim Bakanlığı [MEB], 2013). Bilim eğitimi alanında süregelen çalışmalar ağırlıklı olarak Toulmin

(1958) argümantasyon modelini kullanarak öğrencilerin argümanlarını analiz etmişlerdir (Driver vd., 2000; Erduran & Jiménez-Aleixandre, 2007; Erduran, Simon & Osborne, 2004; Jiménez-Aleixandre, Rodríguez, & Duschl 2000; Kelly, Chen & Druker, 1998). Fakat, bazı çalışmalarda bu modelin sınırlıkları olduğu ortaya konmuştur (Bell & Linn, 2000; Kelly vd., 1998; Sampson & Clark, 2008). Örneğin, bazı araştırmacılar, argüman bileşenlerini birbirinden ayırma konusunda karşılaşılan zorlukları dile getirirken, diğerleri bu modelin argüman içeriklerinin bilimsel olarak geçerli olup olmadığı konusunda incelemeye olanak sağlamadığını tartışmışlardır. Bu bağlamda, araştırmacılar Toulmin argümantasyon modelini değiştirmiş veya ek modellemeler geliştirmişlerdir (Erduran vd., 2004; Sandoval, 2003; Zohar & Nemet, 2002). Mesela, Erduran vd. 5 hiyerarşik seviyeden oluşan değerlendirme aracı geliştirerek öğrencilerin argümantasyon niteliklerini incelemiştir. Bazı araştırmacılar ise yapısal boyutta argüman analizlerinin öğrencilerin akıl yürütme ve argüman kurma becerilerini anlama konusunda yetersiz olduğu için kavramsal ve epistemik boyutlarını incelemeye almışlardır. Kavramsal boyutta araştırmacılar argüman içeriklerinin bilimsel olarak uygun olup olmadıklarını incelemişlerdir (Clark & Sampson, 2008; Sandoval & Millwood, 2003). Epistemik boyutta ise araştırmacılar kanıtlarla teorilerin nasıl ilişkilendirildiğini epistemolojik bir bakış açısıyla analiz etmişlerdir (Kelly & Takao, 2002; Sandoval, 2003). Bazı araştırmacılar ise çalışmalarında argümanları birden fazla boyutta inceleyerek argümantasyon sürecini derinlemesine araştırmışlardır (Jiménez-Aleixandre vd, 2000; Tavares, Jiménez-Aleixandre & Mortimer, 2010). Bu çalışmaların sonucunda, öğrencilerin iddialarını desteklemek için yeterli gerekçe oluşturmadıkları (Sandoval, 2003; Zohar & Nemet, 2002), öne sürdükleri iddiaları desteklerken karşıt iddiaları göz önünde bulundurmadıkları (Schwarz, Neuman, Gil, & Ilya, 2003), iddialarını desteklerken bilimsel teorilerden yararlanmadıkları (Clark & Sampson, 2008; Sampson, Grooms & Walker, 2011) ve iddialarını yeterli kanıtlarla desteklemedikleri ortaya konmuştur (Kelly & Takao, 2002; Jiménez-Aleixandre & Bravo, 2009).

Bilim eğitiminde argümantasyon çalışmaları incelediğinde ağırlıklı olarak öğrencilerin argümantasyon uygulamalarının araştırıldığı; fakat öğretmelerin argümantasyon ile ilgili bilgi ve becerilerine çok önem verilmediği görülmektedir.

Ancak, yapılan çalışmalarda öğretmelerin öğrencilerin argümantasyon becerilerine direkt etki ettiği açıkça ortaya konmuştur (Erduran vd., 2004; Newton, Driver & Osborne, 1999). Zohar'ın (2007) belirtiği üzere, öğrencilerin bilimsel argümantasyon uygulamalarına olanak sağlamak ve yönlendirmek için öğretmenlerin bu konuda yeterli donanıma sahip olmaları gerekmektedir. Bu nedenle, öğrencilerden önce öğretmenlerin bu konudaki pedagojik bilgilerinin sorgulanması ve eğer gerekliyse bu konuda eğitimlerin çoğaltılması gerektiği bir çok araştırmacı tarafından dile getirilmiştir (Sampson & Blachard, 2012; Simon, Erduran & Osborne, 2006). Bu nedenle, bu çalışmada fen bilimi öğretmenlerinin evrim teorisi bağlamında argümantasyon uygulamaları analiz edilmiştir.

Bu çalışmada bilimsel argümantasyon uygulamaları evrim teorisi bağlamında incelenmiştir. Evrim teorisi, bütün türlerin ortak bir atadan geldiğini ve evrime etki eden mekanizmalar ile evrimleşme sürecinde türlerin değişimini ve yeni türlerin oluşumunu açıklayan bir teoridir. Charles Darwin 1859 yılında *On the Origin of Species* adlı kitabında doğal seleksiyonla türlerin evrimini açıklamıştır. Daha sonra, doğal seleksiyon teorisi Mendel'in kalıtım üzerine yaptığı çalışmalarla birleştirilerek modern evrim sentezi teorisini ortaya çıkarmıştır. Modern evrim teorisi, mutasyonların ve doğal seleksiyonun nasıl evrimsel değişimlere yol açtığını açıklamaktadır. Her ne kadar son 20 yılda yapılan eğitim reformlarında evrim öğretimi önemle vurgulanmasına rağmen, yapılan çalışmalar öğrencilerin ve hatta öğretmenlerin hala kavram yanılgıları olduğunu göstermektedir (Evans, 2008; Gregory, 2009; Nehm & Schonfeld, 2007). Örneğin, öğrencilerin evrimsel değişimleri Lamarck'ın sonradan kazanılan özelliklerin kalıtımı ve kullanılan organların geliştiği, kullanılmayanların ise köreldiği teorilerini kullanarak açıkladıkları (Bishop & Anderson, 1990; Jensen & Finley, 1996), seçilim değerini sağlıklı ve güçlü olarak algıladıkları (Bishop & Anderson, 1990; Gregory, 2009) ve evrimsel değişimleri birey düzeyinde açıkladıkları ortaya çıkmıştır (Gregory, 2009). Kavram yanılgılarının yanı sıra son yıllarda yapılan çalışmalar ağırlıklı olarak bilişsel önyargılara odaklanmıştır (Evans, 2008; Sinatra, Brem & Evans, 2008). Bu bağlamda, bilişsel bilimler üzerine yapılan çalışmalar evrimi anlamayı zorlaştıran ve aynı zamanda kavram yanılgılarına neden olan 3 temel bilişsel önyargı ortaya çıkmıştır: teleolojik, amaçlılık ve özcülük. Teleolojik önyargı, evrimsel değişimlerin belirli bir amaç doğrultusunda gerçekleştiği ile ilgilidir. Amaçlılık, evrimsel değişimlerin bilişsel olarak kontrol edildiğini varsayan bir bilişsel önyargıdır. Özcülük ise türleri belirli kategorilerde sınıflandırarak popülasyon içerisindeki varyasyonları göz ardı eden eğilime dayalı bir önyargıdır. Bu çalışmada, fen bilimleri öğretmenlerinin argümantasyon uygulamalarında yararlandıkları biyolojik evrim bilgileri incelenecektir. Fen bilimleri öğretmenleri bilim insanlarının evrim konusundaki görüş ve bilgileri ile toplumun ve öğrencilerin evrim ile ilgili bilgi yetersizliği ve kavram yanılgıları arasında bağlantı kurma adına önemli bir köprü görevi üstlenmekte olduğu için bu çalışmanın odak noktasını fen bilimleri öğretmenleri oluşturmaktadır.

Araştırmanın Amacı

Bu çalışma, argümantasyon uygulamaları ve evrim teorisi konusunda kavramsal anlama çalışmalarının kesişiminde konumlanmaktadır. Bu bağlamda, bu çalışmanın amacı, evrim teorisi bağlamında fen bilimleri öğretmenlerinin argümantasyon uygulamalarının kavramsal, yapısal ve epistemik boyutlarda incelemek ve öğretmenlerin evrim kavramları ile argümantasyon uygulamalarının farklı epistemik düzeylerde nasıl birleştiğini araştırmaktır.

Araştırmanın Önemi

Bilim eğitiminde argümantasyon konusunda yapılan araştırmalar incelendiğinde, araştırmacıların ağırlıklı olarak öğrencilerin argümanlarının yapısal boyutta inceledikleri ortaya çıkmaktadır. Yapısal boyutta inceleme, argüman bileşenleri ve akıl yürütme becerileri hakkında bilgilenmemizi sağlamakta; fakat sadece yapısal boyutta inceleme argümantasyon uygulamalarını derinlemesine anlamamızı sınırlandırmaktadır. Şöyle ki, oluşturulan bilimsel argümanların bilimsel bilgiye uygun olup olmadığı ve verilerin teorilerle nasıl ilişkilendirildiği argümantasyon uygulamalarının önemli bileşenlerini oluşturmaktadır. Bu nedenden dolayıdır ki, araştırmacılar argümantasyon analizlerinde farklı ek boyutları da göz önünde bulundurulması gerektiğini belirtmişlerdir (Sampson & Clark, 2008; Sandoval

& Millwood, 2003). Argümanların farklı boyutlarda incelenmesi bilimsel argüman kurma becerileri konusunda anlayışımızı geliştirir ve bu anlayış bilim derslerinde daha verimli bilimsel argümantasyon uygulamalarına olanak sağlamak için müfredat ve ders içeriği hazırlıklarına katkıda bulunabilir.

Ayrıca, argümanların kavramsal açıdan değerlendirilmesi bağlamdaki konu hakkında kavramsal anlamayı analiz etmeye olanak sağlayabilir çünkü argüman kurma süreci kavramsal bilgilerin kullanılmasını ve bağlamdaki konuyu anlamayı gerektirmektedir. Bu nedenle, bu çalışmada fen bilimleri öğretmenlerinin evrim teorisi ile ilgili argümanları incelenerek kavramsal anlama analizi yapılmıştır. Evrim teorisi kapsamında yapılan çalışmalar ağırlıklı olarak öğrencilerin kavramsal anlamalarına odaklanmış ve evrim teorisini bilimsel bilgilere uygun bir şekilde derslerine adapte etmeleri beklenen öğretmenler ile yapılan çalışmalar sınırlı kalmıştır. Bu bağlamda, yapılan çalışmalar öğretmenlerin sahip oldukları bilgilerinin yanı sıra kavram yanılgılarını da derslerine taşıdıkları ve öğrencilerin yeteriz ya da yanlış kavramlar geliştirmelerine neden oldukları önceki çalışmalarda ortaya konmuştur (Smith, 2010). Bu nedenle, fen bilimleri öğretmenlerinin evrim teorisi ile ilgili sahip oldukları kavramları araştırmak, öğretmenlerin alan bilgilerini geliştirmeye odaklanan araştırmacılar ve öğretmen eğitmenleri için önemlidir.

Son olarak, bilim derslerine argümantasyon uygulamalarını entegre etmeleri beklenen fen bilimleri öğretmenlerinin bilimsel argümantasyon konusundaki bilgi ve becerilerini araştıran yetersiz sayıda çalışma mevcuttur. Fakat 2013 yeni fen bilimleri müfredatı argümantasyon tabanlı fen öğretimini önermekte ve bu konuda fen bilimleri öğretmenlerine öğrencilere fikirlerini savunabilecekleri bir ortam dizayn etmeleri, argüman oluşturma süreçlerinde sorularla öğrencileri yönlendirmeleri ve genel olarak argümantasyon sürecini verimli bir şekilde yürütmelerini tavsiye etmektedir. Zohar'ın (2007) önemle altını çizdiği üzere argümantasyon konusunda yeterli bilgi ve becerilere sahip olmayan öğretmenlerden verimli bir argümantasyon süreci yürütmeleri beklenemez. Bu nedenlerden dolayı, fen bilimleri öğretmenlerinin bu konudaki bilgi ve becerilerini ortaya çıkarmayı amaçlayan bu çalışmanın bulguları öğretmen eğitimenleri ve hizmet içi eğitim tasarlayan eğitmenler için yararlı bir kaynak olacağı düşünülmektedir. Ayrıca, bu çalışmada öğretmenlerin bilgi ve becerilerini soru cevap yöntemi ile ortaya çıkarmaktan ziyade, öğretmenleri argümantasyon uygulamalarına direkt katarak bu alandaki pratiklerinin incelenmesi amaçlanmaktadır.

2. Yöntem

Araştırmanın Deseni

Bu araştırmada nitel bir çalışma olan çoklu-durum deseni kullanılmıştır. Veriler 4 farklı uygulamayla toplanmıştır. Bu uygulamalar öncelikle ayrı bir şekilde kendi içinde incelenmiş, daha sonra uygulamalar arasında karşılaştırmalar yapılmıştır.

Örneklem

Çalışma özel ve devlet okullarında fen bilimleri öğretmeni olarak çalışan 4 öğretmen ile yürütülmüştür. Gizlilik ilkesi nedeniyle çalışmada katılımcıların isimleri gizlenerek katılımcılara şu şekilde kod isimler verilmiştir; Burcu, Leyla, Selin ve Beste. Öğretmenlerin seçilmesinde 2 kriter göz önünde bulundurulmuştur. Bunlardan ilki öğretmenlerin evrim dersi almasıdır çünkü veri toplama aracı olarak kullanılan senaryolar evrimsel olayları içermektedir ve öğretmenlerin probleme dayalı evrimsel olaylara cevap verebilmesi için belirli bir düzeyde evrim bilgisine sahip olması beklenmektedir. Diğer kriter ise öğretmenlerin hem aldıkları evrim derslerindeki başarısı hem de evrim öğretimi konusundaki deneyimleri ile ilgilidir. Seçilen öğretmenlerden ikisi (Selin ve Beste) evrim dersinde diğer iki öğretmene (Burcu ve Leyla) nazaran daha başarılıdır, ayrıca 2 öğretmen evrim dersini (Selin ve Beste) 8.sınıflarda işlemiştir, diğerleri (Burcu ve Leyla) ise evrim öğretimi konusunda henüz deneyime sahip değillerdir.

Ölçme Araçları

Senaryolar: Bu çalışmada "Venezuela Lepistesleri", "Balinalar", "Laktoz Duyarsızlığı" ve "Kambriyen Dönemi" olmak üzere farklı evrimsel problemler içeren senaryolar kullanılmıştır. Doğal ve cinsel seçilim ile ilgili "Venezuela Lepistesleri" senaryosu Sampson ve Blanchard'ın (2012) çalışmasından, makro evrim ile ilgili

“Balinalar” senaryosu Yalcinoglu’nun (2007) çalışmasından, kademeli ve sıçramalı evrim ile ilgili “Kambriyen Dönemi” senaryosu ise Tavares vd.’nin (2010) çalışmasından alınmış olup, Türkçeye adapte edilerek çalışmaya uygun olacak şekilde değiştirilmiştir. Senaryoların kullanım izinleri araştırmacı tarafından alınmıştır. Diğer senaryo olan gen-kültür birlikte evrim ile ilgili “Laktoz Duyarsızlığı” senaryosu ise araştırmacı tarafından geliştirilmiştir. Senaryoların Türkçe versiyonu biyoloji alanında uzman 3 kişi tarafından kontrol edilmiş olup 5 fen bilgisi öğretmenliği son sınıf öğrencisi, 3 fen bilimleri öğretmeni ve 3 biyoloji bölümü son sınıf öğrencisiyle pilot çalışması yapılmıştır. Senaryolar, evrimsel bir olay ve bu olayın nasıl meydana geldiği ile ilgili sorular içermektedir. Bu sorulara cevaben 2 ya da 3 alternatif açıklama sunulmaktadır.

Görüşme Çalışmanın verileri Bilişsel Değerlendirme Görüşmesi (Cognitive Appraisal Interview, Silverman, 2010) tekniği ile toplanmıştır. CAI katılımcılara, henüz yaptıkları uygulamalar konusunda derinlemesine düşünme ve mantıksal bir temel oluşturma fırsatı sağlamaktadır. Görüşmelerde senaryolar üzerinden argümantasyon uygulamaları gerçekleştirilmiştir. Öncelikle fen bilimleri öğretmenlerine verilen senaryoyu okumaları ve evrimsel bir olay ile ilgili bir probleme cevap olarak alternatif açıklamalardan birini seçmeleri istenmiştir. Sonrasında karar verdikleri açıklamayı neden seçtikleri sorulmuş ve bu açıklamaya dayalı olarak bir argüman oluşturmaları istenmiştir.

Verilerin Analizi

Veriler 6 farklı ölçme aracı kullanılarak analiz edilmiştir. Fen bilimleri öğretmenlerinin alternatif açıklamaları değerlendirirken kullandıkları kriterlerinin bilimsel olarak geçerli olup olmadığını analiz etmek için Sampson vd.’nin (2011) geliştirdiği ölçüm aracı kullanılmıştır. Öğretmenlerin evrim teorisi bağlamında kavramsal analizi konusunda öncelikle evrimsel kavramları ana kavramlar, kavram yanılgıları ve bilişsel önyargılar olmak üzere 3 ana kategoride sınıflandırmak amacıyla Nehm vd.’nin (2010) ölçüm aracı kullanılmış, sonrasında ise bu kategorilere dayalı olarak kavramsal anlamaları Abraham vd.’nin (1992) 6 düzeyden oluşan ölçüm aracı ile kodlanmıştır. Öğretmenlerin argümantasyon uygulamalarının yapısal boyutu Erduran vd.'nin (2004) hiyerarşik yapıya sahip 5 düzeyden oluşan argümantasyon modeli kullanılarak incelenmiştir. Bu modele göre, 1. düzeyde argümanlar sadece iddialar içerir; 2. düzeyde argümanlar iddialar ve iddiaları destekleyen gerekçe ve kanıtlar içerir; 3. düzeyde iddialar ve gerekçelerin yanında zayıf çürütücü iddialar bulunur; 4. düzeyde 1 adet güçlü çürütücü argüman varken, 5. düzeyde ise birden fazla, güçlü delilerle desteklenen çürütücü argümanlar bulunmaktadır. Öğretmenlerin argümantasyon uygulamalarının epistemik boyutu ise Tavares vd.'nin (2010) ölçüm aracı kullanılarak analiz edilmiştir. Bu ölçüm aracı Kelly ve Takao (2002) tarafından geliştirilmiştir. Bu modelde, en altında en özel, temel iddialar; en üstünde daha genel, teorik iddialar içermektedir. Epistemik düzeyler hiyerarşik yapıda değillerdir; onun yerine güçlü argümanlar farklı epistemik düzeyler içermektedir. Bilimsel argümanları savunma süreci spesifik alan bilgisi gerektirir (Kelly ve Takao, 2002). Bu bağlamda, Tavares vd. (2010) bu modeli biyolojik evrime adapte etmişlerdir. Bu model 5 epistemik düzeyden oluşmaktadır: 1. düzeyde, iddialar senaryolarda bulunan ampirik verileri içerir; 2. düzeydeki iddialar önceki deneyim ve bilgilerden oluşturulan kanıtları içerir; 3. düzeyde, iddialar teorik bilgiler ya da konuya spesifik veriler içerir; 4. düzeydeki iddialar tartışılan konuya spesifik biyolojik evrim ile ilgili teorik bilgiler içerir; 5. düzeydeki iddialar sadece konuya spesifik bilgiler yerine, evrim teorisi ile ilgili genel teorik bilgiler içermektedir. Son olarak, öğretmenlerin kavramsal bilgilerini kullanarak argümantasyonlarını farklı epistemik düzeylerde nasıl oluşturduklarını incelemek için ise Tavares vd.'nin (2010) bir diğer ölçüm aracı kullanılmıştır. Bu ölçüm aracı argümantasyon uygulamalarının 3 boyutunun birbiriyle nasıl entegre olduğunu analiz edilmesini sağlamaktadır.

3. Bulgular ve Tartışma

Çalışmanın sonuçları fen bilimleri öğretmenlerinin alternatif açıklamaları değerlendirirken genel olarak bilimsel anlamda geçerli kriterler kullandıklarını göstermiştir. Bu kriterler arasında iddianın verilerle ve bilimsel teorilerle uyumlu olması öğretmenler arasında en çok kullanılan kriterlerdir. Öğretmenler arasında kullanılan kriterler farklılık göstermektedir. Kavramsal anlamaları daha yüksek düzeylerde olan öğretmenler ağırlıklı olarak iddiaların bilimsel teorilerle uyumluluğuna bakarken, kavramsal anlamaları diğerlerine göre daha düşük düzeylerde olanlar verilerin iddialarla uyumluluğunu daha çok göz önünde bulundurmuşlardır. Bu bulgu, Sampson ve Blanchard'ın (2012) bulgularıyla paralellik göstermektedir. Sampson ve Blanchard bilim öğretmenleri ile yaptıkları çalışmada kavramsal bilgileri yüksek olanların düşük olanlara kıyasla alternatif açıklamaları değerlendirirken daha çok bilimsel teorilerin uyumluluğu kriterini kullandıkları sonucuna varmışlardır. Araştırmacılar konu hakkında yeterli bilgisi olmayan öğretmenlerin genellikle verilere dayalı olarak karar verdiklerini ortaya çıkarmıştır. Sonuç olarak, bu çalışmanın sonuçları bu bulguları destekler niteliktedir ve kavramsal anlamının kullanılan kriterleri etkilediği ortaya konmuştur.

Bunların yanı sıra, kavramsal anlama düzeyleri düşük olan öğretmenlerin bazı senaryolarda informal, yani bilimsel olarak geçerli olmayan daha çok günlük hayatlarında kullandıkları kişisel teorilere başvurdukları da bulunan sonuçlar arasındadır. Bu konuda Sampson vd. (2011) kişisel teoriler eğer bilimsel olarak geçerli bilgilerle birleşirse anlamlı bir değerlendirme olacağını dile getirmiştir. Bu çalışmada da kavramsal anlama düzeyi diğerlerine göre daha düşük olan bir öğretmen alternatif açıklamaları değerlendirirken genellikle yanlış sonuca vardığı; fakat kavramsal anlama düzeyleri yüksek olan öğretmenlerin ise genellikle doğru alternatif açıklamalara yöneldikleri ve bazen yanlış olan alternatif açıklamaları değiştirerek bilimsel olarak geçerli açıklamalarda ve değerlendirmelerde bulundukları ortaya çıkmıştır. Bu bulgu Sampson ve Clark'in (2011) kavramsal bilgileri konusunda yüksek ve düşük performanslı gruplarla yaptıkları çalışmanın sonucuna paralellik taşımaktadır. Böylece kavramsal anlama bilimsel olarak geçerli kriterlerin kullanılmasında belirleyici olabilir.

Ayrıca bu çalışma kavramsal anlama düzeyleri konusunda 4 farklı profil ortaya çıkarmıştır. Öğretmenlerden bir tanesi (Leyla) diğerlerine göre kavramsal anlama düzeyi düşüktür; yani argümanlarında evrim konusunda ana kavramları hemen hemen hiç kullanmazken, ağırlıklı olarak adaptasyon ve Lamarck'ın kullanılan organların geliştiği kullanılmayanların köreldiği teorisi ile ilgili kavram yanılgıları ve teleolojik ve özcülük ile ilgili bilişsel önyargıları ortaya çıkmıştır. Bir diğer öğretmen (Burcu) ise argümanlarında evrim konusunda ana kavramlara (örn. varyasyon, genlerin kalıtsal aktarımı, doğal seçilim) çokça başvurmasına rağmen hala kavram yanılgıları ve teleolojik ve özcülük ile ilgili bilişsel ön yargılarının olduğu ortaya konmuştur. Diğer iki öğretmenin (Selin ve Beste) ise ağırlıklı olarak evrim ile ilgili ana kavramlara başvurdukları görülmüştür; fakat Selin'in Beste'ye nazaran ana kavramlara daha çok ağırlık vermesine rağmen Selin'in bazı konularda bilişsel önyargısı olduğu, Beste'nin ise herhangi bir kavram yanılgısı ve bilişsel önyargısı olmadığı ulaşılan sonuçlar arasındadır.

Bu çalışmada özellikle iki öğretmenin (Selin ve Burcu) ana kavramları kullanırken bununla birlikte kavram yanılgılarının ve bilişsel önyargılarının olduğu saptanmıştır. Bu sonuç Opfer, Nehm ve Ha'nın (2012) sonuçlarıyla benzerlik taşımaktadır. 3 öğretmen (Selin, Leyla ve Burcu) arasında teleolojik bilişsel önyargının (örn. "yaşamak *için*", "hayatta kalmak *adına*") öne çıktığı gözlemlenmiştir. Bu bulgu, önceden yapılan çalışmaların sonuçlarını desteklemektedir (Ha & Nehm, 2014; Jensen & Finley, 1996; Nehm & Schonfeld, 2007). Ayrıca, Sinatra vd. (2008) ve Moore vd. (2002) çalışmalarında bilişsel önyargıların kavram yanılgılarına neden olacağını tartışmışlardır. Bu çalışmada bu sonuca paralel bulgulara rastlanmıştır. Öğretmenlerin bilişsel önyargıları nedeniyle özellikle adaptasyon konularında kavram yanılgıları ortaya çıkmıştır (örn. "hayatta kalmak için ortama adapte olmuşlardır"). Yani, bazı öğretmenler adaptasyonu hayatta kalmak amacıyla gerçekleştiğini savunmuşlardır; diğer bir deyişle adaptasyonu bir amaç doğrultusunda gerçekleştiğini düşünmektedirler.

Bu bulgulara ek olarak, öğretmenlerin argümantasyon uygulamaları yapısal boyutta incelendiği zaman, ağırlıklı olarak 2. düzeyde argüman oluşturdukları ortaya çıkmıştır. Diğer bir deyişle, öğretmenler seçtikleri iddiaları veri, gerekçe ve desteklerle savunurken, diğer alternatif açıklamaları çok fazla göz önünde bulundurmamış ve karşı argümanlar oluşturmamışlardır. Bu bulgu Sampson vd.'nin (2011) bulduğu sonuçlarla uyumludur. Sampson vd. bu eğilimin onaylı önyargıdan kaynaklandığını, bu önyargı yoluyla öğrencilerin sadece kendi düşüncelerine desteklemeye eğilimli olduklarını tartışmıştır. Bu çalışmanın bulguları da öğretmenlerin onaylı önyargılara sahip olduklarını göstermektedir. Yapısal boyutta öğretmenlerin argümantasyon uygulamaları arasında göze çarpan bir farklılık olmamasına rağmen, oluşturdukları karşı argümanların nitelik ve sayısında bazı farklılıklar saptanmıştır. Yani, genellikle kavramsal anlama düzeyleri yüksek olan öğretmenlerin düşük düzeyde olanlara nazaran daha çok karşı argümanlar ürettikleri ortaya çıkmıştır. Bu bulgu önceki yapılan çalışmalarla benzerlik taşımaktadır (Acar, 2008; von Aufschnaiter, Erduran, Osborne & Simon, 2008; Sadler & Donnelly, 2006). Sonuç olarak, bulunan sonuçlar ışığında, kavramsal anlamanın argümantasyon uygulamalarına belirli bir dereceye kadar katkısı olsa da, yapısal boyutta yüksek düzeylerde argüman oluşturma becerisi için sadece kavramsal anlama yeterli olmadığı sonucuna varılabilir.

Fen bilimleri öğretmenlerinin argümantasyon uygulamaları epistemik boyutta incelendiği zaman, bütün öğretmenlerin verilere dayalı önermelere nazaran çoğunlukla teorik önermeler oluşturdukları ortaya çıkmıştır. Diğer bir deyişle, öğretmenler teorik önermelerini yeterli verilerle desteklememiştir. Bu bulgu öğrencilerle yapılan çalışmaların sonuçları ile paralellik göstermektedir (Jiménez-Aleixandre & Bravo, 2009; Kelly & Takao, 2002; Maloney, 2007; Tavares vd., 2010). Bu bulgu iki olasılıkla açıklanabilir. İlki, kavramsal anlama düzeyleri yüksek olan öğretmenlerin daha çok teorik önermelere yöneldiği ile ilgilidir. Her ne kadar öğretmenlerin hepsi yetersiz veri kullansalar da, öğretmenler arasında bu konuda bir farklılık gözlenmiştir. Kavramsal anlama düzeyi diğerlerine nazaran daha düşük olan Leyla, diğer öğretmenlere kıyasla daha fazla verilere dayalı önermeler öne sürmüştür. Bu açıdan bakıldığı zaman kavramsal anlama, aynı alternatif açıklamaları değerlendirirken kullandıkları kriterlerde de olduğu gibi daha fazla teorik bilgilerin ortaya çıkmasını sağlamıştır. Aynı zamanda, Jiménez-Aleixandre ve Bravo (2009) çalışmalarında tartıştığı üzere, bu sonuç öğretmenlerin veri ve teoriyi ilişkilendirme konusunda yetersiz olduklarının da bir göstergesi olabilir.

Çalışmada kullanılan senaryolar arası varyasyonlara bakıldığında, kullanılan kriterler, epistemik ve yapısal boyuttaki argümantasyon uygulamalarında herhangi bir değişikliğe rastlanılmamıştır. Ancak, öğretmenlerin kavramsal boyutta argümantasyon uygulamaları incelendiğinde, öğretmenlerin özellikle “Laktoz Duyarsızlığı” senaryosunda daha çok teleolojik ve amaçlılık bilişsel önyargıları çıktığı saptanmıştır.

Laktoz Duyarsızlığı senaryosunun insan evrim ile ilgili olduğu göz önünde bulundurulursa, bu sonuç beklenilen bir sonuçtur çünkü günlük hayatta insanların davranışları ve olaylara yaklaşımı bilinçli ve bir amaç doğrultusunda olduğu için öğretmenlerin insan evriminin de bu yaklaşımlarla gerçekleştiğini düşünmeleri şaşırtıcı değildir.

Son olarak, bu çalışma fen bilimleri öğretmenlerinin kavramsal bilgilerini kullanarak argümanlarını farklı epistemik düzeylerde nasıl oluşturduklarını incelemiş ve argümanlarında evrim teorisi ile ilgili ana kavramların yanında özellikle 2 öğretmenin (Burcu ve Leyla) kavram yanılgılarını kullandıkları ortaya çıkan sonuçlar arasındadır. Kullandıkları bu önermelerin çoğunluğu ağırlıklı olarak konuyla ilgili ya da genel teorik bilgiler içermektedir. Aynı zamanda, argümantasyon uygulamaları kavramsal, yapısal ve epistemik boyutlarda incelendiği zaman bu üç boyutun birbirleriyle ilişkili oldukları da ortaya konmuştur. Başka bir deyişle, bilimsel argüman kurma sürecinde, bilimsel olarak geçerli kanıt ve gerekçelerin kullanılması, uygun karşı argümanların oluşturulması ve bunların arasındaki ilişkiyi bilimsel olarak uygun bir şekilde kurulması kavramsal anlamayı gerektirmektedir.

4. Öneriler

Bu çalışmada, argümantasyon uygulamalarının kavramsal, yapısal ve epistemik boyutlarda incelenmesi bu boyutların birbirleriyle ilişkisini açık bir şekilde ortaya koymuştur. Daha açık bir şekilde izah etmek gerekirse, kavram yanılgıları ya da bilimsel bilgiyle çelişen alternatif açıklamaları çürütebilmek, bilimsel olarak uygun kanıt ve destekler sunabilmek için kavramsal anlamalarının, verilerle teorileri uygun bir şekilde ilişkilendirmek içinse kanıt kullanma becerilerinin geliştirilmesi gereklidir. Boyutlar arasındaki bu ilişki iki şekilde yorumlanabilir. İlki, argümantasyon uygulamalarında yeterli ve uygun kanıt kullanmaya ve bilimsel olarak geçerli kavramlar oluşturmaya yapılan vurgu, öğrencilerin ve öğretmenlerin hem kavramsal hem de epistemolojik anlayışlarını geliştirebilir. Aynı zamanda bu becerilere yapılan vurgular bireylerin bilimsel argümantasyon becerilerini de geliştirecektir. Bu anlamda, fen bilimleri dersi ve öğretmen eğitimi müfredatlarını geliştirenler için bu bulgular şu şekilde kullanılabilir; argümantasyon uygulamaları bu becerilere yapılan vurgularla yürütülebilir.

Yukarıda bahsi geçen konuyla ilgili olarak, bu çalışmada argümantasyon uygulamaları evrim teorisi bağlamında incelenmiştir. Bu bağlamda, evrim teorisini anlama, uygun kanıt ve gerekçelerin kullanılması, bilimsel olarak geçerli teorilerle kanıtların ilişkilendirilmesi ve kavram yanılgıları ve yanlış bilgiler içeren alternatif açıklamaları çürütmek için gerekli olduğu saptanmıştır. Bu yönüyle, argümantasyon uygulamaları evrim teorisi konusunda kavramsal anlamayı geliştirebilir. Diğer bir deyişle, katılımcılar alternatif açıklamaları değerlendirirken ve uygun kanıtlarla kavramsal bilgilerini ilişkilendirirken aslında aynı zamanda var olan kavramsal bilgilerini değerlendirme ve farklı epistemik düzeylerde bu bilgilerini birleştirme fırsatı bulmuş olurlar. Bu nedenle, bu süreç bilgiyi işleme ve yapılandırma süreci olarak karşımıza çıkmaktadır. Bu yönüyle, argüman oluşturma süreci aslında bilgiyi yapılandırma süreci olarak evrimsel bilginin gelişmesini sağlamıştır. Bu açıdan bakıldığında, argümantasyon uygulamaları evrim öğretimine katkıda bulunurken, evrimsel kavramların gelişmesi de bilimsel argümantasyon uygulamalarını geliştirebilir. Sonuç olarak, yukarıda bahsedilen sonuçların 2 uygulaması olabilir. İlki, argümantasyon uygulamaları evrim bilgisini geliştirmek adına bir aracı olabilir ve aynı zamanda, birçok bilimsel disiplini kapsayıcı rolüyle evrim teorisi bilimsel argümantasyon uygulamaları için uygun bir konu olabilir.

Bu önerilere ek olarak, incelenen 3 boyutun arasındaki ilişki ve öğretmenlerin bu 3 boyuttaki yetersizlikleri göz önünde bulundurulduğunda, bu çalışmanın sonuçları bilimsel argümantasyon süreci için gerekli olan bazı becerilerin altını çizmektedir. Bunlar, bilimsel olarak geçerli kavramsal bilgilerin argüman oluşturma sürecinde kullanılması, kanıtların uygun teorik önermelerle birleştirilmesi ve uygun karşı argümanlar oluşturulmasını kapsamaktadır. Bu bağlamda, bu becerilerin müfredat kazanımlarında ele alınması konusunda fen bilimleri öğretmen eğitimcileri ve aynı zamanda fen bilimleri eğitimi müfredat geliştiricileri için önemli birer çıktı olduğu düşünülmektedir.

Son olarak, bu çalışmada fen bilimleri öğretmenlerinin evrim teorisi ile ilgi kavram yanılgıları ve bilişsel önyargıları olduğu tespit edilmiştir. Özellikle, evrimsel ana kavramların çoğunlukla kullanıldığı öğretmenlerde hala bilişsel önyargıların olması fen bilimleri öğretmen ve adayları için hazırlanan eğitimlerde sadece ana kavramların öğretimi değil aynı zamanda bilişsel önyargılarında ele alınması gerektiğini göstermiştir.

APPENDIX E

TEZ FOTOKOPİSİ İZİN FORMU

ENSTİTÜ

Fen Bilimleri Enstitüsü	
Sosyal Bilimler Enstitüsü	X
Uygulamalı Matematik Enstitüsü	
Enformatik Enstitüsü	
Deniz Bilimleri Enstitüsü	

YAZARIN

Soyadı :Yeşilyurt
Adı : Ezgi
Bölümü : İlköğretim

TEZİN ADI (İngilizce) : Conceptual, Structural and Epistemic Aspects of Science Teachers' Argumentation Practices In The Context of Evolutionary Theory

TEZİN TÜRÜ : Yüksek Lisans [X] Doktora [ ]

1.	Tezimin tamamından kaynak gösterilmek şartıyla fotokopi alınabilir.	
2.	Tezimin içindekiler sayfası, özet, indeks sayfalarından ve/veya bir bölümünden kaynak gösterilmek şartıyla fotokopi alınabilir.	
3.	Tezimden bir bir (1) yıl süreyle fotokopi alınamaz.	X

TEZİN KÜTÜPHANEYE TESLİM TARİHİ: