Effect of dialogic argumentation on grade eight students' epistemic knowledge of science: A mixed methods design

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This is to certify that the dissertation prepared by Getachew Tarekegn, entitled: Effect of dialogic argumentation on grade eight students' epistemic knowledge of science: A mixed methods design and submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy in Physics Education complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

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Getachew Tarekegn
Addis Ababa University, 2020

This dissertation aims to explore the effect of dialogic argumentation on grade 8 students' epistemic knowledge of science in physics learning and to identify the practices and challenges faced to promote epistemic knowledge through dialogic argumentation. The study used a mixed methods experimental design research approach where a quasi-experimental design was employed to compare experimental, and control groups' epistemic knowledge of science and a collective case study design was employed to identify teachers' challenges in promoting students' epistemic knowledge in argumentation lessons. Fourteen classrooms were randomly selected from twelve schools and assigned to intervention (239 students from seven classrooms) and control (240 students from seven classrooms) groups. A pre-intervention physics reasoning test was administered to both groups and small group classroom discussions were video recorded. Then, physics teachers in the intervention group had trained for three days about dialogic argumentation and its implementation. In addition, *Talking Physics Students Activities* manual, that contains fifty-two argumenattives physics activities were distributed and used in a yearlong dialogic argumentation intervention. Post-intervention data were obtained from a physics reasoning test administered to both groups, video records of small group classroom discussions from both groups and whole-class teaching and audio records of teacher interviews from intervention group. The test scores and the quantized qualitative data of small group discussions were analyzed using inferential statistics. Video data of classroom teaching were quantitized using quantitative ethnography and analyzed using epistemic network analysis. Teachers interviews were also qualitatively analyzed using a thematic analysis. Mann-Whitney U test results indicated that the post-test scores of grade 8 students in the argumentaion lessons significantly increased in their level of epistemic knowledge compared to the non-argumentation groups, $z = -4.509$, $p = .000$, and $r = .21$, but not in the pre-test scores, $z = -1.038$ and $p = .299$. However, both pre- and post-test scores of both groups were relatively low. The intervention groups showed significant improvements in the quality of their argumentation on the ASAC scale, $z = 2.111$, $p = .035$, and $r = .56$, but not the control groups, $z = 1.068$ and $p = .285$. The epistemic network analysis of the wholeclass teaching in the intervention group showed weak and less frequent connections epistemic aims, epistemic processes of construction, justification, and evaluation of knowledge. The study found evidence that argumentation-based lessons improved both the epistemic knowledge and the quality of dialogic argumentations of grade 8 students and that students' level of epistemic knowledge and the quality of their dialogic argumentations were strongly correlated. However, teachers had failed to teach argumentation as an epistemic practice. To make a better use of dialogic argumentation, therefore, well-thought-out and research-supported training needs to be given to science teachers as part of their continuous professional development. Future studies are necessary to address the effects of such trainings and to determine if there are other hidden factors, apart from teachers' inadequacy, that affect students' epistemic knowledge of science.

Dedicated to

My late father

Tarekegn Zegeye Habtu

(ጥር 11፤ 1949 ዓ.ም. - ሐምሌ 7፤ 2010 ዓ.ም.)

(19th January 1957 – 14st July 2018)

&

My late teacher

Professor Per Morten Kind

(1st October 1960 – 1st October 2017)

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NB: Even though I did not participate and present at the following international conferences due to financial constraints, manuscripts developed from this dissertation were accepted for presentation at ASERA 2019, ESERA 2019, and NARST 2020.

The titles of those papers were:

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ESERA (2019) and NARST (2020) *Qualitative analysis to elicit features of epistemic knowledge when middle school students engaged in dialogical argumentation*: Tarekegn, G., Osborne, J., & Tadesse, M.

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List of Acronyms

AIR	Aims, epistemic Ideals, and epistemically Reliable
ASAC	Assessment of Scientific Argumentation in the Classroom
CTE	College of Teacher Education
DA	Dialogic Argumentation
EKI	Epistemic Knowledge Test Items
ENA	Epistemic network analysis
EPS	Epistemic practice of science
HPS	History and philosophy of science
IRE/F	Initiate–Response– Evaluate/ Feedback
NLA	National Learning Assessment
NOS	Nature of science
PCK	Pedagogical Content Knowledge
SRA	Scientific reasoning and argumentation
STEM	Science, Technology, Engineering and Mathematics
TAP	Toulmin's Argument Pattern
TPSS	Transforming the Pedagogy of STEM Subjects
ZPD	Zone of Proximal Development

Chapter 1 Introduction

1.1 Background of the study

Throughout the world, scientific literacy of citizens is recognized as a key to transform and to bring an overall development and prosperity of nations (Roberts, 2013). Roberts states that scientific literacy is important to train future professionals in science and technology as well as to make citizens informed decision makers about socioscientific issues and to judge and question information and products of science and technology. As a result, many countries, including Ethiopia, had supported the induction of the scientific literacy concept into their K-12 science education curriculum and instructions (MoE & JICA, 2016).

Scientific literacy plays an important role in the development of students understanding of the nature of science and its practices. OECD (2013) defined scientific literacy using three scientific competencies, namely: "explain phenomena scientifically, evaluate and design scientific enquiry, and interpret data and evidence scientifically" (p.5). The first competency requires the knowledge of the content of science (content knowledge). The second competency requires the knowledge of the standard procedures used to conduct scientific enquiry and to establish scientific knowledge (procedural knowledge), whereas the third competency requires knowledge of the epistemic criteria and epistemic process of science (epistemic knowledge).

Nature of science is an increasingly important area in science education. However, science education research confirmed that students are not comprehensively conceptualizing the nature of science (NOS) and developing scientific practices (Erduran & Dagher, 2014). For example, Alemu, Kind, Tadesse, Atnafu, and Michael (2017) confirmed that Ethiopian preservice students are low in their scientific reasoning abilities. Moreover, Alemu et al.'s comparison of these students' scientific reasoning in physics against other nations, mainly European, reveal Ethiopian students have scored the lowest mark in some selected items of the Trends in International Mathematics and Science Study (TIMSS) physics reasoning test. This poor scientific literacy of Ethiopian students calls for further actions. One way to promote scientific literacy is through enhancing students' scientific thinking, particularly student's epistemology of science.

Epistemic knowledge of science is the knowledge of how we know what we know (Kind & Osborne, 2017; OECD, 2013). Epistemic knowledge is essential to reconstruct and justify the knowledge produced by science. Such knowledge empowers one's functional understandings of the nature of science (Manz, 2015; Niaz, 2017). Its development also introduces students to core scientific practices (Kuhn, 2010). Epistemic knowledge ranges from knowing and recognizing different scientific constructs such as hypothesis and theory to being able to justify ideas from evidence and understanding the justification for various forms of scientific inquiry (Berland et al., 2016; Öberg & Campbell, 2019).

Thus, it is inevitable to search for a teaching approach that promotes students epistemic knowledge of science (EKS). Recently, dialogic argumentation has been advanced as a productive teaching strategy to develop scientific knowledge of students. Dialogic argumentation is a classroom discourse between two or more arguers that holds competing views about a particular issue. The purpose is to justify or refute claims based on evidence, to construct ideas socially through a mediation of language, and to enhance shared understanding (Tadesse, 2015). It is argued that such discourse contributes to enhancing students' scientific literacy and the competencies to "explain phenomena scientifically, to evaluate and design scientific enquiry; and interpret data and evidence scientifically" (OECD, 2013, p. 5). These competencies, in turn, require a synthesis of three forms of scientific knowledge: content, procedural, and epistemic knowledge. Content knowledge is referred to the object of reasoning in the form of domain-specific concepts. Procedural knowledge is a measure of the tools and concepts established for way of knowing in science, whereas, epistemic knowledge is understood as knowledge of epistemic constructs, validation, and justification of scientific assertions (Duschl, 2008a; Kind & Osborne, 2017; OECD, 2013; Osborne, Rafanelli, & Kind, 2018). Many studies have attested the success of dialogic argumentation in improving conceptual knowledge in Africa and elsewhere (Iwuanyanwu & Ogunniyi, 2020; Mhakure & Otulaja, 2017; Murphy et al., 2018; Von Aufschnaiter, Erduran, Osborne, & Simon, 2008; Walker & Sampson, 2013). However, science education studies that focuses on the influence of dialogic argumentation on epistemic knowledge of science are sparse.

This study investigates how engagement in dialogic argumentation influences students' epistemic knowledge of science. Reform documents have consistently identified epistemic knowledge of science as a key objective of science education to introduce science-as-a-practice (OECD, 2013). The common focus of the development of scientific knowledge in science education, however, has been on elements of content knowledge and not the elements of epistemic and procedural knowledge. In addition, the goals of learning science are shifting from outcomes, such as problem solving, conceptual learning, and science process skills, towards introducing and developing the competencies required for the generation of scientific knowledge and the tools required for the construction of scientific knowledge (Stroupe, Moon, & Michaels, 2019). This change has brought a greater emphasis on argumentation from evidence and the role of epistemic knowledge of science to the fore.

Moreover, developing epistemic knowledge is particularly important in an African cultural context where knowledge is often constructed on the basis of authoritative statements, e.g. from the teacher, the elders, or the book. The traditional Ethiopian culture advances a stereotypical and authoritative conception of knowledge. Consequently, science teachers perceive and portray (scientific) knowledge as permanent and transcendent truth. This conception impedes teachers' understanding of how science works and ultimately the teaching and learning of school science. The dominant teacher-centered approach to science teaching, science classrooms without a hint of scientific inquiry, and school science assessments that focus on rote memory are the natural extension of such culture. Thus, Africa requires considerable effort in transforming the nature of its science education to change fundamentally the innate beliefs about knowledge of both teachers and students (Mhakure & Otulaja, 2017). Such paradigm shift in the pedagogy for science education requires significant improvement of teachers and students' epistemic knowledge. In general, previous studies have not paid attention to examining the development of all elements of scientific knowledge; particularly epistemic knowledge of science; moreover, these studies have failed to investigate the development of epistemic knowledge because of engaging in dialogic argumentation. Hence, we investigate how dialogic argumentation can influence epistemic knowledge of middle school students.

1.2 Rationale of the Study

1.2.1 Practical rationale

A survey of teaching and learning in Ethiopian classrooms, arguably at all levels of education and in all subjects, revealed the dominance of didactic teaching in the form of standard traditional lecture format (Frost & Little, 2014; Hagos & Tefera, 2015). Physics classrooms are no exception. Much research, done in Ethiopia and elsewhere, has shown didactic teaching impedes students' motivation, conceptual understanding, critical thinking, and scientific reasoning (Hake, 1998; Halloun & Hestenes, 1985; Mazur, 1997; Semela, 2010). Hence, didactic teaching is considered to be ineffective to develop the scientific know-how of students. In addition, didactic teaching perpetuates an incorrect picture about what science is, how science works, and how science is practiced by scientists (Asterhan & Schwarz, 2007). As a consequence, students' difficulty in learning physics concepts is enduring (McNeill, 2009; Pizzolato, Fazio, Mineo, & Adorno, 2014; Taibu, Schuster, & Rudge, 2017). Such learning difficulties may be a product of misconceptions, a gap in scientific knowledge and skills, the wrong approach to learning and understanding physics, and mismatch between teaching and learning (McDermott, 1991).

As a physics instructor at colleges of teacher education for the past ten years, I observed many upper primary school science students struggling to understand the basic concepts of physics. Specifically, my practicum class observations brought to the surface the predicaments of the system of education manifested as students' failures such as the use of equations without recognizing the theoretical concepts behind them, 'solving' problems without making sense of the solutions, and studying without comprehension. One of the factors for such futile learning may be the poor epistemic knowledge of the teachers themselves and textbooks' presentation of science (Lidar, Lundqvist, & Östman, 2006; Tsai, 2002). In other words, poor epistemic knowledge of both teachers and students prevented them from undertaking challenging cognitive tasks and contributed to unsuccessful science teaching and learning (Neber & Schommer-Aikins, 2002). These global problems urge science education researchers to look for better instructional strategies such as the one chosen by this study – dialogic argumentation.

This dissertation intended to move away STEM teaching towards students-oriented teaching in middle school physics classrooms so as to develop a better epistemic understanding in particular. To this end, the study introduced dialogic argumentation to engage students into the practices of science and to improve their epistemic knowledge of science. Furthermore, this transformation of STEM pedagogy towards dialogic argumentation supports the attempts of the ministry to shift the existing didactic culture of teaching and learning science in elementary schools. Perhaps, the pedagogical strategy used here enables Ethiopia to educate its young people to be informed and became critical consumer of scientific knowledge, which is an important and lifelong competency required in the 21st century (MoE & JICA, 2016).

1.2.2 Theoretical rationale

This study was dominantly guided by sociocultural learning theory and sociocultural view of science. Sociocultural learning theory claims that talking, which is socially and culturally mediated activity, is necessary for development of scientific reasoning when learning science. Vygotsky (1978) says that knowledge is evaluating ideas. The science culture favors evidence-based argumentation with support in empirical and theoretical evidence. The sociocultural views of science characterize scientific practices as both societal and rational. The practices of science are rational, hence there is a focus on empirical evidence to justify knowledge claims and logical reasoning. In addition to this, the practices of science are also social, hence there is an emphasis on social interaction and its norms. These depiction of science and its practices are not contradictory in nature. Rather, it manifests the scientists practices as socially bounded and driven by rational thinking. That is why science learning theories view cognition as a product of the interaction of sociocultural and individual activities. Hence, classroom pedagogies should support students sense-making of various natural phenomena and becoming scientifically literate.

The main argument is that STEM pedagogy that encourage dialogic argumentation in science classrooms help students not only to develop their conceptual understanding but also to grasp others aspects of scientific reasoning, such as epistemic knowledge of science (Kind & Osborne, 2017). Epistemic knowledge enables students to implement scientists' ways of thinking and to enculturate practices of doing science (Kuhn, 2010; Manz, 2015). Thus, a pedagogy that draws from the contemporary view of student learning as well as from the contexts and situations of physics classrooms of Ethiopia is needed. Accordingly, science educators, researchers, and teachers have developed various instructional strategies to help students be active participants, to address their alternative conceptions explicitly, and to develop their cognition and metacognition during instruction. Recently, science education scholars have suggested using dialogic argumentation as a pedagogical strategy for a more effective teaching and learning of school science (Jiménez-Aleixandre & Erduran, 2007; Khine, 2012; Tadesse, 2015). The implication to this study is that students should be given an opportunity to talk science in their teaching and learning processes. From this perspective, it is apparent that the teacher-oriented didactic teaching does not stimulate student talk, and hence science educators argue for a new alternative pedagogy to transform STEM pedagogy education.

1.2.3 Empirical evidence

In the past couple of decades, dialogic argumentation emerged as a means to bring the practice of science to the classroom, which in turn is seen to develop students' scientific knowledge and literacy (Driver, Newton, & Osborne, 2000). Argumentation in science classrooms engages students in the same types of practices in which scientists engage and, in the process, it develops students' scientific knowledge (Duschl, 1990), and scientific literacy (Cavagnetto, 2010; Driver et al., 2000). This recognition arose from the notion that science is both a body of knowledge and a way of knowing. When scientists do science, they engage in argumentation to back their claims with data, to assess their evidence, and to examine alternative explanations (Kuhn, 1993). Doing science involves an ensemble of interconnected procedural, social, and epistemic practices. Scientific knowledge is socially constructed and involves complex social and epistemic activities (Christodoulou & Osborne, 2014; Ford & Wargo, 2012; Zohar & Nemet, 2002). The know-how of the elements of scientific knowledge empowers students' functional understanding of the nature of science (Duschl, 2008b; Erduran, 2014; Nussbaum, Sinatra, & Poliquin, 2008) and develops their understanding of the core practices of science (Papadouris & Constantinou, 2014).

Taking dialogic argumentation to school introduces students to the core standard and practice of science and leads to the gradual understanding of the practices of science (Leach, Hind, & Ryder, 2003; Sandoval, 2005). Findings from several studies attested that dialogic argumentation improves communication skills, conceptual understanding, deeper thinking, and scientific reasoning (Alexander, 2008; Driver et al., 2000; Ford & Wargo, 2012). Argumentation in the science classroom is a way of immersing students in epistemic discourse that allows them to consolidate their prior knowledge and to construct new knowledge (Sandoval & Morrison, 2003). Previous research has shown the poor quality of students' argumentation in school science classrooms and mentioned some possible affecting factors such as the poor conceptual understanding of physical concepts by students, the methods of teaching, the epistemological ideas students have and implement during argumentation tasks, and the students' belief and knowledge of how scientific knowledge develops (Berland & Reiser, 2009; Berland et al., 2016; Hake, 1998; Sandoval, 2005). Also, studies exploring students' epistemic conceptions in science education have shown that students tend to develop a naïve view of science in their early undergraduate studies, and that, as they transfer from junior to senior years, they demonstrate a substantial attitudinal and epistemological-belief shift towards a more expert understanding. The shift towards expertize shows that students' view of science arises mainly from their academic experience. Conceptualization of science in pieces (diSessa, 1993; Hammer, 1994; Lising & Elby, 2005), failure to connect real phenomenon with scientific explanations (Berland et al., 2016), and poor science instruction led students to hold a common sense (naïve) view about science (Buehl & Fives, 2016; Ding & Mollohan, 2015; Hammer, 1994; Hammer & Elby, 2003; Tsai, 2002). To sum up, students' epistemology of science may depend on the context in which epistemological ideas were produced and the complex and sophisticated nature of students' practice of science.

Relatedly, Erduran and colleagues concluded that students' scientific knowledge showed much progress concerning conceptual understanding and scientific reasoning as a result of their engagement in argumentation (Erduran, Simon, & Osborne, 2004). Another study that looked into the epistemic moves (e.g. effort to support or refute the scientific claims and back it with evidence) showed claims were forwarded haphazardly and without any appropriate justifications (Jimenez-Aleixandre, Rodríguez, & Duschl, 2000). In most arguments, students fail to support their claims with relevant and suitable evidence as well as to back their claims with warrants (Sandoval, 2003, 2005). Students also fail to infer evidence from data (Kelly & Takao, 2002). What students do and do not do during their participation in scientific argumentation in science classroom reveals their underlying epistemic knowledge about building scientific knowledge.

1.3 Statement of the problem

Several studies have advanced the argument that science education aims to equip the next generation with the tools essential for life in a scientific and technology-dependent society (Fensham, 1985; Millar & Osborne, 1998). This argument has led to the notion of scientific literacy which has now got much attention in the school science curriculum and has incorporated various scientific competencies and different forms of scientific knowledge (OECD, 2013). For schools to produce scientifically literate citizens who could explain scientific phenomena, evaluate and design scientific enquiry, and interpret data and evidence (the three competencies of scientific literacy defined by the OECD), it has been argued that they must transform science teaching through engaging students in argumentative tasks (Jiménez-Aleixandre & Erduran, 2007) and teaching the nature of science explicitly (Erduran, 2014; McDonald, 2010). Unfortunately, numerous reform efforts in science education still witness poor critical thinking and poor understanding of the practices of science.

The didactic teaching method, which is widely used as a major instructional strategy in Ethiopia, greatly limits students' conceptual understanding, critical thinking and scientific reasoning (Semela, 2010; Tadesse, 2015). All forms of didactic (teacher-centered) instructional approaches have long been blamed for their limitations in addressing misconception, enhancing reasoning skills, and improving communication skills. Changing the classroom instruction from monologic teaching to dialogic teaching would allow students to engage in classroom discourses actively and to promote their epistemic understanding of science and how science works. On the contrary, when an epistemic understanding is not properly identified and addressed during science instruction, subsequent learning difficulties that hinder students' learning are inevitable (diSessa, 1993). Nowadays science classrooms demand mastery of the science content and understanding of the practice, norm, and values of science, which, in turn, require instructional strategies that address the conceptual and epistemic aspects of science learning.

Studies that have investigated the relationship between argumentation and scientific knowledge have only considered conceptual understanding as the primary form of scientific knowledge (Von Aufschnaiter et al., 2008). However, more research is needed to understand what effects argumentation will have on students' procedural and epistemic knowledge of science. To the best of the researcher's knowledge, such studies are rare in science education. This study, therefore, attempted to explore how grade eight students' engagement in dialogic argumentation influences their epistemic knowledge in physics compared to didactic teaching. It also tried to explore the nature and characteristics of teachers epistemic practices during dialogic argumentation lessons as well as the challenges and prospects teachers have faced when attempting to promote epistemic knowledge.

1.4 Significance of the study

This study has the following significance. First, it contributes to the growing number of disciplinary and general science education research. Specifically, it adds value to and complements the few studies that investigated the influence of dialogic argumentation on epistemic knowledge.

Second, the current study contributes to the field of argumentation in science education by providing empirical evidence for science educators and science education researchers. In particular, the findings provide further evidence to support the need to transform physics pedagogy in teacher training institutions from prevailing traditional instructional approaches to dialogic pedagogy which, in turn, supports the efforts to transform upper primary school physics pedagogy from didactic to dialogic.

Third, the study informs physics teachers, physics curriculum experts, and physics teacher educators on the type instructions that lead to quality science learning. Also, the study findings will help to align the physics classroom instructional designs with the development of scientific competencies and scientific knowledge. This study will also contribute to the physics education community's understanding of students' learning difficulties and performance differences in physics. Finally, the study will serve as a starting point for future research in further understanding and framing epistemic knowledge in science education.

1.5 Purpose of the study and research questions

Argumentation is a core epistemic practice of science that provides evidence-based justification of claims to support existing theory and create new knowledge. Student involvement in such discursive and reasoning practice enables them to talk science, to develop their language of science through dialogic argumentation, and eventually to mould their views of science and its practices. Besides, student engagement in such discursive interactions in science classrooms further hones their argumentation skills (epistemic understanding) to construct, justify, and evaluate scientific knowledge claims.

Science education pedagogy need to shift from mere transmission of a set of scientific facts towards teaching strategies that promote students' critical appraisal of scientific facts by supporting claims with evidence and by justifying scientific ideas with tools of scientific reasoning (Berland & Reiser, 2009). This suggests that dialogue in science should promote students' epistemic knowledge of science through well-crafted argumentative tasks and systematic communication with their science teacher (Lehesvuori, 2013; Mortimer & Scott, 2003). Thus, research that explores the development of students' epistemic knowledge of science and that elicits the features of epistemic knowledge emerging is needed in science education.

This study explores how epistemic knowledge and its various features evolve as a result of argumentative instructions compared with non-argumentative instructions, guided by the following research questions:

1) To what extent and in what ways do engagement in dialogic argumentation affect grade eight students' epistemic knowledge?
2) Is there a relationship between the quality of dialogic argumentation generated by grade eight students and their level of epistemic knowledge?
3) What are the nature and characteristic of teachers' epistemic practices as well as constraints faced to promote students' epistemic knowledge through dialogic argumentation? Particularly
   a) What are the features of epistemic practices observed in teachers' discursive action during dialogic argumentation lessons?
   b) What are the challenges teachers' have faced when implementing dialogic argumentation?

1.6 Definitions of terms

For enhancing the clarity of terms and concepts addressed in this research, we used the following operational definitions. Here, important conceptual terms are defined precisely using measurable events that either produce or characterize it. In this study, we recognize that upper primary school students come to science classrooms with their own ways of generating and evaluating knowledge claims that were developed because of their sociocultural environments.

a) Epistemic knowledge

Epistemic knowledge refers to a component of scientific knowledge that was developed historically by the scientific communities as this community attempted to uncover the natural world. Epistemic knowledge is knowledge of the epistemic constructs and values and how these are used to justify science's claims to know (Kind & Osborne, 2017, p. 10).

b) Dialogic Argumentation:

Dialogic argumentation is a classroom discourse between two or more arguers that holds competing views about a particular issue. The purpose is to justify or refute claims based on evidence, to construct ideas socially through a mediation of language, and to enhance shared understanding (Tadesse, 2015). In dialogic argumentation, due emphasis is given to co-construction of a knowledge claim through collaborative mediation of language (Asterhan & Schwarz, 2007; Duschl & Osborne, 2002). Dialogic argumentation helps students understand the nature and ways of knowledge construction in the sciences.

c) Upper primary school:

In this study, upper primary school represents, in particular contexts, Grade 8 students of the second cycle primary education in Ethiopia, and both Grade 7 and 8 students in a general sense.

d) Epistemic Knowledge Test Items (EKIs)

Epistemic knowledge test items are items selected from the physics reasoning test that were considered to measure the students' epistemic knowledge of science. Epistemic knowledge of science included items that assess upper primary school students' ways of knowing, justifications and scientific reasoning skills.

1.7 Overview of the study

This dissertation contains six chapters. The write up of the chapters gives due attention to how dialogic argumentation instructions contribute to the development of upper primary school (grade 8) students' epistemic knowledge of science. In this study, we recognize that upper primary school students come to science classrooms with at least some subject knowledge that enable them to generate and evaluate knowledge claims.

1.7.1 Chapter One: Introduction

Chapter 1 provides the background and purpose of the study, the questions the study sought to answer and the significance of those questions as well as their answers to the primary science education in Ethiopia and elsewhere. The chapter addresses the purpose of the research to: (1) understand the extent and the ways engagement in dialogic argumentation affect upper primary school students' epistemic knowledge; (2) relate quality of dialogic argumentation generated by upper primary school students and their level of epistemic knowledge; and (3) identify challenges and prospects to promote epistemic knowledge in dialogic argumentation physics instructional settings.

1.7.2 Chapter Two: Literature Review

Chapter 2 provides a more detailed review of relevant literature in relation to dialogic argumentation and epistemic knowledge of science. First, competing views in science learning about epistemology of science will be presented and the position of this dissertation will also be clearly communicated. Second, epistemic knowledge of science will be conceptualized and its features identified. Third, a critical review of the literature on science teaching and learning through dialogic argumentation to promote students' epistemic knowledge of will be presented. Fourth, theoretical perspectives that situate the constructs of this dissertation, namely epistemic knowledge and dialogic argumentation, will be thoroughly discussed and relations with this study established. The Chapter finally deals with the analytical framework that has been used in this dissertation and its associated analysis techniques, i.e., the epistemic network analysis.

1.7.3 Chapter Three: Research Methodology

Chapter 3 presents the research design, the participants and context of the study, the interventions, the methods used for data collection and analysis for both quantitative and qualitative methods. It also discusses the instruments used in this research: Epistemic Knowledge Items (EKIs), video records of students' small group discussion on given argumentative tasks and whole class teaching, and semi-structured interviews. The need for the qualitative analysis, the utility of the analytical frameworks and the analysis techniques will be clearly described and illustrated here.

1.7.4 Chapter Four: Results

Chapter 4 presents analyses of both quantitative and qualitative data. The quantitative analysis makes use of inferential statistics and students' small group discussions quantitated using ASAC (Assessment of Scientific Argumentation in the Classroom). The epistemic network analysis (ENA) and thematic analysis have been used for qualitative and mixed analysis of grade 8 physics teachers' epistemic practice of science in their argumentation lessons. Students' epistemic knowledge will also be compared based on their EKI pre- and post-test scores.

1.7.5 Chapter Five: Discussion

Chapter 5 presents the synthesis of the results and relates the research findings to the research questions raised in Chapter 1. In addition, the findings of this study will be discussed in line with previous research findings in the strand of argumentation, epistemology of science and nature of science. Moreover, as an attempt to situate this study in the realm of related endeavors and mark its contributions to science education research, justifications and explanations are given for the findings in comparison with previous findings.

1.7.6 Chapter Six: Conclusion and Implications

Chapter 6 provides a synopsis of the major findings and their implications for primary science education in transforming STEM pedagogy. Chapter 6 also provides recommendations for improving physics teaching and learning, science teacher education, curriculum policy, and education programs.

Chapter 2 Literature Review

A considerable amount of research has been conducted in science education to understand how students reason and argue. Many of these studies relate dialogic argumentation to the development of students' scientific knowledge in science classrooms. This chapter critically looks into the existing body of knowledge with a focus on dialogic argumentation and epistemic knowledge and outlines relevant ideas, practices, and theories in the argumentation strand of science education studies that would later serve to construct a framework for this dissertation.

The chapter begins with a review of science teachings and learning in schools aiming at the development of students' epistemology of science. Next, efforts are made to define and operationalize *epistemic knowledge*. Argumentation-based research on teaching and learning of science/physics and research on the relation between dialogic argumentation and epistemic knowledge of science will also be discussed. Much emphasis will be on dialogic argumentation instructional strategies that promote epistemic knowledge and on challenges and opportunities to promote epistemic knowledge in argumentative instructions. This research draws on the sociocultural view of science, the cognitive history of science, the sociocultural learning theory, and the dialogic view of argumentation theory to outline the study's analytical frameworks and support its theoretical explanations. Major findings and some implications from previous related studies will be summarized.

2.1 Science learning and epistemology of science

Since the turn of the century, science education has made a paradigm shift from studying 'science learning products' toward exploring 'science learning processes and practices'

(Duschl & Grandy, 2011; Kelly & Licona, 2018). Recent conceptual and theoretical developments in learning theory and philosophy of science have favored the processes and practices of students in science classrooms over the learning products of science. Scholars in history and philosophy of science (HPS) have recognized the disparity between the knowledge production processes and practices of scientists and its reconstruction in schools and argued for coherence in scientific knowledge production by scientists and its reconstruction by students (Matthews, 2015). Science educators have responded by acknowledging the role of argumentation, explanation, and model building in science classrooms at K-12 levels in promoting students' scientific thinking and reasoning skills. Nowadays, the tradition that considered students as a mere-recipient of scientific knowledge is being substituted by a paradigm that considered students as knowledge producers (Duschl & Grandy, 2008). Many reforms in science education, around the globe and at various grade levels, aligned themselves with these views and advocated students' argumentative discourses. Though the contribution of the epistemology of science toward students' science learning is not contested, less consensus has been reached about science learning insights drawn from epistemology (Jimenez-Aleixandre, 2014). In science education literature, there are still debates on the features of epistemology and the epistemological positions relevant to science, and the ideal approach to investigate epistemology and science learning.

2.1.1 Domain-general vs domain-specific epistemic features

One group of scholars assume that attributes of scientific knowledge production and the associated explanatory power are common to *all* sciences, and the assumptions about these features can be implicit or explicit. Others disagree with such a depiction of epistemic features of science and emphasize the domain-specificity of epistemic features. The domain-general position does not acknowledge the existence of unique approaches across various disciplines of sciences. This position is dubbed *reductionist* by the proponents of the domain-specific position and has been considered problematic. These critics argue for a shift from unitary views to epistemologically pluralistic views of science (Jimenez-Aleixandre, 2014).

2.1.2 Personal Epistemology vs Practical Epistemology

Personal epistemology is a view or belief about knowledge and ways of knowing (Feucht & Bendixen, 2010). In their seminal article, Hofer and Pintrich (1997) identify four dimensions of personal epistemology: the certainty of knowledge, simplicity of knowledge, justification of knowledge, and source of knowledge. Several studies have revealed that student epistemologies should consider science as tentative, complex, and reliant on reason and evidence. Elby, Macrander, and Hammer (2016) argue for student epistemologies to be contextual, domain-specific, and developed through topic-specific discussion. These authors point out that sometimes naïve realism (i.e. a belief system that considered knowledge as certain) might be useful to support learning and sometimes depictions of knowledge as tentative might not be productive. In line with these critical insights, Sandoval (2005) argues that students' understanding of the nature of science (NOS) and their scientific practices guide their practical epistemologies. Practical epistemology is related to epistemic criteria students apply to build and evaluate scientific knowledge when engaged in scientific practices. Sandoval (2005) indicates that scientific epistemology is contextual and dependent on practices, like inquiry and argumentation. Furthermore, studies on the epistemology of science should focus on practical epistemology rather than surveys of epistemic beliefs (Sandoval, 2014; Sandoval, Greene, &

Bråten, 2016). Thus, this dissertation endorses the concept of practical epistemology to study the effect of dialogic argumentation on students' epistemic practices of science.

2.2 Epistemic knowledge of science: defined and operationalized

Epistemic knowledge is the knowledge of how we know what we know (Kind & Osborne, 2017; OECD, 2013). Epistemic knowledge is essential to reconstruct and justify the knowledge produced by science. Such knowledge empowers one's functional understandings of the nature of science (Manz, 2015; Niaz, 2017). Its development also introduces students to core scientific practices (Kuhn, 2010). Epistemic knowledge ranges from knowing and recognizing different scientific constructs such as hypothesis and theory to being able to justify ideas from evidence and understanding the justification for various forms of scientific inquiry (Berland et al., 2016; Öberg & Campbell, 2019).

In physics, scientific knowledge identifies the entities that exist in the world, develops explanatory models of causal relationships, and explains how we know what we know. In the natural world, there are many identifiable and varying parameters (variables). Variables are isolated and identified to understand their specific roles and contributions in explaining what is happening in the natural world (Kuhn, 1970). In understanding what specific variable contributes to the observed phenomena, it is appropriate to control other variables to look at the change brought by that specific variable. Ultimately, in science, creating knowledge requires an understanding of why a particular method is employed, and how the approach is both systematic and reproducible. Such an understanding is part of what is to be defined as epistemic knowledge.

Many scholars view science as a body of knowledge and a way of knowing (Erduran & Dagher, 2014; Matthews, 2015). At the same time, scientific knowledge and way of knowing did not develop overnight. Science has marched a long and challenging journey before the methods of science achieved the present level of systemic ways of knowing. The history of science records many accounts of the flawed views of scientists and incorrect explanations and reasoning advanced to explain many natural phenomena (Matthews, 2015). Justifications for claims to know are heavily reliant on evidence taken from data and the quality of the reasoning used to support the scientific arguments. Such arguments are vital components in scientific practice and maybe hypothetico-deductive (*e.g.* Copernicus' argument for the heliocentric system), inductive (the conservation of energy), or inference to the best explanations (Darwin's theory of evolution or Wegener's argument for moving continents) depending upon the focus of investigations and the nature of the data (OECD, 2013).

Understanding the role and nature of such arguments is important for the development of scientific literacy. Scientific literacy requires students to know what the constructs and the defining features of science (OECD, 2013) are. Understanding the underpinnings of scientific observations, facts, hypotheses, models and theories, purposes, goals and values, and the styles of reasoning used are integral to appreciate and grasp the nature, meaning and significance of science. Thus, epistemic knowledge enables us to understand the role, the goal, and the methodology of enquiry in producing knowledge and justifying claims. To understand science, it is vital to know-how we think about science.

2.3 Characterizing features of epistemic knowledge

As outlined above, epistemic knowledge is fundamental to the process of knowledge production in science. Epistemic knowledge equips students with the knowledge of the constructs used in reasoning in science – that is, the role and constituent features of these constructs in justifying scientific knowledge. Such knowledge helps students to grasp the intellectual achievement of scientific ideas and their development. Another feature of epistemic knowledge is that it enables students to think more deeply about the natural phenomenon they are investigating using constructs such as the notion of a hypothesis, theory, facts, models, and theories. These constructs are instrumental in producing model-based explanations about how the natural world works which is the goal of science. Higher level of epistemic knowledge requires the use of warrants and backings to support arguments, which, in turn, requires that students understand what constitutes a scientific question and what observations might generate appropriate data. Here the students' epistemic knowledge plays a paramount role in selecting a suitable form of empirical enquiry and in justifying the ensuing design. Then students need to analyze and interpret data to figure out how those data inform their hypotheses and theories. Asking questions like "do the data support one idea over others?" help to refute an idea, or suggest an entirely new explanation. In addition, epistemic knowledge includes an understanding of how uncertainty in measurement affects our level of confidence in our claims to know. Moreover, students need to use various forms of reasoning in science such as deductive, inductive, inference to the best explanation (abductive), analogical, and model-based (Duschl, 2008b; Kind & Osborne, 2017; Öberg & Campbell, 2019; OECD, 2013; Osborne et al., 2018; Yang et al., 2018).

2.4 Teaching and learning physics through argumentation

Over the last three decades, major practices of physics education in schools sought to equip students with a solid conceptual understanding of physics, to help them acquire problem-solving skills and perform scientific experiments either through imitation or by following prescribed procedures in the laboratory manual. Moreover, physics textbooks are heavily inclined toward a quantitative and analytic approach to physics. Niaz (2017) explained that the assumption was students' involvement in intensive practices of solving physics problems would lead them to grasp the conceptual underpinnings. Much physics education research has shown convincingly that students' manipulation of physics formulas and equations does not secure a conceptual and epistemological understanding of physics. Even worse, these research findings revealed that many elementary and high school students harbored various misconceptions and misunderstandings of various physics principles (Allen, 2014; diSessa, 1993; Hammer, 2000; Neidorf, Arora, Erberber, Tsokodayi, & Mai, 2020; Vosniadou, 2012).

To surmount this difficulty, many reform-based instructional approaches were proposed to shift toward a model of teaching science as a practice (NRC, 2012). NRC (2012), claimed that the goal of science education should be to enhance students' knowledge of science and knowledge about science using methods of inquiry and argumentation in the school science classroom. This requires students to use evidence, to develop a scientifically sound argument, to evaluate and criticize explanations and models of physical phenomena, and to depict the epistemic, conceptual, and social aspects of science in their argumentative practices (Driver et al., 2000; Ford, 2015; Stroupe, 2015). Ford (2008) contends that argumentation gives epistemic authority to students to construct, justify, and evaluate scientific knowledge claims. A review of major studies in science education revealed that argumentation has the potential to bring the practice of scientists to school science classrooms (Erduran, Ozdem, & Park, 2015; McDonald & McRobbie, 2012; Osborne, 2012).

2.4.1 Nature of scientific knowledge in physics

Teachers' conceptions about the nature of scientific knowledge and their understanding of scientific knowledge construction have a huge influence on their science teaching and, by extension, on their students' science learning (Erduran & Dagher, 2014). Such understandings shape one's mode of thinking and the way one engages students in scientific practices. A number of science education studies recommend curricular resources and accompanying instructional strategies of science education reforms to reflect NOS and its inquiries as well as practices scientists use in their investigations of the natural world (Kelly, McDonald, & Wickman, 2012; Leach et al., 2003).

Physics is a discipline of science that studies matter and energy, and the interaction between them. Physics has its distinct languages, ways of investigation, theoretical thinking, and understanding of nature. It is a highly philosophical field that dominates the history and philosophy of science for centuries. Moreover, physics uses explanatory language and uses mathematics and experiments to construct knowledge. Physics relies on models, mathematical tools, and argumentation to understand the interaction between matter and energy.

Physicists use words, illustrations, and computations in their practices to advance knowledge. The language of physics gives an intuitive understanding of abstract objects and physical processes. The explanations and descriptions of these abstract objects and processes are the results of human imaginations about how the universe works rather than human perceptions. Hence, abstractions give support to human's ability to understand natural phenomena. In addition, physicists communicate about the nature of scientific knowledge in physics. Their talk includes the nature of evidence evaluation, testing hypothesis, relationships between variables, and modeling of abstract objects, concepts, and processes. The integration of these features of scientific knowledge explains the importance of argumentation.

Modeling and models are common in science. In physics, the three *worlds* namely realities, theories, and models are important. The real natural world is concrete and can be observed and experienced via our senses and scientific instruments. To understand this real world, physical theories play a paramount role in physics. Physical theories are external to the real world and are human constructions using previously agreed-upon rules and principles. Mostly, physical theories are abstracts and conceptions that can be manifested mathematically or linguistically and commonly expressed using mathematical models. Models mediate between theory and reality. Physical models are statements used to simplify and idealize physical systems or phenomena. Physical models are powerful heuristics depictions that allow picturing to visualize explanatory aspects of the physical theory (Lehrer & Schauble, 2005).

Using modeling and models in physics education poses many problems. One problem is related to the representations of models as a replica of reality. Mostly, the use of modeling and models in physics education is devoid of discussions about the development and evaluation of the physical models. Another problem is related to the motivations and strategies of the model to develop correct conceptions of the physics topics under discussions. Often models are presented as the final representation of our knowledge rather than as a tentative approximation of our understanding. More importantly, such views ignored the argument behind the development of the scientific model. This view also prohibits students from evaluating and criticizing models. Thus, it is worth to reflect the motivation and strategies on the development of the model (Gilbert & Justi, 2016).

Another common strategy in physics is experimentation. In physics, experiments involve modeling, predicting, and establishing relationships between different variables with precision. High precision often requires to experiment repeatedly. A high level of confidence to claim knowledge can be achieved through evaluation of their design of the experiment, the reliability of instruments, data, and interpretations. During these processes of experimentation, physicists construct models and engage in argumentation to show the explanatory and predictive power of the models and to justify the data and its respective interpretations. Wilcox and Lewandowski (2017) points out that experimental practices of scientists were not properly channeled to the school science classrooms. However, the existing school science curriculum in Ethiopia considered experiments as a means of data collection and interpretations.

In general, science teachers in K-12 need to have sound understandings of models, arguments, and scientific practices of scientists. Only such teachers can guide classroom discourse in a manner that reflects what scientists do and how scientists reason and justify. Besides, such teachers help students to question, to justify claims, to evaluate evidence, and to criticize models. Kelly and Licona (2018) argue for school science curricula that value and address history and philosophy of science. In history and philosophy of science, modeling, inquiry, and argumentation played a paramount role in the advancements of science. These practices should be reflected in the school science curricula and emphasis to engage students in the scientific practices should be in place. Thus, argumentation has emerged as a key productive strategy in sense making of physics phenomena and participating in epistemic practices of science.

2.4.2 Dialogic argumentation: what is it?

Recently, a substantial amount of research has focused on improving physics instruction through more meaningful engagement of students in their learning. One discursive practice that engages students in meaningful scientific practice is dialogic argumentation (Jiménez-Aleixandre & Erduran, 2007). Dialogic argumentation is believed to enhance students' understanding of scientific practices and how evidence is used to support claims to know in science. Argumentation has arisen from the body of evidence that suggests that acquiring new information simply through listening to classroom lectures is a very inefficient form of learning. Consequently, designing instructional models that enable students to learn science, build scientific knowledge, and support the progress of their epistemic knowledge has been subject to considerable efforts in science education research.

Within science education, many alternative and helpful teaching approaches (Duschl, 2008b; Khine, 2012) have been advanced. Argumentation is seen as one form of pedagogy that can assist the engagement of students meaningfully in their science learning. In this study, argumentation is defined as a discursive practice that enculturates students into authentic scientific discourse and practices through rational and rigorous deliberation of scientific evidence and the use of epistemic criteria (Driver et al., 2000). As such, it is a cognitive, epistemic, and social activity that justifies knowledge claims with evidence using the tools of scientific reasoning (Duschl, 2008b). The enterprise of science involves individual cognitive processes as well as social communication (Ford, 2008; Ford & Wargo, 2012). Thus, scientific practices are always a blend of an individual's cognitive process in developing claims and producing relevant evidence for the claim and social mediation that is required to assess, explain, challenge, and defend the scientific claims.

Such social interaction is the key to reaching commonly agreed-upon scientific explanations about the topic of discussion. Conversely, it also involves a social negotiation in which an evidence-based argument is used to evaluate, exchange, debate, challenge, and defend within a specific community to ultimately reach a consensus through discourse (Chinn & Malhotra, 2002; Ford, 2008). Argumentation is not a simple exchange of ideas. A reasoning process strives to persuade others about the scientific legitimacy of the claim. Argumentation shapes the construction of scientific explanations, models, and theories by linking evidence with claims (Toulmin, 1958). In dialogic argumentation, there is always a negotiation to settle the competing views to reach consensus. Argumentation both advances the arguments and assesses the quality of the presented arguments (Newton, Driver, & Osborne, 1999; Simon, Erduran, & Osborne, 2006). To sum up, engagement in argumentation develops content, procedural and epistemic knowledge, and an understanding of the nature of scientific knowledge and the ways we come to know.

2.4.3 Importance of dialogic argumentation in science education

Kuhn's seminal work, *The Structure of Scientific Revolutions*, revisited the historical development of science and concluded that the progress of science through successive scientific revolutions was a result of dialogic argumentation. As Kuhn succinctly put it, scientific progress is not a mere logical progression of conjectures and refutations. In this regard, students' engagement in dialogic argumentation further hones their scientific reasoning ability, and leads to a better understanding of the nature of science, how science works, and how scientific knowledge is constructed. Von Aufschnaiter et al. (2008) mentioned three justifications to promote dialogic argumentation: argumentation develops and further improves ones' scientific knowledge, argumentation engages the society to make decisions in various socio-scientific issues, and argumentation promotes science learning. Subsequent discussions in this chapter will focus on argumentation and student learning.

Osborne, Erduran, and Simon (2004) held that argumentation is key to promote epistemic, cognitive, conceptual, and social aspects of science. These authors emphasized success in teaching argumentation requires intertwined use of appropriate scaffolding activities and instructional strategies. The pedagogical strategies that promote argumentative discourses require a move from more traditional classroom interactions to the adoption of a more dialogic classroom discourse. Due to such pedagogical demand of argumentative instruction, Berland and Reiser (2009) suggest that science education instructions need a shift from mere transmission of facts and concepts to encouraging students to justify and explain their ideas as well as supporting their scientific claims with evidence. To this end, scaffolding activities in argumentative instruction that stimulate discussion and guide student learning should be carefully developed (Jimenez-Aleixandre, 2002; Simon et al., 2006).

When learning science using dialogic argumentation, students get an opportunity to make sense of data, to use data to generate claims, to back up claims with evidence, to consider alternative claims, and to critique claims and justifications forwarded by their peers. Previous research findings that address the effect of instructional strategies on students' epistemology of science have indicated that students' conceptual understandings were also advanced (Ding & Mollohan, 2015). Research has shown, however, that students often maintain their misconceptions after they have learned science at schools. Students sometimes can use one conception when solving a typical school physics item and a different conception when explaining an everyday situation. There are many reasons why students move from one conception to another. In most cases, however, they reject their existing conceptions as wrong and need to hold a better conception as an alternative. Scaffolding activities, in addition to stimulating discussions and guiding learning, play a paramount role in creating a cognitive conflict by challenging students' intuitive ideas. When students engage in argumentative discourses, they understand the need to support claims with data or evidence and to justify critically why the alternative conception is right or wrong (NRC, 2007).

2.4.4 Analyzing argumentation using Assessment of Scientific Argumentation in the Classroom (ASAC)

In this dissertation, grade 8 students' dialogic argumentation was analyzed. In science education literature, Toulmin's Argument Pattern (TAP) and Assessment of Scientific Argumentation in the Classroom (ASAC) are two of the most widely employed argumentation frameworks. This section provides justification for choosing ASAC over TAP as an argumentational frameworks to analyze students' small group discussion and discusses the ASAC observation protocol in more detail.

The common approach to assessing audio-visual recorded argumentation of students is to translate (if necessary) and transcribe the discourse and then code the transcription using Toulmin's Argument Pattern (TAP) (Erduran et al., 2004). Nonetheless, coding argumentation using TAP is challenging. One of the difficulties emanates from the nonlinear nature of arguments. The other difficulties arise when applying TAP. TAP frames arguments in terms of claims, data, warrants, backings, qualifiers, and rebuttals. This illustration of arguments posed two challenges: the challenge to identify claims, data, warrants, backings, and rebuttals from students' arguments and the focus on the structure of arguments. Sampson, Enderle, and

Walker (2012) recognized TAP's limitation to address all aspects of argumentation and designed an observation protocol, which they call *Assessment of Scientific Argumentation in the Classroom* (ASAC; see Appendix D), to assess students' episodes of argumentation. Since ASAC was developed after an extensive review of literature, it captures various aspects of argumentation. This enables ASAC to assess argumentation more comprehensively. Duschl (2008b) identifies that assessing learning science, such as using argumentation, consists of conceptual and cognitive, epistemic, and social aspects and further elaborated when and how to use these elements of argumentation:

(1) The conceptual structures and cognitive processes are used when reasoning scientifically;
(2) The epistemic frameworks are used when developing and evaluating scientific knowledge; and,
(3) The social processes and contexts shape how knowledge is communicated, represented, argued, and debated (p. 277).

In line with, the importance of these aspects of argumentation to generate and evaluate an argument, ASAC has been designed based on these three core aspects of argumentation. Sampson et al. (2012) generated nineteen statements and the associated detailed description for conceptual and cognitive, epistemic, and social aspects of argumentation after an extensive review of literature in argumentation. Seventeen items of ASAC are rated on a scale from 0 (not at all) to 3 (often) whereas the remaining two items of ASAC are rated in reverse from 0 (often) to 3 (not at all).

The Conceptual and Cognitive Aspects of Argumentation: This component is comprised of seven items (from no. 1 to no.7). This section evaluates students' effort to solve problems, students' attempt to consider alternative views, students' disposition to address data anomaly, students' skepticism, students' ability to scientifically reason and support their claims, and students' reasoning strategies. Each of the items has empirical or theoretical foundations in science education and argumentation research. Some of the research that informed this aspect of argumentation include Sampson and Clark (2011), Berland and Reiser (2009), Duschl (2008a), Osborne et al. (2004), Duschl and Osborne (2002), and Driver et al. (2000). Scores on this aspect of argumentation can range from 0 to 21.

The Epistemic Aspects of Argumentation: Seven items comprised this component. The epistemic section addresses issues related to use and evaluation of evidence, to use scientific theories, laws or models, scientific languages, and wrong line of reasoning, and to distinguish inferences from observations. Here, concepts embedded behind the statement of each item reveal emphasis is given to evidence and its role in confronting students' misconceptions. The empirical or theoretical works that guide the development of these seven items are mainly Duschl (2008a), Jiménez-Aleixandre and Erduran (2007), Sandoval (2003), and Driver et al. (2000). Scores on this aspect of argumentation can range from 0 to 21.

The Social Aspects of Argumentation: This section focuses on social interactions of argumentation and it contains five items. The social aspects of argumentation provide a platform to understand students' communications during argumentative talks. This section assesses how students are reflective about their ways of knowing; respectful prepared to discuss, differentiate ideas from the person. Sampson and Clark (2011), Berland and Reiser (2009), Alexopoulou and Driver (1996), Boulter and Gilbert (1995), and Richmond and Striley (1996) are studies that are the theoretical basis for the development of these items. Scores on this aspect of argumentation can range from 0 to 15. Due to the comprehensive nature of ASAC, this dissertation scored the students' argumentation using ASAC.

2.5 Teaching science to promote epistemic knowledge of students

Scientists follow various processes and engage in various activities in their endeavor to construct and justify knowledge. They have established common approaches to select data to support their knowledge claims and employ methods and analysis techniques that are embraced by the scientific community. These practices of scientists are epistemic in nature because they are the activities they engage to enable knowledge production and its justification. Helping students to understand and participate in the practice of science requires a substantial shift from the current instructional strategies, particularly in the African instructional context. Of course, recent observations indicate that a curricular shift toward reflecting the practices of scientists is becoming more common in the school science classroom. The traditional instructional approaches in science education have portrayed science as simplistic, guided by a series of procedural steps (i.e., the steps followed include asking questions, formulating hypotheses, performing experiments, collecting data, and drawing conclusions), and a collection of facts, which is a naïve conception of science. Teachers need, therefore, to shift towards instructional approaches which depict science as a way of knowing and understanding of the natural world (Lehrer & Schauble, 2015). The implication is that researchers and educators should give particular emphasis to instructional approaches that portrait the epistemic practices of science.

Kelly (2008) defined epistemic practices as ‘the specific ways members of a community propose, justify, evaluate, and legitimize knowledge claims within a disciplinary framework' (p.99). Similarly, others state the epistemic practice of science (EPS) as the social, rational, evaluative, and communicative practice (Christodoulou & Osborne, 2014). Briefly, EPS is a scientific process of constructing, justifying, and evaluating scientific knowledge claims. Though EPS is central to show the process of science, teaching epistemic practices of science requires a complete reframing of students' and teachers' roles, curricular materials, and utilization of instructional strategies. Science teachers need to be well prepared to generate scientific questions, to conduct students' investigations and argumentations, to analyze and interpret data, and to use evidence. Chinn and Rinehart (2016) consider these as epistemic processes, which this study considers as central to the knowledge production process in science. Hence, science teachers' instructional approaches need to go hand in hand with strategies that help students to understand and engage in the EPS (Duschl, 2008a; Kelly, 2008).

In science education, the theoretical foundation for teaching EPS is well articulated and recognized. But the practice to promote EPS in school science classrooms is often absent in the teaching process and curricular materials. Sandoval, Kawasaki, Cournoyer, and Rodriguez (2016) suggest that science teachers should be supported to develop their understanding of the epistemic aspects of science and should be guided to incorporate the EPS in their teaching. One of the objectives of this study is to understand teachers' instructional challenges in promoting the epistemic knowledge of their students using argumentative discourses. Conceptualizing teaching science as epistemic practice, the study strives to address how argumentative instruction serves this purpose and uses the apt-AIR (epistemic Aims, epistemic Ideals, and epistemically Reliable processes) framework to analyze epistemic practices.

2.6 Promoting epistemic knowledge with dialogic argumentation

In framing the argument that using dialogic argumentation promotes the development of epistemic knowledge, Mercan (2012) argued that an ability to evaluate data critically is an important skill for science students. Science students collect data in the field or the laboratory, carefully analyze and critically evaluate the data and use the data to construct model-based explanations.

When students become curious, they are driven to solve problems, sometimes by engaging in scientific argumentation (Berland & Hammer, 2012a, 2012b). However, the selection of an appropriate learning environment plays a paramount role in facilitating argumentation. For students to generate and acquire knowledge through social interaction, a method that enables students to work with their peers is required (Lemke, 1990).

Each student has their style of belief and way of constructing arguments during any discourse. Teachers cannot change these beliefs and thus cannot directly teach skills of argument construction (Berland & Hammer, 2012a). Teachers can, however, produce a learning environment that encourages students to think critically, present claims, back up claims with evidence, and engage in scientific discourse (Simon et al., 2006). Eventually, it is hoped that, through such opportunities, students develop an improved competency with constructing arguments (Berland & Reiser, 2009).

Argumentation skills can be enhanced through the systematic and continuous engagement of students in cognitively complex learning tasks (Osborne et al., 2004). Such skills shape the student's mode of thinking and ease the effort to justify or refute claims. This, in turn, facilitates students' higher-order thinking that leads to meaningful learning of science and builds an understanding of the importance of critique to the process of knowledge construction (Ford, 2008). Cavagnetto (2010) further suggests that argumentation foster scientific literacy by developing communicative and collaborative skills, meta-cognitive awareness, and critical thinking.

To build competency with scientific argumentation, students need to be trained in the process of scientific critique, fostering their inquisitiveness and analytic thinking. Questioning contributes to the development of such skills encouraging students' critical thinking and problem-solving abilities (Chin & Osborne, 2010). Thus, building teachers' capability to ask more cognitively demanding and open questions should help to promote dialogic argumentation and empower students' opportunities to engage in knowledge construction and the learning of science (Chin, 2007).

Stimulating students' curiosity is an essential precursor to the implementation of argument-based inquiry learning and student engagement with argument-based learning. Questions should aim to be engaging and be generative in posing a mystery to be solved. Having said this, epistemic knowledge is important because it is fundamental to how we think in science. Without some means of understanding how we acquire scientific knowledge, how we rely upon our senses, and how we develop concepts in our minds, we have no coherent framework for our scientific thinking. Hence, sound epistemic knowledge is necessary for the existence of sound thinking and scientific reasoning (Evans, Legare, & Rosengren, 2011).

2.7 Challenges to promote student's epistemic knowledge in argumentative instructions

Erduran and Dagher (2014) point out that engaging students in argumentation enables them to see science as a rational practice and to evaluate the strengths and weaknesses that occurred during knowledge building in science. In short, such arguments frame argumentation as an epistemic activity and point to the importance of introducing argumentation as one of the foci of science teaching.

Argumentation reveals the epistemic process involved in producing and evaluating scientific knowledge claims. This epistemic process, in turn, uses epistemic criteria to select evidence, to evaluate claims and evidence, to generate counter-claims, and to communicate convincingly with others. The epistemic actions teachers make in science classrooms and various epistemic tools used to help students to enact scientific practices play a paramount role to impart the epistemic knowledge of science on students. Hence, it is important to consider the role of teachers' epistemic action, the epistemic tools used to support knowledge building and to scaffold student enactment in scientific practices, and to identify challenges and opportunities to promote students' epistemic knowledge of science in argumentative instructions.

2.7.1 Challenges related to physics teachers

It is important to notice the role of teachers to enhance epistemic knowledge of science of students. Lemke (1990) reveals that most of the science teachings are devoid of argumentative elements such as competing views and contradictory or inconsistent data sets useful to instigate argumentation. Berland and Hammer (2012a) mentioned that science teachers lack the expertise to facilitate argumentative discussions and to deal succinctly with students' cognitive conflicts inflicted by the data anomaly, and hence recommended an explicit training about argumentation and teaching strategies to facilitate students' discursive interaction. Such training paves a way for science teachers to shift their classroom discourse from non-interactive and authoritative toward interactive and dialogic discourse (Yun & Kim, 2015).

In Ethiopia, the IRE (Initiate-Response-Evaluate) pattern of interaction is very common in science classrooms. Usually, the teacher puts forward questions (i.e. initiate students thinking), a student responds to the questions and the teacher evaluates his or her answer. The exchange is not very long and stops normally after the teacher's feedback. Teachers who present textbook ideas and ask questions to check what students have learned to dominate many physics lessons. The role of students in this teaching is trying to understand what the teacher is saying and thinking. Students' own ideas are not exposed or considered as important to the lesson. The physics lessons are devoid of practices that encourage the knowledge building process of science.

One of the challenges is the *dialogic nature of argumentation*. Many science teachers failed to capture students thinking based on the context and content of students' argumentative discourse (Louca & Zacharia, 2012). Dialogic argumentation puts students at the heart of the teaching-learning process and gives control to the community of learners to hone their grasp of the scientific knowledge-building processes and values of science. This requires teachers to make a significant shift in their classroom interaction from an authoritative or teacher-centered approaches to a more dialogic and student-centered interaction (Berland & Hammer, 2012a). Teachers need to give students access and power to participate in dialogue and should listen to them without intervening. This challenges teacher pedagogic behaviors such as thinking carefully about group size and composition, giving exact instructions about what students should do, not disturbing students' discussion unnecessary, and bringing forward students' explanations without simply telling the "right' answer (Yun & Kim, 2015).

The second challenge is the *epistemic aspects of argumentation*. The established epistemic understanding of teachers and students about science and the way of knowing in science are expected to either foster or prohibit the implementation of argumentation as a pedagogy (Christodoulou & Osborne, 2014). Dialogic argumentation demands teachers to have solid understandings about scientific evidence, scientific explanation, and the process of scientific reasoning. In argumentative instructions, the science teacher becomes the expert representing the cultural value and criteria of the epistemic practice of science. In other words, when students do experiments or debate scientific claims, the teacher's role is to ask for evidence using questions such as 'how do you know' and encourage students to think critically. Teachers tailored questions make students justify their claims and beliefs, generate opposing arguments, and reveal their epistemic criteria when selecting evidence (Hundal, Levin, & Keselman, 2014).

The third challenge is teachers' *confidence and skills to use argumentation* discourse in their teaching as well as the level of implementing argumentative instructions. The common difficulties teachers face include poor overall understanding as well as the application of argumentation and its components (Braund, Scholtz, Sadeck, & Koopman, 2013; Christodoulou & Osborne, 2014; McNeill & Knight, 2013), failure to offer argumentative questions (McNeill & Knight, 2013), recollecting and summarizing discussions (Shemwell, Chase, & Schwartz, 2015), or differentiating everyday arguments from scientific ones (Sampson & Blanchard, 2012).

Teachers who comprehend the dialogic and epistemic aspects of argumentation can realize the epistemic practices of science by teaching their students how scientific knowledge claims are justified and evaluated. As evidenced by previous studies, however, teachers lack a firm grasp of NOS and elements of argumentation. Hence, science teachers need the training to well-equip themselves with the function of argumentation and implementation of dialogic argumentation as a teaching strategy.

The teacher training may include explicit teaching of reasoning and argumentation skills, but most important strategies of designing a range of discussion activities to practice different styles of reasoning such as:

- Experimental reasoning based on evaluating and analyzing data and experimental methods
- Model-based reasoning based on using and evaluating scientific theories and ideas; and
- Mathematical-deductive reasoning based on using formulas and mathematical equations.

2.7.2 Challenges related to students

When students become curious, they drive themselves to solve problems, sometimes by engaging in scientific argumentation (Berland & Hammer, 2012a). So, the selection of an appropriate learning environment plays a paramount role. To make a student generate knowledge and gain knowledge through social interaction, a method that enables students to work with their peers is required (Lemke, 1990).

Each student has his style of belief and way of constructing arguments during any discourse. In order to guide these beliefs, teachers can produce a learning environment that encourages students to think critically, present claims, back up claims with evidence, and engage in scientific discourses (Simon et al., 2006). Eventually, students might develop their trademark of constructing arguments with confidence and ease (Berland & Reiser, 2009). Probing prior knowledge serves students to bridge the previous and newly acquired knowledge and it serves teachers to identify students learning difficulties (Chin & Osborne, 2010).

One of the student challenges is the *lack of willingness and preparation* to involve themselves in demanding discursive actions. Sampson and Blanchard (2012) mention that students have a low attitude toward science and, as a result, their scientific process skills and their understandings of scientific practices failed them when required to perform scientific investigations and discourse using evidence (Berland & Reiser, 2009; Hundal et al., 2014).

The second challenge is related to students' *poor critical thinking skills*, owing to which students developed a low level of understanding about the nature of science and the way of constructing knowledge in science (Choi, Klein, & Hershberger, 2015; Herrenkohl & Cornelius, 2013). Low level conceptual and epistemic understanding of physics concepts and phenomena hinder students from performing fruitful discursive moves during argumentation.

The third challenge is related to *inter-student power and group dynamics* (Yun & Kim, 2015). The power struggle between students contributed significantly to work smoothly and effectively as well as to involve themselves collaboratively in the argumentation process with their peers.

The fourth challenge is related to *students' age and relevant curricular tools and pedagogical strategies* that suit their particular age group. Rapanta (2019) conducted a comparative analysis between students' age level and the instructional techniques and strategies implemented by the teacher. Eleven studies were used for this comparison. Rapanta's analysis revealed that older students require discourse-based instructional strategies. Furthermore, the analysis showed that students between the ages of 11 and 14 years used the structure of an argument as a strategy whereas students between 15 and 17 years old used different strategies. Some of the successful strategies are an emphasis on reaching consensus, role-play as facilitator and challenger (Archila, 2015), persuade, differentiate evidence from inferences (Berland & Reiser, 2009), attending to others arguments (Gray & Kang, 2014), and supporting claims by evidence (Sampson & Blanchard, 2012). Hence, grade 8 students, aged from 14 to 16 years, can be considered as suitable and, of course, worthwhile subjects to investigate the effect of argumentation on epistemic knowledge of students.

2.7.3 Challenges related to science curricular materials

Time and curriculum are other important factors that constraint the development of epistemic knowledge of students via argumentative instruction (Choi et al., 2015; Hundal et al., 2014). Recently science education reforms promote argumentation at the K-12 level. However, the excessive attention given to assessments has forced science teachers to strictly follow the intended curriculum and the associated textbooks.

2.8 Argument-promoting discourse moves to promote epistemic discourses

The challenges and prospects of physics teachers in their attempts to promote epistemic knowledge of students via dialogic argumentation can be understood through careful analysis of argumentative discourse instruction. Studies in this area revealed that various discursive moves can be employed to promote scientific argumentation. Rapanta (2019) categorized this discourse moves as science-related moves, critical thinking moves, and discourse facilitation moves. The categorization is in line with the three aspects of argumentation observed in a classroom: substantive (related with content knowledge and level of conceptual understanding), epistemological (related with practicing the scientific mode of thinking and way of doing science), and syntactical (related with making sense of physics concepts and phenomena using scientific language) (Berland & Reiser, 2009; Herrenkohl & Cornelius, 2013; Kuhn, 2010).

In a classroom practice, substantive approach views the purpose of argumentation is to strengthen content knowledge and conceptual understanding. It is the “arguing to learn” approach. In the “arguing to learn” approach, student progress is evaluated based on students’ knowledge of principles and theories (Von Aufschnaiter et al., 2008). The epistemological approach considers argumentation as a tool that brings the practices of scientists into the school science classrooms. Here, arguments serve students to think and do science as scientists think and do (Kuhn, 2010). Syntactic approach is “learning to argue” approach. This approach enables students to understand and apply evidence and various ways and means of investigation and analysis when constructing scientific knowledge. Unlike substantive approach, syntactic approach meet with unfamiliar concepts, theories, and evidence. Students are expected to search, select and wove together the pieces of information and knowledge provided, so that they can make sense of the phenomena under investigation. Syntactic approach is a venue to evidence based argument in the classroom (Berland & Reiser, 2009). Next, detailed descriptions of these three argument-promoting discourse moves are discussed.

2.8.1 Science-related moves

Discourse moves under this category include moves that represent the scientific knowledge and the quality of scientific reasoning of either teachers or students. Teachers and students manifest different science-related discourse moves. Teachers’ science-related moves that emerge in their argumentative instructions are: giving resources and feedbacks when necessary, providing the opportunity to persuade or convince each other so that students can do the practices of scientists, formulating arguments, prompting to model and predict, and generalizing (Avraamidou & Zembal-Saul, 2005; Christodoulou & Osborne, 2014; Martin & Hand, 2009). Such teachers’ prompts enable students to revise their arguments, to predict, to justify, to compare and contrast predictions and competing views, and to engage in the evaluative process. Hence, this science-related discourse move corresponds with the first types of argumentation approaches namely the substantive aspects of argumentation.

2.8.2 Critical thinking moves

In this category, discursive moves display teachers' and students' insights about the functions and tools of scientific thinking in their discursive actions. Thus, teacher critical thinking moves include constructive critique, counter-arguments, forward the right prompt at the right moment, analyze students' arguments carefully, forward argumentative questions, prompts to include evidence or data to support students' reasoning (Chin & Osborne, 2010; Christodoulou & Osborne, 2014; Louca, Zacharia, & Tzialli, 2012; Martin & Hand, 2009; McNeill & Pimentel, 2010). Critical thinking moves enable students to engage in argumentative discourse, evaluate their arguments, justify or back up their ideas, to give explanations or reasoning about their claims. The critical thinking discourse move addresses the epistemological aspects of argumentation.

2.8.3 Discourse facilitating moves

This category contains discourse moves manifested by teachers' discursive actions only. These moves are related to a teacher's effort to instigate and facilitate students into an argument. Discourse facilitative moves include prompts performed to engage and encourage students into the argument processes, generating the right question at the right moment to further hone students' thinking, articulate and elaborate students' ideas, and listen and follow-up intently student's line of argumentation (Chen, Hand, & Norton-Meier, 2017; Chin & Osborne, 2010; Larrain, Freire, & Howe, 2014; Martin & Hand, 2009). Simon et al. (2006) suggest that teachers should allow students voices to be heard and should encourage their exploratory talks, and should not interrupt unnecessarily. Therefore, this move focuses on the syntactic aspects of argumentation.

2.9 The theoretical underpinning of this study

One of the purposes of this study was to elicit the features of epistemic knowledge acquired by upper primary school students as a consequence of argumentative and non-argumentative instructions. Epistemic knowledge of science is linked with constructing, justifying, and evaluating scientific knowledge claims. Since the study focused on the effect of dialogic argumentation, it requires a good deal of insight into how to engage students in the science classroom in dialogic argumentations using activities in either a small group or whole-class discussion format. In dialogic argumentation classrooms, students argue about competing theories and multiple ideas based on evidence and justification. Many theoretical perspectives could be used to situate the effect of argumentation in science classrooms on epistemic knowledge. The theoretical perspectives that framed the current study are the sociocultural view of science, the sociocultural theory of learning, the cognitive history of science, and the dialogic view of argumentation theory. How these will inform the current study is briefly discussed in the subsections that follow.

2.9.1 Sociocultural view of science

The sociocultural view of science draws on Kuhn's (1970) historicist critique of scientific knowledge. According to Kuhn, science is inherently a social phenomenon; scientific knowledge is a social construct. Studies on history and philosophy of science reveal that scientists practice science in a particular social context and follow the specific social values and norms established. But the widespread picture of science seems to depict it as a discipline with a universal method. The global acceptance of science and the knowledge it generates are a direct consequence of embracing the view that there is a "universal scientific method" (Erduran & Dagher, 2014). This view gives the impression that science is a non-human and a non-social entity. These perspectives, consequently, moulded science teaching and science textbooks.

History and philosophy of science (HPS) scholars have argued that there is no such thing called *the scientific method* that serves as an umbrella term to the overall scientific practices developed for centuries (Matthews, 2015). There are no unique, universal, and singular methods of doing science. HPS takes *the scientific method* as one way of knowing among the diversity of methods in science. Scholars with a sociocultural view consider science as a culture with its own language and tools. Science is a discipline that reflects the integrated culture of the communities of its practitioners, i.e., the scientific community. To this group of researchers, science is a social practices and scientific knowledge is its product that results from the integration of various cultures, histories and individual experiences of the scientific community. Scientists reach consensus and create scientific knowledge through critical debates, i.e. dialogic argumentation and scientific reasoning (Duschl & Osborne, 2002; Longino, 2002). Longino (2002) further noted that the science culture has developed conceptual knowledge, procedural knowledge, epistemic concepts, and norms which guide scientific research and debates. The epistemic practices of science are social as well as rational. These are also the characteristics of argumentation.

Drawing from sociocultural view of science, there are many implications for science education. First, scientific knowledge taught in schools is guided by the culture and social nature of the scientific community (Aikenhead, 2006). In the scientific community, there is a continuous battle between new scientific claims, which is inspired by new evidence. In light with this change in evidence, the established claims is substituted with the new one. Hence, a paradigm shift is observed in science (Kuhn, 1970). School science, informed by this dynamic sociocultural nature of scientific practices, intends to help students develop new ways of perceiving reality through sharing ideas amongst each other and with the teacher (Erduran & Dagher, 2014). Second, the act of engaging with the social values and activities of science play a paramount role in acquiring the epistemic as well as the cognitive aspects of science. The social norms in which science is practiced enable students to understand how the social structure within which science operates influenced and shaped its development. Science classrooms are venues to enculturate students into the practices of a scientific community, where they can be exposed to the scientific views and procedures, encouraged to develop their understandings of these concepts and procedures by using tools for solving problems, make and discuss scientific claims, and testing their ideas (Smith, 2013). Thus, socially rich environments help students to explore scientific knowledge with their peers and teachers.

2.9.2 Cognitive history of science

Literature in science education brought forth a fresh and detailed conceptualization of epistemic knowledge (see Kind & Osborne, 2017; OECD, 2013; Osborne et al., 2018). Kind and Osborne (2017) approach epistemic knowledge from the perspective of the cognitive history of science. Cognitive historians recognize the importance of historicity (a view that *scientific knowledge developed historically*) to understand human reasoning given that there are no rules of reasoning. The styles of reasoning emerge from the analysis of the nature and diversity of scientific thought from a cognitive perspective in the history of science. Examination of the development of the science culture revealed different styles of scientific reasoning: mathematical deduction, experimental evaluation, hypothetical modeling, categorization and classification, probabilistic reasoning, and history-based evolutionary reasoning. Each style of scientific reasoning requires a distinct set of content, procedural, and epistemic entities (Kind & Osborne, 2017). Reasoning in physics, for example, may require mathematical-deductive reasoning, model-based reasoning with physics ideas, and experimental reasoning with data.

2.9.2.1 Mathematical-deductive reasoning

The associated feature of epistemic knowledge in mathematical-deductive reasoning is the application of deduction as a mode of argument to generate scientific knowledge. Here, students should be aware of and better prepared to represent the physical phenomena with mathematical tools.

2.9.2.2 Model-based reasoning

The associated features of epistemic knowledge in model-based reasoning include an understanding of the heuristic value of models as a cognitive tool, developing explanatory coherence, and identify the limitations of the model to representational accuracy and/or similarity. Modeling and models in science education are vital tools in understanding and communicating science (Mulder, Bollen, de Jong, & Lazonder, 2016). Many research attested that models simplified the learning of a complex process of natural phenomena and paved the way for its conceptual understanding (Halloun, 2004, 2007). Models also boosted and allowed better scientific discourses. Science teaching, therefore, need to be designed so it imparts knowledge that enables developing such models in science classrooms.

2.9.2.3 Experimental reasoning

The associated features of epistemic knowledge in mathematical-deductive reasoning are deducing testable hypothesis, analyzing experimental tests, arguing based on controlling variables, comparing predictions with findings, and understanding the role of replication in science.

In sum: students learn the styles of reasoning from participating in domain-specific discourses and arguments. The domain-specific discourses and arguments pave the way for a student to grasp the epistemic identity of science.

2.9.3 Sociocultural learning theory

Recent developments in educational research do not portray learning as an individual task (Ormrod, 2011). Since the work of Vygotsky became widely available in the West, the focus of research on science teaching and learning has shifted toward a contextual and situational aspect of learning. The sociocultural learning theory views learning as a process of interactions and communications between learners through the mediation of language. This approach put learning inextricably within the environmental situations, which in turn guide science education research to investigate the features of classroom interaction and communication, rather than the learning outcomes (Leach & Scott, 2003; Lemke, 1990).

Sociocultural learning theory recognizes the importance of language in science teaching (Mercer, 2002). Many science education studies are guided by this theory in framing the significance of interaction and communication in science classrooms. For example, Ruiz-Primo (2011) identified teacher talk as a “powerful cultural tool” to shape the construction of scientific knowledge. Christodoulou and Osborne (2014) mentioned the importance of teachers talk to present and engage students in epistemic practices of science. Often teacher talk helps students to make sense of the discussion points. Teacher talk also promotes students thinking about a particular phenomenon, acknowledge the underlying principles, and make conclusions (Sharpe, 2008).

Several studies have reported the use of scaffolding to give the support students needed (Lin et al., 2012). Scaffolding is an education means used by teachers to support the development of students' cognitive understanding and the achievement of learning goals. The teacher should know when to assist and when to refrain from helping students' cognition and thinking during a discussion. The teacher plays a significant role in activating students' prior knowledge, in deconstructing complex tasks, and in situating student's line of reasoning in a proper way (Laugksch, 2000). Ruiz-Primo (2011) emphasizes, however, the importance of balancing challenge and support in classroom dialogues. Scaffolding is a supportive technique that helps students carry out a difficult task. This is the reason that the Zone of Proximal Development (ZPD) is considered as a core of sociocultural learning theory. ZPD is the gap between what students perform with the support of others and what they perform individually. It is a means by which the interactions with learning materials and communications with each other in the social platform transforms into students' knowledge through internalization (Ormrod, 2011). Here, the main notion is that learning occurs when students interact with social and cultural spheres. The internal and external attributes of learning are inextricably intertwined.

Even though sociocultural learning theory have been found insightful within the context of social construction of meaning, ZPD deals with learning at an individual level. Students can perform better with the help and guidance of others than perform independently. There is a range of tasks between what students perform with the support of knowledgeable others and what students perform individually. This range is called ZPD. Here, participants were considered as a competent individual who initiates, supports, and guides the dialog and meaning making. Lehesvouri and colleagues argue that ZPD moulded the deeds, the unique characters and emotions in the reciprocal teaching environment (Lehesvuori, Viiri, & Rasku-Puttonen, 2011). In brief, learning is viewed as a collective social endeavor, which in turn brings community of learners that have common understanding to achieve common goals through active participation by coordinating tasks and efforts and mutual supports and communicate thoughts.

Participation in communal activities helps individuals develop not only shared social meanings, but also knowledge of "the tools and processes needed to function successfully within that community. In this way, cultural knowledge is acquired as individual knowledge" Smith (2013, p. 17). The concept of *participation* in communal activities and the *co-construction* of knowledge are appealing to science educators and researchers as they provide opportunities to students to develop their understanding of scientific concepts through dialogue between themselves and with the teacher.

Previously, much emphasis was given to scientific methods and hands-on experimental investigations in science education. Recently, instructional approaches that allow participating in authentic activities that are intertwined with the epistemic aspects of science seem favored and widely popularized (Kelly & Licona, 2018; Ko & Krist, 2019; Settlage & Southerland, 2019). Dialogic argumentation is one of such instructional approaches that create scientific communities engaging in epistemic practices in the classroom. Argumentation is epistemic and contextual in nature. According to Iordanou and Constantinou (2015), dialogic argumentation make students to use evidence, to bring additional evidence in order to challenge their opponents claims, and to communicate effectively about evidence. These findings implies the development of epistemic knowledge of students. Hence, teachers can bring the epistemic practices of science into the classrooms using argumentation. Consistent with these findings, dialogue in the classroom might help growth in students' epistemic understanding (Christodoulou & Osborne, 2014; Iordanou & Constantinou, 2015; Ryu & Sandoval, 2012)

2.9.4 Dialogic view of argumentation theory

In this study, dialogic argumentation serves as a pedagogy. Hence, it is important to discuss the dialogic dimensions of learning. Dialogic teaching reflects the socio-constructivists' view of learning. Sociocultural viewpoints considered learning as a process that occurs in the minds of the student as well as a dialogic process that occurs in a social sphere. Classroom talk is a core feature in any educational setting. Previous studies show that dialogic discourse in science classrooms supports argumentation (Duschl & Osborne, 2002). Empirical evidence, however, has found that the classroom talk is not very dialogic (Alexander, 2008; Bleicher, Tobin, & McRobbie, 2003). These studies have also revealed the wide gap between classroom practices and recommendations of learning theories. In many countries, particularly in low-income countries such as Ethiopia, classroom talk deviates further from the insights of contemporary learning theories, by failing to address the importance of social interaction. Monologue teaching makes students listen and use rote and recall in building their knowledge. Teachers implemented the IRE/F (Initiate–Response– Evaluate/ Feedback) technique to involve students in their lessons. Questioning in the IRE/F technique serves to make students active and align in the teachers' line of reasoning. Students' talking focuses on a mere effort to answer teacher's questions, rather than building scientific knowledge in didactic teaching (Lemke, 1990).

Dialogic teaching situates the classroom context to be supportive, communicative, reciprocal, and purposeful (Alexander, 2008). In this regard, Mortimer and Scott (2003) proposed two key dimensions that control the classroom talk. These are *who are talking* and *whose ideas are dominating the dialogue*. The first dimension categorizes classroom talk as interactive and non-interactive. In an interactive classroom, both teachers and students are talking, whereas in a non-interactive classroom, mostly teachers talk. The second dimension put classroom discourse as dialogic when the dialogue involves students' ideas, and authoritative, when the discourse relies on teacher's ideas only (Mortimer & Scott, 2003).

A look at teaching through the eyes of these two dimensions reveals the existence of various communicative approaches. Teaching might be non-interactive and authoritative, non-interactive and dialogic, interactive and authoritative, and interactive and dialogic (Mortimer & Scott, 2003). The existence of different communicative approaches in the classroom might promote or hinder student involvement in the discourse. Dialogic teaching is interactive and involves students' ideas. A shift toward dialogic teaching demands science teachers to have relevant pedagogical skills for argumentation. These skills include the ability to create and shape dialogic interaction as per the objectives of the lesson, the ability to deliver well-measured support, and the ability to guide the classroom discussion to the conclusion (Eshach, 2010; Mortimer & Machado, 2000; Mortimer & Scott, 2003).

The sociocultural viewpoint leads to the concept of 'learning as participation' in disciplinary practices. That is, learning is not seen as a process that takes place solely in the mind of the learner but as a dialogic process both at the interpersonal and intrapersonal levels (Kelly & Green, 2019). Science education researchers also consider the notion of dialogic discourse as a central idea in science learning and teaching. Duschl and Osborne (2002), for example, strongly argued in favor of dialogic discourse to support the use of argumentation in a science classroom.

With dialogic teaching students are guided to construct knowledge through the student-teacher talk without the teacher being over-authoritative (Lehesvuori et al., 2011). In sharp contrast to monologic pedagogy in which knowledge simply 'flows' from the teacher's mind to the students' mind, dialogic discourses entertain multiple ideas from students to enhance their reasoning skills and understanding. Classroom dialogue "explicitly seeks to make attention and engagement mandatory and to chain exchanges into a meaningful sequence" (Alexander, 2013, p. 104).

Dialogue creates a relaxed classroom environment where the teacher and the students deal with learning tasks together, sharing and respecting each other's ideas, and constructing knowledge jointly to achieve the learning goals through open discourse directed by the teacher or the students themselves. Allowing purposeful classroom talk offers students the opportunity to make scientific claims and construct arguments for and against the claims they make. It helps students gain a better conceptual understanding and epistemic knowledge of science. As Newton et al. (1999) pointed out "knowledge is co-constructed by the group as the group interaction enables the emergence of an understanding whose whole is more than the sum of the individual contributions" (p. 554).

A classroom argument between students becomes dialogic when multiple contrasting viewpoints about a scientific issue emerge. Dialogic or multi-voiced arguments involve different views being examined to reach an agreement on acceptable claims or courses of action (Driver et al., 2000). Basing classroom interactions on dialogic argumentation is becoming a viable pedagogical strategy not only for enhancing students' conceptual understanding of science but also for meeting epistemic, cognitive, and social goals of education (Osborne et al., 2004; Simon et al., 2006).

Disregard for the practice of dialogic argumentation means failure to empower students with higher-order cognitive skills, and hence limiting their ability to examine scientific claims critically and to interpret and decide on matters confronting them in their everyday lives. The emphasis on the dialogic approach cannot be stronger than what Duschl and Osborne (2002, p. 59) said: "Thus what aids cognitive development is dialogic argumentation, period."

2.10 Some implications

The theoretical underpinnings presented above have two implications to this study. The first implication is that dialogic argumentation should replicate domain-specific discourse. The second implication is science teaching should use scaffolding activities to structure classroom discourse. Domain-specific discourse, guided by structured activities, benefits students and teachers in many ways.

One, it enables them to develop and possess attributes of domain-specific epistemology (i.e. epistemic knowledge of science) about nature and acquisition of scientific knowledge (Buehl & Fives, 2016). Domain-specific discourse in dialogic argumentation provides an explanatory power to assist scientific inquiry and to develop scientific argumentation skills (Mason & Scirica, 2006). Furthermore, Braten, Muis, and Reznitskaya (2017) mentioned that domain-specific discourse shapes the epistemic belief of students, i.e. beliefs of students about the nature of knowledge and its ways of knowing in science.

Two, domain-specific epistemic discourses give students and teachers opportunities to gain access to the epistemic aspects of scientific practices (Longino, 2002). As

Stroupe (2015) put it science is a social practice and context-dependent in which its epistemic agency is construed and negotiated among its practitioners. Besides, domain-specific (epistemic) discourses justify students'/teachers' involvement in scientific practices through epistemic agency redistribution. Three, domain-specific (epistemic) discourses make science learning task-specific and organize activities (Schwarz, Passmore, & Reiser, 2017).

Hence, domain-specific aspect of dialogic argumentation offers students opportunities to engage in critical analysis of scientific knowledge claims and extend their epistemic knowledge of science. This study deploys domain-specific classroom discourse using dialogic argumentation and scaffolds the discourse using structured activities.

2.11 An analytical framework to elicit teachers' epistemic practices of science in argumentation lessons

This dissertation used the apt-AIR framework to analyze discursive interactions and to develop the coding schemes used to identify and characterize teachers' epistemic discourses (Barzilai & Chinn, 2018; Chinn & Rinehart, 2016; Chinn & Sandoval, 2018). These coding schemes are also used to understand the challenges of teachers' that employed argumentative instructions. The epistemic discourse illustrates the aims of the community of practices, the epistemic criteria used to construct, critique, and evaluate scientific knowledge claims, and reliable epistemic processes followed to produce scientific knowledge, which is an epistemic product (Barzilai & Chinn, 2018; Sinatra & Chinn, 2012). Thus, Barzilai & Chinn's apt-AIR framework provides a lens to understand argumentation as an epistemic practice of science in which a community of students/teachers construct, justify, and evaluate scientific knowledge claims and develop scientific explanations. In this regard, these communities of practitioners set their goals to critique and evaluate claims, deploy particular epistemic criteria, and follow reliable epistemic processes.

Though argumentation is depicted as an epistemic practice of science, only a few studies had investigated the epistemic discourse of teachers (please see Christodoulou and Osborne (2014) and Bauer et al. (2019) for details). Previous attempts that studied epistemic discourse in argumentative and other instructional approaches focused on thematic analysis based on the frequency of occurrences of epistemic features. This dissertation, in addition to these analysis techniques, used epistemic network analysis (ENA). A detailed explanation of ENA is presented in Section 3.6.2.3.1.

This dissertation applies the apt-AIR framework to understand six teachers' argumentative instructions concerning epistemic aims and ideals in science. Thus, this section provides detailed descriptions of various elements of the apt-AIR framework and the associated implications to learn science. First, I describe the epistemic aims of science. Then, we present the epistemic ideals and processes in unison. Martin (2019) claimed that there is a significant overlap between epistemic ideals and epistemic processes and distinguishing them is challenging, hence he recommended to embed notion of epistemic processes into the discussions of epistemic ideals. In argumentation discourse, three epistemic processes are important. Our discussion about epistemic ideals encompasses these three processes, namely: constructing scientific knowledge claims, justifying scientific knowledge claims, and evaluating scientific knowledge claims (Kelly, 2008). In any sense, I do not suggest that this is the only comprehensive list of all the criteria that students' need to learn to successfully engaged in any argumentative discourses. The next subsections focus on conceptualizing the epistemic aims and epistemic ideals (construction, justification, and evaluation) and connecting them to the notion of argumentations, which is naturally the epistemic practices of science. Furthermore, these subsections draw attention to how teachers, who implemented argumentative instructions, help the development of their students' epistemic knowledge of science.

2.11.1 Epistemic aims of scientific argumentation

Barzilai and Chinn (2018) defined epistemic aims as goals to generate knowledge and explanations. Science aims to construct epistemic products such as explanations and models (Berland & Reiser, 2009; Osborne, 2014; Sandoval, 2014). Science education studies confirmed that there is a difference between what students practice in school science and what scientists practice when they do science (Sandoval, 2005, 2014). According to situated cognition theory, understanding the epistemic practices of science is quite different from showing these epistemic practices of science in the science classroom. Sandoval (2005) argued that the epistemic knowledge of science is context-dependent. Furthermore, in many instances what students said about the nature of science and what was observed in students' scientific practices were different. Hence, Sandoval (2005) recommends promoting students' practical epistemology than their personal epistemology.

In line with Sandoval's recommendation, science teachers need to devise instructions that can provide opportunities for students to engage in scientific practices and hence can support students to conceptualize and grasp the epistemic aims of science. One instructional strategy, that is appropriate to achieve this purpose, would be argumentation. Argumentation involves knowledge building as well as knowledge evaluation. Engaging in argumentation enables students to achieve epistemic aims of science by constructing knowledge, which is itself an epistemic product. This epistemic practice "involves understanding of why particular aims are important, what they entail, what it takes to achieve them" (Barzilai & Chinn, 2018, p. 18). In other words, argumentation develops students' meta-cognitive knowledge. Meta-cognitive knowledge is one's knowledge, regulation, and awareness of their thinking and learning processes (Buehl & Fives, 2016; Lunn Brownlee, Ferguson, & Ryan, 2017). Meta-cognitive knowledge is a key to challenge new views against existing views consciously and to revise one's conceptions of reality when necessary. Besides, meta-cognitive knowledge enables students to understand to think about why they are doing what they are doing in science. Hence, teachers are advised to deliberately prompt discussions about the aims of the activity. When students know the epistemic goals of the activity or investigations they are engaged in, it helps them to recognize the epistemic aspects of the activity, which is related to the answers to what and why they are doing. Their answers to such questions develop their meta-cognitive knowledge, which is key to their understanding of the epistemic aims of science.

2.11.2 Epistemic ideals of scientific argumentation

Justifying claims and coordinating claims with evidence is the main component of argumentation. These components help acculturate students to the practices of science and to develop epistemic criteria to argue-to-learn or learn-to-argue. Duschl (2008b) mentioned that epistemic criteria guide the epistemic processes of construction and evaluation of scientific knowledge claims. Thus, successful engagements in scientific practices are hugely dependent on the development of epistemic criteria. There are three elements of epistemic foci in argumentation. These are constructing, justifying, and evaluating scientific knowledge claims (Kelly, 2008). To conceptualize the epistemic discourse of teachers and students and to portray the reasoning processes, these epistemic foci in argumentation are further discussed in this section.

2.11.2.1 Constructing Scientific Knowledge Claim

Concerning the construction of scientific knowledge, Osborne (2014) mentions the importance of questions to generate knowledge. Chin and Osborne (2008) have also shown that good questions play a paramount role in students' engagement in science, and of course their learning. To produce argumentative discourses, questions should be argumentative or contain competing views. To design such an argumentative question, teachers must carefully analyze phenomena and models. Epistemic features that reveal teachers' or students' attempt to construct scientific knowledge include: proposing a position or claim with some evidentiary support, asking to provide an argument to convince others about proposed ideas, prompting to provide definitions of concepts, requesting to describe an event, phenomenon or process, providing information or data, which can then be used as evidence for investigations or activities, and requesting to provide information/data/evidence for the topic under discussion and a representation of a process or concept.

In argumentation lessons, questions that trigger arguments, questions that request evidence or data to support claims are important. Argumentative prompts should request explanations and guide the discourse toward deducing relationships and patterns. Chin and Osborne (2008) said that 'how' and 'why' questions lead toward argumentative discourse because such questions intrinsically seek the development of explanations. Moreover, compared to 'yes' or 'no' questions, 'how' and 'why' questions usually require higher-order thinking skills.

Science teachers, whose aim is to enhance students' understanding of the nature of science should support their students to understand the epistemic process of knowledge building in science. Thus, teachers need to challenge students' claims to scientific knowledge, need to request evidence, need to prompt for definition, explanations, and descriptions of a physics concept or construct. In such classrooms, students delve into their learning because the argument-driven atmosphere of the classroom supports them to build knowledge, to pose questions, to explain their reasoning or explanations, and to justify or back up their ideas. When science teachers create such a classroom, students get an opportunity to participate in the epistemic practices of science and to understand the epistemic criteria to evaluate argumentation. This eventually enhances their epistemic knowledge of science.

2.11.2.2 Justifying Scientific Knowledge Claim

Knowledge is commonly defined as a justified belief. Justification in science is related to the belief held based on scientific reasoning. Mercan (2012) puts that "Justification for knowing covers a continuum from justifying claims through observation, by authority, or by intuition to personally evaluating and integrating the views of the experts." (p.1413). To justify a claim to knowledge, students must accustom themselves to the notion that using evidence is core to scientific understanding. Whenever students explain a certain concept or model or a certain phenomenon, their explanations and models convince others only when their claims are supported by evidence. In argumentation lessons, using evidence to justify claims is critical to persuading other students about your side of the argument. In the scientific community, scientific knowledge cannot be established and accepted without relevant evidence.

Many scholars in science education propose various instructional strategies to help the student to develop this fundamental epistemic process of science. One of the instructional practices widely acknowledged to support students' epistemic knowledge of science is argumentation. Argumentation supports students' attempts to construct and evaluate scientific knowledge by structuring their explanations and argumentations. Besides, prompt for justification in an argumentation lesson enable students to participate in both knowledge-creation and knowledge evaluation. In argumentation, a common epistemic enquiry (question) is 'how do you know or why you prefer one scientific criterion over another'. Such questions instigate students into arguments to defend or reason their perspectives. Hence, justification is fundamental to participate in the epistemic practices of science.

2.11.2.3 Evaluating Scientific Knowledge Claim

In simple terms, evaluation of scientific knowledge claims is related to scientific standards to conduct argumentative interactions; evaluation is a process necessary to analyze or interpret data or evidence. Science has its norms and standards to make sense of data and to use scientific reasoning. Many science education scholars have related this epistemic practice of science with identifying variables, deducing patterns, or relationships. For example, in argumentation, students might deduce patterns between variables that change together from the given data. However, students should give due emphasis to which data are important and what data are used as evidence and examine data for patterns and relationships and why the data are important. Also, along with systematic deduction of conclusion from data, students need to understand why supporting or refuting claims based on data are an important epistemic aspect of science. When students try to analyze and evaluate data, they will face epistemic and cognitive challenges. Overcoming these challenges enhances epistemic knowledge. However, studies show that students fail to infer claims from data, back their answers using scientific reasoning or data, and draw appropriate conclusions from data.

Science education researchers have revealed that students are usually able to identify linear relationships but failed to identify complex and nonlinear relationships (Kanari & Millar, 2004; Zimmerman, 2007). Therefore, the teacher in their argumentation lesson should support students to use data as evidence and to draw a conclusion to back their ideas. Argumentation instruction is a key approach to creating such opportunities for students. Activities might include manipulating data, understanding, explaining, and reading graphs or deducing patterns. Activities that support the reasoning using visual cases can also be used. The teacher should help students to identify variables, make connections, and see relationships in their epistemic talks.

To sum up, this dissertation used the above epistemic aims and ideals to understand how teachers' epistemic talk promotes epistemic knowledge of students. In science education, research that investigates and produces an understanding of the epistemic features of teacher talk to promote students' epistemic knowledge of science is an important need. In response to this call, one of the research questions of this dissertation is framed to address this demand.

2.12 Summary of chapter

The purpose of this chapter was to review the literature and bring an in-depth understanding into the context of dialogic argumentation and epistemology of science. The review started by situating the importance of epistemology to science learning. Then, it provided meanings to the epistemic knowledge of science and depicted various feature of epistemic knowledge of science. Science education scholars have sought to make dialogic argumentation a prominent pedagogical practice to generate and construct scientific knowledge, to improve conceptual and epistemic understanding, and to illustrate the epistemic practices of science.

The review of the literature informed, guided, and shaped the research purpose, the research design and methods, and the theoretical underpinning of this dissertation. The review also provided evidence to support the selection of dialogic argumentation instruction to promote students epistemic knowledge of science. Argumentation is fundamentally an epistemic practice of science. Hence, using dialogic argumentation enables students to engage in a genuine scientific practices of constructing, justifying, and evaluating scientific knowledge claims in a natural classroom setting. In addition, the review provided evidential support to use ASAC and ENA for assessing students argumentation tasks and teacher epistemic talks during whole class teaching respectively. Studies on dialogic argumentation and epistemology of science indicated that better argumentation relates with complex epistemic knowledge (Iordanou, Kendeo, & Beker, 2016).

Though dialogic argumentation has gained momentum and more attention in the current science education literature, most of the studies have focused on its uses to foster the students' conceptual understanding and ways to improve students' argumentation. To the best knowledge of the author of this dissertation, little work has been gone to examine the effect of dialogic argumentation on students' epistemic knowledge of science. This indicates a need for more research in science education in relating dialogic argumentation with epistemology of science. Therefore, this dissertation explored the impact of dialogic argumentation on grade 8 students' epistemic knowledge of science. The next chapter presents in-depth explanations of the research design and methods used to address the aims of this dissertation.

Chapter 3 Research Methodology

This study used data collected by the Transforming the Pedagogy of STEM Subjects (TPSS) Project. TPSS was a three-year research study project that attempted to transform the pedagogy of STEM subjects in Ethiopian colleges of teacher education and upper primary schools. It started by designing and implementing a strategy to transform the pedagogy of physics education from didactic to dialogic. The strategy consisted of training CTE lecturers and primary school science teachers in dialogic argumentation and observing them implementing the strategy in their physics classes in Phase 1 (CTE Phase) and repeating the same strategy in schools in Phase 2 (School Phase). The period for Phase I was from September 2015 to June 2016 and Phase II was from September 2016 to June 2017.

TPSS was supported by a joint funding from ESRC-DFID (Economic & Social Research Council - Department for International Development) and was jointly run by Durham University and Addis Ababa University. The author of this study is one of the five PhD students recruited by the TPSS Project to participate in implementing the intervention program during Phase 1, and work as research assistants during Phase 2.

This chapter presents the research design, methods, participants, and contexts, and discusses data collection, data analysis, and data interpretation procedures and techniques. Finally, issues related to the validity and reliability of both quantitative and qualitative data will be briefly summarized.

3.1 Pragmatism – philosophical rationale

In educational research, the worldview of the researcher plays a paramount role in selecting the research methodology and the subsequent methods of data collection and analysis.

Hence, this section aims to communicate the philosophical perspectives and underlying assumptions that are held and used to guide this study. In educational research, different worldviews or paradigms guide different research methodologies. Quantitative research draws on the positivist/post positivist paradigm, qualitative research maintains the constructivist worldview, and mixed methods research follows the pragmatist agenda. Worldviews or paradigms describe the philosophical assumptions that shape ones research approaches (Leavy, 2017; Mertens, 2010).

The philosophical perspective that guides this study is pragmatism, a worldview founded on the utility and efficacy of any given actions, situations, and consequences and not on whether the nature of reality is real or socially constructed. Pragmatism rejects the positivist/empiricist and phenomenologist/interpretivist divisions. According to Johnson and Onwuegbuzie (2004), pragmatism aims to find out research approaches that suit the purpose of the problem under investigation. Furthermore, pragmatism gives a practical solution between the two dominant approaches – the quantitative and qualitative methodologies.

I consider myself primarily as a pragmatist, with an inclination towards postpositivism. In a pragmatist worldview, discussions of the nature of reality as being either single or multiple are considered unworthy to pursue. Since the main purpose of any research endeavor in pragmatism is to find answers to the issues and interests embedded in the research questions, the researcher can adopt suitable philosophies from both quantitative and qualitative methodological foundations (Creswell & Guetterman, 2019).

In a positivist/postpositivists worldview, the researcher assumes a single objective reality that can be known using scientific methods. Positivism asserts that reality exists outside of human conceptions and is governed by unchanging natural laws; hence, reality can be uncovered using scientific methods. Positivists believe that ways of knowing in science are unbiased and the knowledge science produces is absolute. Also, postpositivists recognize facts as theory-laden and research as value-laden and maintain the idea that reality can only be known with probability. Postpositivists endorse the traditional scientific approach of research which is reductionist and deterministic in its nature and which requires accurate and precise data collection and analysis at multiple levels.

In a constructivist worldview, the researcher assumes multiple reality that is either individually or socially constructed. The reality, here, is subjective and continuously shaped by the individual's perceptions and experiences (Mertens, 2010). Constructivists contend that researchers are prone to bias in their studies due to subjective views and social interactions.

Pragmatism focuses on outcomes (action, situation and consequence of inquiry) not on antecedent conditions. No single philosophy fits this view. The methods, techniques or procedures selected are based mainly on suitability and workability (Johnson, Onwuegbuzie, & Turner, 2007; Mertens, 2010). The researcher with this paradigm uses multiple methods of data collection, both qualitative and quantitative, to address their research problem. This makes pragmatism the appropriate philosophical imperative for mixed methods research. Drawing from the firm stances of postpositivists and constructivists, the current study used both quantitative and qualitative methods to answer the research questions raised in Chapter 1 in a more pragmatic way.

Informed by pragmatism, I took the position that reality is single, but our knowledge of this reality is constructed by individual interpretation (Stake, 2005).

3.2 Research methodology: mixed methods

This section presents the justifications to the relevance, appropriateness, and suitability of the mixed methods experimental design employed in this study. We used a quasi-experimental mixed methods design by integrating the quantitative methods from the postpositivist worldview and the qualitative methods from the constructivist worldview. Epistemic Knowledge Test items were used to collect quantitative data about eighth-grade students' level of epistemic knowledge from both argumentation lesson groups and non-argumentation lesson groups before and after intervention. Video recorded observations of teachers' whole classroom teaching and audio recorded teacher interviews were used to collect qualitative data. Creswell and Clark (2018) defined mixed methods experimental (or intervention) design as "a mixed methods approach in which the researcher embeds the collection, analysis, and integration of both quantitative and qualitative data within an experimental quantitative research design" (p.139). To better understand the effect of dialogic argumentation on the development of students' epistemic knowledge, therefore, this study requires not only quantitative data from epistemic knowledge test scores but also qualitative data from observations of students' argumentation and teachers' epistemic talks.

In the past few decades, mixed methods research has emerged with its own unique and distinct philosophical and methodological assumptions (Creswell & Clark, 2018) that made it a third viable alternative for research. The combination of quantitative and qualitative methods provides high validity to the research reports by either corroborating results of different methods, elaborating results of one method, informing the other method, providing a comprehensive account of results reported by one method, and even contradicting results of one method

(Bryman, 2012; Creswell & Clark, 2018). These features made mixed methods relevant and appropriate for this study.

The study aimed to explore the extent to which dialogic argumentation, implemented in physics lessons, affects eighth-grade students' epistemic knowledge and to explain the challenges of physics teachers to promote the epistemic knowledge of their students during argumentative lessons. The first part of this study explored the impact of dialogic argumentation (independent variable) on the epistemic knowledge (dependent variable) of grade eight students and the *quality* of their dialogic argumentation (dependent variable). In this first part, an experimental research method is used to confirm whether there is an effect of the independent variable on dependent variables and to establish causal relationships. Research groups were randomly assigned in their natural settings, in our case, school classrooms. Specifically, a quasi-experimental design was implemented for the quantitative part of this study. In the second part of the study, it was attempted to explore teachers' challenges in promoting their students' epistemic knowledge during argumentation lessons. To explain the epistemic talks of physics teachers in argumentation lessons, a collective case study design was used. The combination of these two methods situated the dissertation within the pragmatic paradigm and justified the mixed methods experimental (or intervention) design.

Moreover, mixed methods experimental (or intervention) design was selected because the intent of the study was not only to know the influence of argumentation lessons on epistemic knowledge but also to gain a better understanding of how the treatment works. The mixed method experimental design adopted in this study is concurrent embedded design in which quantitative and qualitative data are collected simultaneously, but during analysis the less weighted strand is nested within the more weighted strand (Creswell & Clark, 2018). Here, the quantitative strand is given a dominant status over the qualitative one.

Data collection procedures integrated longitudinal study (quantitative) and collective case study (qualitative). The longitudinal study administered pre and post conceptual physics tests to both control and intervention groups to observe changes over the yearlong intervention, the use of argumentative instructions in our cases. Longitudinal data were also collected from the intervention and control groups using physics reasoning test and videotaped small group argumentative tasks before and after the intervention. The longitudinal research design was used to investigate the effect of the intervention on students' physics achievement and physics reasoning and to find causal relations between dependent and independent variables. The case study was adopted to gain a better understanding of the challenges and prospects to promote students' epistemic knowledge through dialogic argumentation. Research methodology scholars employed case study research design in both quantitative and qualitative designs. The quantitative case study design adopted the positivist/postpositivist approach to research, whereas the qualitative case study design enshrine the constructivist view of research (Stake, 2013; Yin & Campbell, 2018). In both strategies, case studies investigate the case in its natural settings within its real contexts and provide an in-depth description and profound insights of the undertaking case. This dissertation shared the constructivist views of research to investigate how teachers' argumentative instructions promote students' epistemic knowledge of science. Thus, analysis of teachers' epistemic talks during argumentation lessons provide comprehensive insights of teachers' epistemic practices. The collective case study was used to gain a better understanding of teachers' epistemic practices and the challenges they faced to promote students' epistemic knowledge through dialogic argumentation. Each case was videotaped during whole-class teaching and interviewed after the intervention.

To put it briefly, the study adopted a mixed method experimental design by integrating quantitative and qualitative approaches to science education research.

3.3 Participants

A convenience sampling, based on medium of instruction (English), access to transport, and willingness to participate in this study, was used to select twelve primary schools. Fourteen classrooms were randomly selected from these schools and assigned to intervention (N = 7) and control (N = 7) groups. A total of 479 grade eight students were involved in this study, among which 273 (57.0 %) were female, and 206 (43.0 %) were male. The intervention group is comprised of 239 (49.9%) students from seven primary schools, whereas the control group contained 240 (50.1%) grade eight students from the other seven primary schools.

3.4 Context of the study

This study was part of a broader research project called Transforming the Pedagogy of STEM Subjects (TPSS) that aimed to transform Ethiopian STEM pedagogy from didactic to dialogic through the use of classroom argumentative discourses. TPSS conducted the research in two phases. In Phase 1, CTE lecturers were trained to use dialogic teaching, changes to classroom teaching were observed and effects on senior-year pre-service teachers were measured. In Phase 2 the same procedures were replicated in the primary schools: teachers were trained to use dialogic teaching, changes to classroom teaching were observed and effects on school students were measured.

This researcher, having been trained in the first (CTE) phase, was part of the group of trainers in the second (school) phase. The training program, conducted in 2017/2018 under the guidance of TPSS, prepared Grade 7 and 8 physics teachers to use the dialogic argumentation pedagogy in their physics teaching. In the three-day training, elementary physics teachers analyzed the hitherto existing tradition of physics teaching and learning, and the physics curriculum of Ethiopia. Then, they were introduced about scientific reasoning and argumentation theory. They had also been trained on how to trigger argumentation in their classroom. TPSS used scaffolding activities that would make students reflect and discuss science ideas (see Appendix B). All the activities were carefully designed to guide students to develop particular ways of talking and expressing ideas and taking part in a structured cultural discourse thereby stimulating their learning. The cultural discourse in science is described as scientific argumentation. The scaffolding activities target common misconceptions known from science education research and draw on a wide range of reasoning styles typical to scientific argumentation. No change in either the schools' academic calendar or the content of the curriculum was made. The natural setting of the schools participated in this study was maintained.

3.4.1 Science Education in Primary Schools of Ethiopia

Ethiopia promotes science education starting from the early childhood when the child is curious and creative. Thus, science is offered as environmental science (integrated form) in the first cycle of primary school education (Grades 1 to 4). It is further offered as integrated science in Grades 5 and 6, and separately as biology, chemistry and physics in Grade 7 and 8 in the second cycle of primary school education. The purpose of STEM (science, technology, engineering, and mathematics) education is not only to address the demand of scientists, engineers, and doctors for the nation but also to bear scientifically literate citizens (MoE, 2009). Thus, it is important to bring quality in science and mathematics education. Students' textbooks, teacher's guide, syllabus, minimum learning competency guides, audio-video materials, and other teaching learning resources are taken to be important in improving the quality of science and mathematics education (FMoE, 2015).

However, successive measures of student achievements in Ethiopian primary schools showed that composite mean scores of Grade 4 and Grade 8 students fall below the National Learning Assessment (NLA) achievement standards (NEAEA, 2013). Grade 10 and Grade 12 national assessments also revealed composite mean scores below the 50% threshold for all subjects, physics being the subject with the lowest scores (FMoE, 2010; MoE & JICA, 2016; NAE, 2010). Students' poor performance in science, especially in physics, could be attributed to the emphasis on transferring the content of science, to the dominance of didactic teaching and the shortage or absence of relevant educational resources in science classrooms (Hagos & Tefera, 2015; Tadesse, 2015). Despite Ethiopia's success in boosting access of education for all citizens, a recent report warns that "the quality of education as indicated in successive national learning assessments and national examinations is still a critical challenge for the nation" (GPE, 2019, p. 5).

3.4.2 Overview of Grade 7 and 8 Physics Curriculum of Ethiopia

Physics is one of the natural science subjects given in grade 7 and 8 in Ethiopian schools. It was hoped that learning of physics enables students to understand the physical world, to carryout observations and experiments related with physical events and phenomena, and to enhance students' interest in nature. Moreover, the curriculum also recognizes the importance of physics to study other STEM subjects and students' understanding of the scientific practices. In learning physics, students gain scientific knowledge, skills, and attitudes which enable them realize that problems can be solved. That is, it develops self confidence in the part of learners not only to solve problems in physics but also other real-life problems.

The grade 7 physics textbook for Ethiopian schools consisted of 8 units and covers: Physics and Measurement, Motion, Force and Newton's laws of Motion, Work, Energy, & Power, Simple Machines, Temperature & Heat, Sound, and Electricity & Magnetism. The grade 8 physics textbook for Ethiopian schools consisted of 6 units and covers: Physics and Measurement, Motion in One Dimension, Pressure, Heat Energy, Electricity & Magnetism, and Light.

Ministry of Education forwarded the following advantage of studying physics. These are:

- helps to understand the working principles of many of our daily utensils and tools,
- helps to discover nature and how it works,
- helps to apply the knowledge of physics to other sciences and disciplines, and
- helps to solve practical and real-life problems.

Having such essential role to understand nature and natural phenomena, physics should be taught by doing science and practical activities rather than telling facts to students. The STEM curriculum clearly indicated that learner-centered approaches and the constructivist epistemology to be followed in the teaching-learning process. In this approach, physics as a process and scientific practice is advocated rather than physics as a product or body of established knowledge. The core idea here is students are little scientists and need to be engaged in knowledge building processes.

3.4.3 Challenges facing Science Education in Ethiopia

Ethiopia considers STEM education as a venue to national prosperity. Thus, STEM teachers are responsible to equip the next generation of trained professionals with basic scientific skills in their school science lessons. The daunting challenge that still persists in school science in Ethiopia is the below average (50 %) scores of students in national assessment tests. MoE & JICA (2016) identified some of the major challenges facing science education in Ethiopia. The major challenges include:

(1) The existing science education curriculum and pedagogy ignored local contexts and devalued indigenous knowledge systems. The adopted science, which is deeply rooted in the Western culture, alienated, delocalized and decontextualized the application of science and its ways of knowing in the society.

(2) In Ethiopia, science education emphasized on content transmission and the science pedagogy focused on rote memorization and recall of facts. Teaching of STEM subjects is dominated by explanations and prescriptive in nature. The science pedagogy is devoid of any innovative approaches that promote scientific thinking and reasoning.

(3) Science textbooks are the sole source of knowledge to both teachers and students, particularly, in many government and rural schools. The textbooks are loaded with content and facts, packed by questions that probe lower-order thinking, and encouraged

domination of teachers talk in the classroom. Science textbooks discourage innovation and creativity of students. As a consequence, the science teaching, which was guided by these textbooks, did not promote innovation and utilization of locally available materials with the content of science.

(4) STEM subjects are not structured in an integrated manner. Technology is not also integrated with science subjects in ways that enable the capacity of children to utilize foreign technologies.

(5) In Africa, science teachers are the sole source of knowledge in many schools. However, science teacher training and their professional developments afterwards depicted the poor status of science teachers' pedagogical content knowledge and content knowledge of STEM subjects.

In a globalized and knowledge-based economy of the 21st century, these challenges require due attention of the stakeholders of Ethiopian STEM education. One way to address these challenges is pedagogical reform. Such attempts should be research-based efforts to transform the pedagogy from the dominant didactic teaching to dialogic argumentation. Dialogic argumentation has improved students' scientific reasoning and has enabled students to comprehend science as a way of knowing and to identify the epistemic features of science (Berland & Hammer, 2012a; Lubben, Sadeck, Scholtz, & Braund, 2010). Here, the implication is that without science pedagogy that spurs student epistemic discourses in science classrooms, students are unlikely to build their own scientific knowledge and become scientifically literate (Simon et al., 2006).

3.5 The intervention

The intervention for the middle school physics teachers began with visiting of local education offers and school directors and communicating about the objectives of TPSS and research plans. During this visit, we obtained permission from the local education office to conduct the study in the selected middle schools. We, then, trained the selected middle schools physics teachers.

Talking Physics are teaching materials used in the training. *Talking Physics* have three booklets. The first booklet, *Talking Physics In-Service Training,* presents dialogic argumentation as ways of moving physics teaching away from overreliance on traditional teacher-led didactic teaching, which makes students passive and limits their reasoning, towards more use of student-oriented dialogic teaching. In TPSS, students engaged in scientific argumentation and learnt to use theoretical and empirical evidence critically to evaluate the ideas. During the training, physics teachers had analyzed the nature of physics teaching, student learning, and physics curriculum of Ethiopia with particular emphasis to the upper primary physics. Scientific reasoning, argumentation theory, and ways to stimulate dialogic argumentation in the classroom were the major contents of the training too. The second booklet, *Talking Physics Student Activities,* contains teaching activities. The training introduced the fifty-two teaching activities. Physics teachers did all these activities using the pedagogy that we were encouraged them to use in their physics teaching. The third booklet, *Talking Physics Teacher Guide,* gives advice to physics teachers on how to change their teaching. This booklet helps teachers to work stepwise towards establishing dialogic argumentation in their classroom teaching. Thus, suggestions related to time and group organization as well as strategies of implementation of dialogic argumentation into their teaching were dealt in this booklet. In addition, a correct answer is suggested for each activity.

In the training, we discussed the underpinning ideas of all the fifty-two activities, ways of utilizing these activities to Grade 7 and 8 physics lessons, and the importance of student talk in physics teaching. The training was organized and delivered by four teacher education colleges. The training took three days. At the end of the training, *Talking Physics Student Activities* booklets were distributed according to the number of students in the intervention classroom. Physics education researchers at Addis Ababa University and Durham University prepared the Talking Physics booklets. Teachers used activities either after introducing a topic as a way to assess scientific knowledge or before as a way to bring out students' scientific understanding. Teachers had also explained the task and told students what they should do and how much time allocated. In addition, teachers visited groups and asked questions to stimulate discussion. Teachers helped students talk about their ideas rather than just gave the right answer. Finally, teachers summarized group discussions in whole class discussions. Whole class discussion was critical to show why wrong answers are wrong and to give the correct answers.

3.6 Methods

3.6.1 Quantitative methods

3.6.1.1 Quantitative research design

A quasi-experimental design was used to compare the effects of argumentative instruction and traditional instruction on students' epistemic knowledge. The intervention group receives a pre-test, taught using argumentative instructions, and a post-test. The control group receives only the pre-test and post-test. Thus, the quasi-experimental design enables to make claims about the effect of dialogic argumentation on students' epistemic knowledge by comparing the test scores of the control and intervention groups via parametric statistical procedures.

It is worth noting here that although each school was randomly assigned to a control or intervention group, intact physics sections in each of the intervention groups' school have received the treatment. The random selection of schools in a quasi-experiment might raise a validity issue. This will be addressed under the section *Reliability and Validity Issues*.

3.6.1.2 Quantitative data collection

3.6.1.2.1 Students' Epistemic Knowledge of Science (DV1)

To assess the epistemic knowledge of students, quantitative data were collected using a physics reasoning test with twenty-six items and a maximum possible score of thirty. The test format comprised multiple-choice and short answer items. The test was well-crafted to evaluate students' conceptual, procedural, and epistemic knowledge.

Ten items from the reasoning test (see Appendix A) had been pinpointed as items that measure the epistemic entity of scientific knowledge based on features identified by (Kind & Osborne, 2017; OECD, 2013; Osborne et al., 2018). These items were identified by the researcher and three recruited PhD candidates doing science education research at Addis Ababa University. The PhD candidates took the courses *Scientific Reasoning and Argumentation in Science Education* and *Assessment in Physics Education* in their doctoral study and hence they were considered appropriate to identify items that measure epistemic knowledge. We asked them to categorize each of the twenty-six items in the physics reasoning test as either content, procedural, and epistemic knowledge or the combination of these scientific knowledge. Computing the inter-rater reliability yielded a Cohen's kappa of .833, indicating good to excellent agreement between the raters in identifying the items associated with epistemic knowledge.

An item was assigned to a specific knowledge group when the item is categorized in that group by three or more raters. In case of a tie between the raters on a particular item, discussions were held with the researcher to make a decision. In this way, 23items were initially categorized as measures of content, procedural, and epistemic knowledge based on the three or more raters' agreement while the remaining three items needed further discussions. Two of the three items were assigned in the epistemic knowledge category while the remaining one item were categorized as procedural knowledge. The physics reasoning test now contained three content knowledge, twelve procedural knowledge, and ten epistemic knowledge items. In this study, we used these ten epistemic knowledge items (EKIs) with a maximum possible score of fifteen points. The ten EKIs are presented in Appendix A.

The selected EKIs assess the epistemic construct of deduction as a mode of argument in building scientific knowledge, the knowledge required for experimental evaluation in science, and the role of scientific theories and ideas in model-based scientific reasoning. The EKIs aim at evaluating how students know what they know in science. All the items are relevant to the upper primary school physics curriculum of Ethiopia. To capture the notion of epistemic knowledge, we followed the conception of epistemic knowledge as outlined in (Kind & Osborne, 2017; OECD, 2013; Osborne et al., 2018). Thus, items of epistemic knowledge assess students' reasoning about how they know that a particular physics concept or phenomenon is right or wrong, their understanding of how data is represented and used to justify claims and conclusions using evidence scientifically, and their knowledge about making inferences.

At two time points in the TPSS intervention year, data were collected using pre and post-tests on physics reasoning and video records of small group discussion tasks. The physics reasoning test instruments were developed to assess students' physics reasoning that are comprised of content, procedural, and epistemic knowledge. The quantitative data used included the pre and post scores of the selected ten EKIs from physics reasoning tests to assess students' epistemic knowledge.

3.6.1.2.2 Quality of dialogic argumentation (DV2)

Many argumentation frameworks have been developed to analyze episodes of argumentation. ASAC was developed by Sampson et al. (2012). Sampson et al.'s main reason for the development of ASAC was to provide a tool "that can be used to assess the nature and quality of argumentation that occurs between students inside the science classroom" (p. 236). ASAC, composed of nineteen items, situated argumentation as a process and targeted conceptual and cognitive, epistemic, and social aspects of argumentation. The *conceptual and cognitive* aspects of argumentation (seven items) assess students' level of scientific argumentation, utilization of alternative claims, detection of inconsistency and amendment of claims or explanations, ability to challenge and negotiate presented ideas, and use of different lines of reasoning. The *epistemic* aspects of argumentation (seven items) evaluate how students use evidence, theories, and models, how students evaluate evidence, and how students use scientific languages in their discussion. The *socia*l aspects of argumentation (five items) assess students' reflection of what they know and how they know, respect for ideas, willingness to contribute, and balanced engagement of group members.

The ASAC observation protocol is a Likert scale that ranges from 0 (Not at all) to 3 (Often) with Items 6 and 8 to be reverse coded before analysis. Sampson and colleagues presented an elaborated discussion about the theoretical underpinnings of ASAC and the methodological approaches they followed to confirm the construct validity, criterion validity, and reliability of the ASAC tool (Sampson et al., 2012). This study used ASAC because comparison of this tool and the TAP framework indicated a strong correlation between the two (ibid), hence suggesting ASAC as a reliable tool to assess the quality of students' argumentation.

To measure the quality of students' dialogic argumentation, we took twenty-eight video records of student group tasks from fourteen primary school classrooms. Discussion groups of 3-6 students were randomly selected. The discussion tasks required students to use scientific reasoning and argumentation. Overall, fourteen video records were gathered for each of the activities from the intervention and the control groups. Students were also encouraged to use the language that eases communication among themselves. All these video recordings were used in this study.

3.6.1.3 Quantitative data analysis

3.6.1.3.1 Students' Epistemic Knowledge of Science (DV1)

To determine the effect of dialogic argumentation on students' epistemic knowledge of science, analyses of the physics reasoning pre and post-tests were carried out using the two-sample t-test (to make comparisons between intervention and control groups) and the repeated t-test (to make comparisons between pre-test and post-test scores within each group).

Only students who took both pre-test and post-test were included in the analysis. Screening participants accordingly produced a valid sample size of 239 students for the intervention group and 240 students for the control group. An independent sample t-test was selected to compare the mean scores between control and intervention groups. We found that pre-test and post-test scores for both control and intervention groups did not meet the assumption for normality required to use the *t*-test. Hence, we resorted to the Mann-Whitney U test to compare students' pre-test and post-test mean scores between control and intervention groups (between-subject comparison). We also computed the gains and normalized gains of each group between their pre-test and post-test scores (within-subject comparison). MS Excel and SPSS were used to analyze the data and produce visual outputs.

3.6.1.3.2 Quality of Dialogic Argumentation (DV2)

To assess the quality of students' dialogic argumentation, we recorded 28 small group discussions: fourteen videos before and fourteen after intervention. The video records were collected from seven intervention and seven control groups. This study used the ASAC observation protocol Sampson et al. (2012) to analyze students' dialogic argumentation. ASAC considers conceptual, epistemic, and social aspects of argumentation as the fundamental constructs in any argumentative discourse and therefore provides researchers with a means to measure essential elements of argumentation such as its nature and quality and to analyze students' argumentation comprehensively.

The ASAC tool contains nineteen items in which seven items examine conceptual aspects of argumentation, seven items address the epistemic aspects of argumentation, and the remaining five items focus on the social aspect of argumentation. Each item is to be rated on a scale that ranges from 0 (Not at all) to 3 (Often) with the exception of Items 6 and 8 which must be reverse rated, i.e., from 3 (Not at all) to 0 (Often). In this study, the ASAC observation protocol was used to evaluate and compare the progress of grade 8 students, across all aspects of argumentation, following the yearlong instructional intervention they received. To ensure inter-rater reliability of ASAC for this study, the first author and a second-rater, who was a physics teacher educator and a PhD candidate in physics education at Addis Ababa University, scored four randomly chosen episodes of argumentative group discussions of students. The computed Cohen's kappa (κ =.775) confirmed that ASAC has acceptable inter-rater reliability.

Twenty-eight recorded argumentative student tasks were rated using the ASAC observation protocol tool. The mean scores of *conceptual and cognitive* aspects, *epistemic aspects*, and *social* aspects of argumentation, and the overall ASAC mean scores of each school were computed and comparisons were made between intervention and control groups. Due to the small group sizes, Kruskal-Wallis tests were conducted to compare the quality of argumentation between intervention groups and control groups for the pre-intervention and post-intervention videos. A Mann-Whitney test was run to determine if there were substantial differences in the quality of dialogic argumentation and various aspects of argumentation generated by intervention and control groups as a result of their engagement in argumentative and non-argumentative instructions respectively.

3.6.1.3.3 Correlation between Epistemic Knowledge and Dialogic Argumentation

The relationship between epistemic knowledge of students, as measured by the mean scores on epistemic knowledge items, and the quality of students' dialogic argumentation, as measured by ASAC observation protocol, was determined by Pearson's correlation statistic. The correlation was done for fourteen school cases between the mean scores of epistemic knowledge items and the mean scores of ASAC.

3.6.1.4 Reliability and validity issues

A strong validity issue in this study may arise from the random selection of schools and their random assignment into intervention and control groups. This is a legitimate concern as it might cause some confounding study findings, which are undesirable in education research. To avoid such results, owing to variables beyond the researcher's control, this study had conducted comparisons between the control and intervention groups on their level of epistemic knowledge using their pre-test scores.

3.6.2 Qualitative methods

3.6.2.1 Qualitative research design

Qualitatively, this study attempted to examine challenges and prospects to promote epistemic knowledge of students in a dialogic argumentation physics classroom. This dissertation also examine how the teacher implemented dialogic argumentation pedagogy in the classroom to scaffold and support growth of epistemic knowledge. This requires an understanding of how teachers support their students to learn science as epistemic practice in classrooms Lederman and Gess-Newsome (1999) recommend that a better understanding of the teacher's practice is achieved through a closer examination of the knowledge base of physics teachers. This is critical to understand the epistemic practices of physics teachers and also to know school teachers' status and their professional needs so that proper assistance can be arranged. The selection of appropriate and suitable types of case study design should be guided by the purpose of the research question sought to answer (Baxter & Jack, 2008). Using a collective case study and cross-case analysis, the challenges and prospects to promote epistemic knowledge in upper primary schools were studied by interviewing and observing the classes of six physics teachers from the intervention group. The audio-video records of teacher interviews and classroom observations at the end of the intervention year were qualitatively analyzed. All the six schools were government schools: two schools from northern region, three schools from central region, and one school from southern region. (See Table 3.1).

Table 3.1 Characteristics of the six (TPSS) case studies

Case Study	Teachers	Class Size	Recorded Science Topic
CS-1	Mr. Landabo	42	Transformers
CS-2	Mr. Dawud	62	Summary of light
CS-3	Mr. Aregawi	60	Image formation by curved mirrors
CS-4	Mr. Teshome	31	Reflection of light
CS-5	Mr. Megerissa	60	Motion in one dimension
CS-6	Mrs. Ethiopia	48	Light

Each case study was first explored as an independent cases, then collective cases study design was deployed for a cross-case analysis purpose (Stake, 2013). There are a number of similarities and differences between collective study and multiple-case study research designs (Yin & Campbell, 2018). The similarity was both research designs enable to examine similarities and differences within and between several case studies. The differences mainly originated from the focus of emphasis, purpose of analysis, and level of relationship between selected cases. Multiple-case study design focuses on a single case taken from a group of similar cases, with the intention of replications (Yin, 2014). In this dissertation, cases were selected not to replicate but to examine a particular case in details and to establish assertions during the cross-case analysis. A collective case study is suitable to address part of this study due to many reasons. First, the selected teachers participated in the TPSS project, trained to use argumentative instructions in their lessons, and a *Talking Physics* module was given to their students to support their argumentative instructions. Second, the intervention effectively disturbs the natural setting. Third, TPSS was responsible for the implementation and assessment of the research project. These situations made ethnography and action research unsuitable to this study. A collective case study is rather right for this particular investigation to produce a thick description of teachers' epistemic practice of science (Stake, 2005). A case in this study is the individual teacher who used argumentative instruction in a physics classroom. Classroom talks were used to explore multiple cases' epistemic practices of science with their students. Besides, this study explores case similarity and differences in argumentative instruction.

In educational research, case studies are appropriate to investigate events that are unfolding in the classroom. Such investigations commonly focused on the teaching and learning process, not on its outcomes. Furthermore, case studies could be used to focus on particular instances of a certain investigation as a part of wide research projects such as TPSS. Stake (2005) emphasized that a case study approach is appropriate to "particularization" and a full description of the case. Usually, the "particularization" of the case study reveals information that cannot be obtained from the wider research. Hence, this study focused on only a small part of the intervention that took place under the TPSS project.

The collective case study used in this study investigated six grade 8 physics teachers' epistemic practices of science in their argumentative instructions. The small sample provides an opportunity to use the in-depth qualitative account of teachers' epistemic practices. In physics education, little is known about the epistemic practices and epistemic challenges of teachers who use argumentation in their instructions. So, this study conducted a detailed investigation of the epistemic discourse of the six physics teachers to understand and characterize their challenges and prospects to promote epistemic knowledge of students. Each case contains a grade 8 physics teacher bounded their utilization of argumentative instructions in their lesson.

3.6.2.2 Qualitative data collection

Videotaped whole class teachings were collected from six upper primary schools. Two video cameras were used to capture the teacher talk and overall classroom interactions. One camera, mounted at the back of the class, followed and recorded the teacher talk with a flymicrophone attached to the teacher. Another wide-angle camera, mounted at the front of the class, was used to record students' activities. Six lessons were recorded in this way, after which the teachers were invited, with consent, for interviews which were audio recorded. All six video and audio records were taken at the end of the intervention year. The interview provided information about teachers' experience in a dialogic classroom that informed the qualitative analysis of teacher epistemic practice of science.

3.6.2.3 Qualitative data analysis

Since the classroom language in Ethiopia combines Amharic and English, all data from classroom teaching and school teacher interviews were translated into and transcribed in English. The data representing epistemic practices of teachers emerged from thematic analysis of classroom teaching and teacher interviews.

We used only classroom videos of six teachers from among seven grade 8 physics teachers who implemented argumentative instructions. One of the teachers was not video recorded due to technical problems. Of all the argumentative instructional practices captured by the video cameras, particular attention is given to teachers' epistemic practices of science that either promote or hinder students' epistemic knowledge. The post-intervention videos were used to identify teachers' challenges and prospects in their argumentative instruction.

Each of the lessons recorded covered various topics in grade 8 physics curriculum. Within each of the lessons, episodes that reflect epistemic practices were carefully selected to show how teachers conduct and facilitate argumentation to construct, justify, and evaluate scientific knowledge claims. In these episodes, teachers engaged students in various epistemic activities (such as construction, justification, and evaluation of claims) intending to enhance the students' epistemic knowledge. The epistemic knowledge of students should meet the scientific community's criteria to produce knowledge (such as construction, justification, and evaluation). Hence, these episodes provided many opportunities to understand the epistemic aims and ideals of teachers and to identify teachers' instructional challenges and prospects to support students' knowledge-building process.

3.6.2.3.1 Epistemic network analysis theory

Epistemic network analysis (ENA) is a quantitative ethnographic technique for modeling the structure of connections in data. ENA assumes: (1) that it is possible to identify systematically a set of meaningful features in the data (codes); (2) that the data has local structures (conversations); and (3) that an important feature of the data is the way that codes are connected within conversations (Shaffer, 2017; Shaffer, Collier, & Ruis, 2016; Shaffer & Ruis, 2017). For example, if a team is working on a design project, they talk about important codes such as production processes, design specifications, budget, and so on. They have a series of conversations at design meetings, and a key part of understanding their design process is modeling how they think about the relationships between production processes, specifications, budget, and other key parts of their design work (Arastoopour, Shaffer, Swiecki, Ruis, & Chesler, 2016). In an interview transcript, each answer to a question might be a unique conversation (Eagan & Hamilton, 2018), or in a collection of documents, each document or section of a document (Shaffer & Ruis, 2017). ENA models the connections between codes by quantifying the co-occurrence of codes within conversations, producing a weighted network of co-occurrences, along with associated visualizations for each unit of analysis in the data. Critically, ENA analyzes all of the networks simultaneously, resulting in a set of networks that can be compared both visually and statistically.

ENA was originally developed to model theories of cognition, discourse, and culture that argue that the connections people make in discourse are a critical level of analysis (Shaffer et al., 2009). diSessa (1988), for example, characterized learning as a process by which isolated elements of experiential knowledge are connected through theoretical frameworks to develop both new knowledge and deep, systematic understanding. Similarly, Linn, Eylon, and Davis (2013) argue that learners develop STEM expertise by constructing a knowledge web: a repertoire of ideas and the connections among them. (Shaffer, 2006a, 2006b, 2012) characterized learning as the development of an epistemic frame: a pattern of connections among knowledge, skills, habits of mind, and other cognitive elements that characterize communities of practice (Hutchins, 1995; Shaffer, 2003), or groups of people who share similar ways of framing, investigating, and solving complex problems.

While ENA was originally designed to address challenges in learning analytics, the method is not limited to analyses of learning data. For example, ENA has been used to analyze (a) surgery trainees' operative performance during a simulated procedure; (b) gaze coordination during collaborative work and (c) communication among health care teams (Sullivan et al., 2018; Wooldridge, Carayon, Shaffer, & Eagan, 2018). The key assumption of the method is that the structure of connections in the data is most important in the analysis. In other words, ENA is an appropriate technique for any context in which the structure of connections is meaningful. ENA is thus a useful technique for modeling the epistemic features of argumentative discourses because it can model the relationships among its various features such as constructing, justifying, and evaluating scientific knowledge claims as they occur within this dissertation.

3.6.2.3.2 Analysis for Epistemic Practices of Teachers in Argumentative Instructions

Epistemic operations are discursive and serve to build and develop scientific knowledge (Christodoulou & Osborne, 2014). Epistemic operations are the venue to engage in epistemic practices, which in turn play a paramount role to generate knowledge. In dialogic argumentation instruction, students and teachers deploy various discursive actions to forward claims, to evaluate evidence, and to contrast conflicting views. Understanding the epistemic practices of teachers when engaged in discursive interactions require to elicit the functions of talks and texts using epistemic operations (Jimenez-Aleixandre et al., 2000; Pontecorvo & Girardet, 1993). However, different scholars ascribe different entities to the construct of epistemic operation. In line with the goals of this study, we summarize the analytical frameworks designed to study the epistemic aspects of reasoning in argumentative instruction.

The Jimenez-Aleixandre et al. (2000) framework draws on the work of Pontecorvo and Girardet (1993) and Sober (1993) to identify epistemic operations. The identified epistemic operations include: *induction* (looking for patterns or regularities), *deduction* (identifying instances of rules and laws), *causality* (looking for mechanisms, cause-effect relation, predictions), *definition* (stating the meaning of a concept), *classification* (grouping objects or organisms according to criteria), *appeal* (to analogies, exemplar/instances, attribute or authority as a means of explanation), *consistency* (with other knowledge, experience, metaphysical factors and commitment to consistency), and *plausibility* (predication or evaluation of own or others' knowledge).

Later, in light of new research findings and recommendations (e.g., ; Jimenez-Aleixandre, Mortimer, Silva, and Diaz (2008); Sandoval (2005); Kelly (2008)) important elements of the construct of epistemic operation was refined to evaluate epistemic practices in science classrooms. The revised epistemic operations include: *describing*, *defining*, *explaining*, *constructing arguments*, *classifying*, *generalizing*, *appealing to authority*, *calculating*, and *constructing*.

Jimenez-Aleixandre et al. (2000) and Jimenez-Aleixandre et al. (2008) frameworks are used to assess students' construction and evaluation of arguments within small group discussions and whole-class teaching. Both frameworks can be applied to assess how students justify their claims and to reveal the epistemic nature of students' reasoning to some extent. The Duschl (2008a) framework argued against the adequacies of the TAP model to assess argumentation and devised a novel approach to apply Walton's Argumentation Scheme for the study of classroom discourse. Walton grounded dialogic argumentation on presumptions and anchored his twenty-five argumentation schemes on how presumptions associate premises with conclusions. Duschl (2008a) retuned these twenty-five categories into nine and then into four categories on the ground that coding students' arguments using the revised nine categories was confirmed to be complicated. The final four epistemic operations include *request for information*, *expert opinion*, *inference*, and *analogy*. This framework is suitable whenever students' small group discussion is guided (scaffold) by structured activities, and the aim is to reach on an agreed-upon solution to a problem. Goals of dialogic argumentation, theoretical assumptions, and domain-specific norms should be taken into consideration when using this framework.

Christodoulou and Osborne (2014) reviewed previous studies about the epistemic operation construct and found that most of the studies did not address how different epistemic operations promoted other epistemic practices. Hence, Christodoulou and Osborne (2014) developed a comprehensive list of epistemic operations and then categorized them as teacher-performed and teacher-prompted. Teacher-performed is simple discursive actions used by the teacher to explain or describe an event whereas teacher-prompted is discursive actions that aimed to instigate students thinking and engage them in the discourse about the event being discussed. Moreover, each of the identified epistemic operations is further categorized based on their significance to construct, justify, and evaluate scientific knowledge claims. The epistemic operations of Christodoulou and Osborne (2014) and their respective descriptions are presented in Table 3.2.

Table 3.2 Epistemic operations and their description (Christodoulou & Osborne, 2014)

Epistemic Operations	Description of the Epistemic Operation
analogies & metaphors	use an analogy or a metaphor to help students understand a concept
Argument	proposing a claim with some evidentiary support
prompts for argument	asking students to provide an argument to convince other of their ideas
Definition	defines a term/concept
prompts for definition	prompting to provide definitions of concepts
Description	providing a descriptive account of an event or phenomenon
prompts for description	requests to describe an event, phenomenon or process
provides evidence	provides information or data as evidence for the investigations
prompts for evidence	requesting to provide information/data/evidence for the topic under discussion
exemplification	provides examples to help understanding of a concept or phenomenon under discussion
Explanation	provides a detailed account of a scientific phenomenon in a way that the link between the concepts discussed is made explicit
generalization	provides a summarized version of ones' talk
modelling	discusses ways of representing a concept, process or idea
prompts for modelling	requests to provide a representation of a process or concept
prediction	predicting or hypothesizing what might happen in a scenario under discussion
prompts for prediction	requests students to hypothesize/guess what would happen in a given situation
justification	providing a justification for or against his/her or the students actions or views
prompts for justification	prompting students to justify their actions or opinions, usually using the question 'why'
compare & contrast	compares and contrasts the information provided by him or the students
prompts for comparison	prompting students to compare and contrast information, events or processes
counter-argument	provides a counter-claim or argument to what the students have presented or when the teacher is playing devil's advocate with the students
prompts for counter-argument	encourages students to consider alternative positions to their own or those discussed in the lesson
evaluation	evaluating a process, idea or students' talk
prompts for evaluation	encourages students to make an evaluative judgment about a process, their work or others' ideas)

Fischer et al. (2014) reviewed many studies in scientific reasoning and argumentation (SRA) and argued that the motive of participants to engage in SRA is in line with three distinct epistemic modes of SRA: to advance and build theory, to apply SRA to solve contextual problems and artifact-centered SRA. These three epistemic modes, in turn, require eight distinct epistemic activities, which include *problem identification* (built problem representation), *questioning* (identify one or more questions), *hypothesis generation* (develop possible answers to the raised questions), *construction and redesign of an artifact, evidence generation, evidence evaluation, drawing conclusions, and communicating and scrutinizing.*

Several previous studies attempted to outline the constituent of epistemic operation construct and provided a comprehensive list of epistemic operations and their respective descriptions. However, these studies did not address *epistemic aims of the epistemic practices*, which defines the goals and the strategies of the scientific or the classroom community to construct knowledge. In addition, these studies focused on counting the frequencies of the epistemic operations rather than striving to study the interconnections between the various dimensions of epistemic knowledge of science. This dissertation used the apt-AIR framework to develop the coding schemes used to identify and characterize students' feature of epistemic knowledge and the Epistemic Network Analysis (ENA) to frame the analysis of epistemic discursive interactions (Barzilai & Chinn, 2018; Chinn, Duncan, Hung, & Rinehart, 2016; Shaffer, 2018). The coding schemes used to understand the challenge of teachers that implemented argumentative instructions were also used in this framework. The apt-AIR framework is appropriate for this study because it frames the epistemic discourse about the goals of the community of practitioners and how they attempt to achieve these goals. Besides, this framework illustrates epistemic discourse in terms of epistemic Aims, epistemic Ideals, and epistemically Reliable processes (AIR). The epistemic discourse illustrates the aims of the community of practice, the epistemic criteria used to construct, critique and evaluate scientific knowledge claims, and the reliable epistemic processes followed to produce scientific knowledge, which is an epistemic product (Barzilai & Chinn, 2018; Chinn et al., 2016). Thus, Barzilai & Chinn's (2018) apt-AIR framework provides a lens to understand argumentation as an epistemic practice of science in which a community of students/teachers construct, justify, and evaluate scientific knowledge claims and develop scientific explanations. In this regard, the community of students set their goals to critique and evaluate claims, deploy particular epistemic criteria to construct, justify, and evaluate, and follow reliable epistemic processes.

Though argumentation is depicted as an epistemic practice of science, only few studies had investigated the epistemic discourse of teachers (e.g., Bauer et al. (2019); Christodoulou and Osborne (2014); Martin (2019)). Previous attempts that studied epistemic discourse in argumentative and other instructional approaches focused on thematic analysis based on the frequency of occurrences of epistemic features. This study, in addition to these analysis techniques, used ENA. A detailed explanation of ENA was presented in Section 2.12.

This dissertation applied the apt-AIR framework to understand in-depth six recorded teachers' argumentative instructions with regard to the epistemic aims and ideals in science. First, discussions about the epistemic aims of science will be presented. Then, the three epistemic processes that describe the epistemic ideals and processes will be discussed. Martin (2019) claimed that there is a significant overlap between epistemic ideals and epistemic processes and that distinguishing them is challenging. He recommended to embed the constituent elements of epistemic processes into the discussions of epistemic ideals. In argumentation discourse, three epistemic processes are essential. Our discussion about epistemic ideals focuses on these three processes, namely: constructing scientific knowledge claims, justifying scientific knowledge claims, and evaluating scientific knowledge claims (Kelly, 2008). In any sense, we did not believe that constructing, justifying, and evaluating knowledge claims are the only constructs involved in one's argumentative discourse. Following the mixed methods approach, the whole-class teaching videos were analyzed to gain a deeper insight into how argumentative instructions help students' epistemic knowledge of science. The researcher transcribed the videos and qualitatively coded the teacher's discourse using thematic coding with due attention given to the inter-reliability of codes which will be described in detail below. Then, the researcher examined how teachers made a connection between epistemic aims and epistemic ideals and explained the epistemic practices observed using post-intervention videos.

Each line of teacher talk was coded to elicit the incident that reveals the occurrences of epistemic aims and epistemic ideals. The coding scheme used to code teacher instruction is presented in Table 3.3. The coding scheme was theory-driven based on the AIR framework and relevant literature reviews about epistemic aims and epistemic ideas presented in Chapter 2. Efforts were made to refine the code using the data. Eventually, twenty four sub-codes were identified that represent epistemic processes associated to epistemic aims (7 sub-codes) and epistemic ideals and processes (17 sub-codes). Table 3.3 shows the description of each code and gives a typical example of each code from classroom videos of argumentative instruction.

Moreover, with each of the descriptions, the associated theoretical basis was described. As discussed in Section 3.4, teachers in the argumentative group used *Talking Physics* module to help their students engage in argumentative discourse smoothly. Hence, in the coding phase, coders focused on teacher's talk that develops students' epistemic knowledge of science. Due emphasis was given to "understanding what those aims and ideals are, and when, why, and how to use them in science" (Martin, 2019, p. 53).

Table 3.3 Coding Scheme for Physics Teachers' Epistemic Talks in grade 8 students' Classroom Videos

Utterances that Depicted Epistemic Aims and Epistemic Ideas in Argumentation	Codes	Sub-codes	Theoretical Foundations
Teacher use analogy or a metaphor to help students understand a concept or process	*Epistemic Aims*	Analogy	(Sandoval, 2005)
The teacher provides a descriptive account of a process, event or phenomenon	*Epistemic Aims*	Description	(Berland & Reiser, 2009)
The teacher provides examples to help students remember or understand a concept or phenomenon under discussion	*Epistemic Aims*	Examples	(McNeill, Lizotte, Krajcik, & Marx, 2006)
The teacher explains thoroughly the conceptual underpinnings of a scientific phenomenon	*Epistemic Aims*	Explanation	(Braaten & Windschitl, 2011; Sandoval, 2005)
The teacher provides a summarized or generalized version of his own or the students' talk	*Epistemic Aims*	Summary	(Sandoval, Greene, et al., 2016)
Teacher discusses ways of representing a concept, process or idea; usually applied when discussing physics constructs	*Epistemic Aims*	Modelling (Construct)	(Sandoval & Reiser, 2004)
Teacher defines a term/concept	*Epistemic Aims*	Definition	
Teacher proposes a position or claims with some evidentiary support	*Constructing SKC**	Propose Position (Argument)	(Kelly, 2008)
The teacher asks students to provide an argument to convince other students or him of their ideas	*Constructing SKC*	Prompt for Argument	(Osborne, 2010)
Teacher prompts students to provide their definitions of concepts	*Constructing SKC*	Prompt to Define	
Teacher requests from the students to describe an event, phenomenon or process	*Constructing SKC*	Prompt to Describe	(McNeill et al., 2006)

Utterances that Depicted Epistemic Aims and Epistemic Ideas in Argumentation	Codes	Sub-codes	Theoretical Foundations
The teacher provides students with information or data, which can then be used as evidence for their investigations or activities	*Constructing SKC*	Provide Evidence	(Berland & Reiser, 2009)
Teacher requests students to provide information/data/evidence for the topic under discussion	*Constructing SKC*	Request Evidence	(Cruz-Guzmán, García-Carmona, & Criado, 2017; Osborne, 2014)
Teacher requests from students to provide a representation of a process or concept	*Constructing SKC*	Prompt to Model (Representation)	(Osborne, 2014)
Teacher predicts or hypothesizes what might happen in a scenario under discussion	*Constructing SKC*	Prediction/Hypothesize	(Lehrer & Schauble, 2015)
Teacher requests students to hypothesize/guess what would happen in a given situation	*Constructing SKC*	Prompt to Prediction/Hypothesize	(Harlen, 2013; Osborne, 2014)
The teacher provides a justification for or against his/her or the students' actions or views	*Justifying SKC*	Justify	
Teacher prompts students to justify their actions or opinions, usually using the question 'why'	*Justifying SKC*	Prompts to Justify	(Osborne, 2014)
Teacher compares and contrasts the information provided by him or the students	*Evaluating SKC*	Compare & Contrast	(Christodoulou & Osborne, 2014)
Teacher prompts students to compare and contrast information, events or processes	*Evaluating SKC*	Prompt to Compare & Contrast	(Braund et al., 2013; Simon et al., 2006)
The teacher provides a counter-claim or argument to what the students have presented or when the teacher is playing devil's advocate with the students	*Evaluating SKC*	Provide Counter-argument	(Christodoulou & Osborne, 2014; Erduran et al., 2004)
The teacher encourages students to consider alternative positions to their own or those discussed in the lesson	*Evaluating SKC*	Consider Alternatives	
The teacher evaluates a process, idea or	*Evaluating SKC*	Evaluation	
The teacher encourages students to make an evaluative judgment about a process, their work, or others' ideas	*Evaluating SKC*	Request to Evaluate	

*Scientific Knowledge Claims (SKC)

Epistemic aims are entities that guide the creation of epistemic products (Barzilai & Chinn, 2018; Chinn & Rinehart, 2016). The theoretically-driven epistemic aim code considered knowledge construction, knowledge justification, and knowledge evaluation as a key aim of science education. Sandoval (2005) promoted practical epistemology over personal epistemology on a ground that epistemology of science is context-dependent and situated. So, the epistemic aim code targeted teacher's discussion about knowledge construction related aims concerning the science topic or the activity under discussion. Epistemic aim codes were applied to recognize teacher's discourse that addresses why particular epistemic aims (such as construct explanation) are important, what it contains (i.e., what does it mean to explain a construct in science), and achieving this epistemic aims (what to do to give a scientific explanation about the construct). Understanding the epistemic aims of teacher's discourse gives a picture of teacher's challenges and prospects they face to enhance epistemic knowledge through dialogic argumentation.

Epistemic ideals are entities that set standards to produce or evaluate scientific knowledge claims. It includes what the standards or norms are, why we use these criteria, when to use and how to apply the criteria in the knowledge-building process (Barzilai & Chinn, 2018). Theoretically based sub-codes were developed for epistemic ideals too, though sub-codes and descriptions were further refined based on the teachers' talk in the classroom videos of our data. Three sub-codes for epistemic ideals are constructing scientific knowledge claims, justifying scientific knowledge claims, and evaluating scientific knowledge claims. All identify various criteria in a scientific claim to knowledge. This code was applied to utterances that recognized teacher's discourse to support students' knowledge about 'how you know what you know' in science and the role of justification in one's endeavor to scientific knowledge claim.

The researcher and another PhD student at Addis Ababa University, who is working on assessment related to scientific reasoning, coded two whole-class video transcripts independently. The inter-rater reliability was significantly over the threshold of $k > 0.65$, indicating substantial agreement. Cohen's kappa and Shaffer's rho had ensured inter-rater reliability for each of the codes and tested κ's generalizability, respectively (Shaffer, 2017). Significant disparities between the two raters have been resolved through discussion-based consensus. The researcher coded the remaining transcripts of the classroom videos.

3.6.2.3.3 Epistemic Network Analysis to Identify Epistemic Practices of Teachers

Epistemic Network Analysis (ENA) is suitable to study the connection between various cognitive elements. ENA argues that epistemic practices of science are intertwined in nature. Hence ENA favored examining the connection between various cognitive elements than to reveal the presence or the absence of these cognitive elements in any discursive actions (Shaffer et al., 2016). Chinn and Rinehart (2016) and Chinn et al. (2016) advised that science instructions and classroom activities should aspire to promote students' understanding about the nature of science and how science works. Such teachers' instruction play an important role in students' understanding of epistemic practices of science.

Moreover, it also helps students to recognize the importance of various argumentative activities in setting the stage that brings the practice of scientists into their science class. In short, ENA is a suitable strategy to study the epistemic practices in science teachers' instruction to count the occurrences of epistemic aims and ideals. In this study, we used ENA to investigate how science instructions connected epistemic aims and ideals to visualize argumentation as an epistemic practice. ENA does "identify, quantify, and model" (Martin, 2019, p. 58) discursive interactions of teachers using networks based on the epistemic practices coded in the data.

A line in transcribed teacher's talk is taken as a unit of analysis to construct the network. ENA deployed a unique algorithm that builds the model for the codes in each line of the transcribed data by considering the occurrence of another code within a predefined number of lines in the teacher's transcribed text (Siebert-Evenstone et al., 2017). In our case, we used an excerpt of ten lines (i.e., the coded line and previous nine lines of teacher's talks) to represent the constituency for teachers that made a connection between various epistemic practices within two or three minutes of teacher talk. The networks for each of the lines in the teacher's discussion are then put together to produce the mean network for the entire teacher's talk. Through this process, the mean network was produced for each of the teachers, who used argumentation instructions.

3.7 Trustworthiness and ethical considerations

3.7.1 Rigor of mixed methods research

In educational research, the findings and conclusions must be trustworthy. Thus, the researcher is expected to demonstrate this. Denscombe (2017) said that studies that used the established practices of educational research must show rigor. According to Creswell and Poth (2018), rigor in research can be established using credibility, transferability, dependability, and confirmability as criteria. The next subsections move on to discuss these criteria.

3.7.1.1 Credibility

Jensen (2008b) points out that credibility of qualitative research can be ensured through lengthy engagement, intensive and critical observation, peer review, and triangulation. The researcher, being research assistant, spent much time and engaged for prolonged periods with participants and data. The length engagement and in-depth inspections of the data enable the researcher to yield credible conclusions (Tracy, 2013). Repeatedly watching video episodes supplemented the in-depth analysis and credibility to this study. Conclusions were drawn after prolonged engagement in the processes of data analysis.

Peer review is “a process of exposing oneself to a disinterested peer in a manner paralleling an analytic session and for the purpose of exploring aspects of the inquiry that might otherwise remain only implicit within the inquirer’s mind” (Lincoln & Guba, 1985, p. 308). Peer review involves colleagues, who are familiar with the topic of the study, its research methodology and research analysis, in the research process to get consultations and relevant feedback. Peer reviewer plays a paramount role in criticizing, posed serious questions on the overall aspects of the study (Lincoln & Guba, 1985). In this dissertation, the researcher had discussed the whole research processes with fellow PhD candidates and instructors during seminars and private discussions. Colleagues insightful comments were critical to investigate bias and provide meaningful interpretations. Besides, Ph. D. candidates were recruited to analyze some of the lessons and teachers interviews to verify that the qualitative analysis performed by the researcher.

Triangulation corroborated evidence from different types of data or from different methods of data collection. In this study, in order to get different perspectives, data were collected from multiple interviews and multiple video recorded classroom teaching. Thus, multiple sources were used to develop meaningful understanding of teacher practices. This triangulation further provides confidence and truthfulness of the data analysis. This dissertation analyzed and reanalyzed post-study argumentation lessons and teachers’ interview. These processes (i.e., lengthy engagement, repeated observations, checking part of the analysis by fellow colleagues, and triangulation) had been used to establish the credibility of this study.

3.7.1.2 Transferability

Yin (2017) suggest that researchers should provide thick description that are substantiated by sufficient information. The information should contain "purposeful account of the context, participants, and research design" (Jensen, 2008c, p. 886). This enables readers to decide whether the findings of this study are accurate expressions and hence can be transferred beyond the contexts and situations of the study. The researcher presents in-depth descriptions supplemented by excerpts of the transcripts.

Among seven teachers in the intervention group, six of the teachers were used. This linked the participants with the context in which this study were done. These six teachers are relevant representation of the intervention group. The selection further ensured that participants represent the limitation and delimitation of the study too.

3.7.1.3 Dependability

Reliability deals with replication of the findings of the quantitative study. However, Yin (2017) argues that replication is not realistic for qualitative study due to the complex and sophisticated influence circles exist in any social settings. One acknowledged practice to establish dependability is audit trial in qualitative research. Audit trial includes systemic documentation such as "description of procedures to collect and analyze the data, extraction of data to develop emerging themes and interpretation of data" (Leech & Onwuegbuzie, 2008, p. 200). Audit trial produce evidence to purport the findings of the study was indeed trustworthy. In line with this perspectives, researcher describes and explains the research procedure and methodological issues in a manner that depict the detailed account of the research process followed.

3.7.1.4 Confirmability

Qualitative studies are apt to researcher's biases. The researchers biases are only tolerated as long as it does not affect the truthfulness of the study (Jensen, 2008a). Confirmability is a means to verify the trustworthiness of this study through unprejudiced reflection of the role of the researcher.

Various confirmability techniques such as using multiple coders and triangulation were used. The researcher rigorously demonstrated that the dissertation was guided by the research questions raised in Section 1.5 and the findings of the study and the interpretations emerged from the data not from researchers perspectives and positional prejudices (Denscombe, 2017). The researcher believes that these strategies weaken the probability of inculcating the researcher's biases in the study.

In this subsection, detailed explanation of how the trustworthiness and the rigor nature of this dissertation were presented. The study can be considered as satisfying the criteria of credibility, transferability, dependability, and confirmability , hence it is rigorous.

3.7.2 Ethical considerations

All data presentations protect the confidentiality and anonymity of the participants and institutions involved in the study. Before the data collection, a brief description of the project's objectives, its potential impact, and the possible outcomes were also communicated to the participant upper primary schools. In addition to this, we had a memorandum of understanding signed between the Project and the local education offices who granted permission to carry out the research. Physics teachers were also informed about the TPSS Project and agreed to be videotaped during their teaching. All participants had signed a declaration of informed consent for their participation and granted approval to use these videos for research conference presentations and training purposes only.

3.8 Summary of chapter

In summary, this chapter has outlined the research approach, research design and procedures for data collection and analysis and has outlined the reasons for this methodology. The study used a mixed methods experimental design and pragmatists approach. Tests and video collected from the teacher and students formed the basis of the data complemented with interviews collected from the teacher. Micro-ethnographic analysis took place to data analysis and a number of checks and balances were put in place to ensure a study with a high degree of rigor. Ethical considerations have been put in place to ensure that the study meets the expected standards.

Chapter 4 Results

This chapter presents the results of both quantitative and qualitative data collected before and after the implementation of dialogic argumentation and presents and describes the results in a systematic and detailed way to provide answers to the research questions.

4.1 Quantitative analysis

EKI test scores and ASAC scores were analyzed to determine the extent to which and how dialogic argumentation affects upper primary school students' epistemic knowledge. The level of epistemic knowledge was determined using the students' scores in 10 EKIs. The mean EKI scores were then compared between groups at each time point, and across time points within each group using SPSS.

4.1.1 Demographics of the participants

Table 4.1 presents the demographics characteristics of grade 8 students from both intervention and control groups. The intervention group was composed of 239 grade 8 students randomly selected from six primary schools. In the intervention group, majority of the participants were females, n = 151 (63 %) whereas the remaining participants are males, n = 88 (27 %). The control group was comprised of nearly equal number of males and females, 118 males (49 %) and 122 females (51 %). As far as the sex composition of participants is concerned, females constitute 57 % of the total.

Table 4.1 Demographic characteristics of participants after data cleaning

Gender		Intervention Group	Control Group	Total
Male	N	88	118	206
	%	36.82 %	49.17 %	43.01 %
Female	N	151	122	273
	%	63.18 %	50.83 %	56.99 %

4.1.2 Students' level of epistemic knowledge of science

Grade 8 students' epistemic knowledge of science was evaluated using ten reasoning test items identified to measure epistemic knowledge, which we refer to as EKIs. An independent sample *t*-test was conducted to determine whether there was a statistically significant change in the students' level of epistemic knowledge over the intervention year. A high score on the EKIs was considered as a sign of high epistemic knowledge. The mean scores for intervention and control groups in the pre-test and post-test were taken as measures of grade 8 students' level of epistemic knowledge.

4.1.2.1 Checking test scores for statistical assumptions

Students' scores were checked for statistical assumptions such as normality, homogeneity, and outliers using SPSS. A boxplot for EKI scores identified seven outliers in the control group datasets (both pre-test and post-test) and four outliers in the intervention group dataset (pre-test). Rather than removing the outliers, we substituted the values of these outliers with the next largest value plus small increments to maintain the ranking in the data (see Figure 4.1).

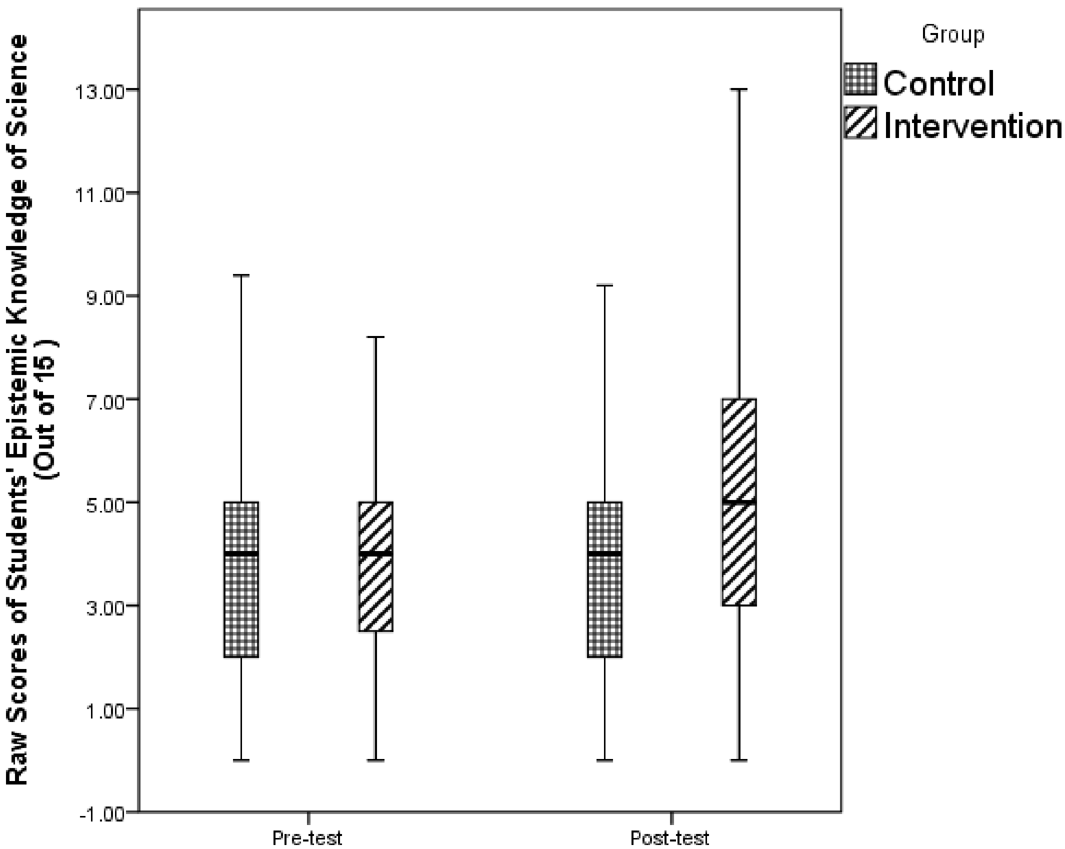


Figure 4.1 Boxplot test scores after removing outliers in pre-test and post-test mean scores of intervention and control groups.

Visual inspection of the histogram and normal Q-Q plot shows that the distribution of students' scores on the 10 EKIs is not markedly different from a normal distribution. Nevertheless, the distributions of pre-test and post-test scores for both intervention and control groups were not normal as determined by the Shapiro-Wilk test ($p < .05$) (see Table 4.2). Having statistical evidence for non-normality, a non-parametric independent samples test was conducted to determine whether there was a statistically significant difference between intervention and control groups in their epistemic knowledge based on pre-test and post-test scores.

Table 4.2 Test of Normality for Control and Intervention Groups Pre-test and Post-test Scores

Mean Test Scores	Groups	Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Pre-test Scores	Control Group	.125	240	.000	.942	240	.000
	Intervention Group	.150	239	.000	.955	239	.000
Post-test Scores	Control Group	.115	240	.000	.952	240	.000
	Intervention Group	.140	239	.000	.958	239	.000

Furthermore, the z-scores for skewness and kurtosis were computed to check if normality held for the pre-test and post-test scores of both the intervention and control groups. We used SPSS to find the statistical measurement of the skewness and kurtosis. Since the SPSS output did not provide the measure of z-scores, we divided the values of skewness and kurtosis to their respective standard errors. As shown in Table 4.3, the z-scores were greater than 1.96 which is significant ($p < .05$). These mean test scores are positively skewed, indicating that the mean EKIs score for both groups in the pre-test and in the post-test are piled-up on the left of the distribution. Clearly, most of the students got low scores.

Table 4.3 Skewness and Kurtosis of Control and Intervention Groups on Pre-test and Post-test Scores

Mean Scores	Groups	N	Mean	Std. Dev.	Skewness			Kurtosis		
					Statistic	S.E.	Z_S	Statistic	S.E.	Z_K
Pre-test Scores	Control Group	240	4.14	2.28	0.87	0.16	5.52	1.17	0.31	3.75
	Intervention Group	239	3.85	1.89	0.46	0.16	2.94	-0.10	0.31	0.33
Post-test Scores	Control Group	240	4.06	2.35	0.64	0.16	4.06	0.28	0.31	0.00
	Intervention Group	239	5.1	2.48	0.59	0.16	3.75	-0.01	0.31	0.00

The mean test scores of both groups taken at two-time points (Control Pre-test Scores, Intervention Pre-test scores, Control Post-test Scores, and Intervention Post-test scores) were found to be significantly non-normal. The data from all these tests were considered to deviate normal distributions. Hence, in light of these statistical evidence for violation of normality, the non-parametric test was conducted.

4.1.2.2 Comparing level of epistemic knowledge

Table 4.3, also shows descriptive Statistics (mean and std. dev.) of control and intervention groups in their pre-test and post-test scores. Measured by the mean test score (±SD), the intervention groups' level of epistemic knowledge of science increased from 3.84 (± 1.89) pre-test score to 5.10 (± 2.48) post-test score. On the contrary, the control groups' level of epistemic knowledge was a little lower in the post-test (4.06 ± 2.35) compared with their pre-test Scores (4.14 ± 2.28). The overall progress by grade 8 students in their level of epistemic knowledge can be clearly observed and compared using the line graph of Figure 4.2 illustrated below. Figure 4.2 shows that the mean score of students in the intervention group showed a slight increase in the post-test compared to their pre-test scores. Not much difference was observed between pre- and post-test scores for the control group.

As shown in Figure 4.2, the intervention group attained more progress in their level of epistemic knowledge than the control group. Considering the pre-test mean scores of both groups as a starting position, one can argue that the observed progress of the intervention group in their level of epistemic knowledge was because of this group's continuous engagement in dialogic argumentation nearly for a year. However, the discrepancy could be attributed to other unexamined factors that may significantly contributed towards the observed variability of the grade 8 students' epistemic knowledge of science in both groups. It is not apparent from

Figure 4.2 that whether the observed difference between intervention and control groups in their level of epistemic knowledge are substantial or not. Additional statistical analyses were, thus, conducted to determine whether the mean EKI score for the intervention group has changed significantly over time compared to that of the control group.

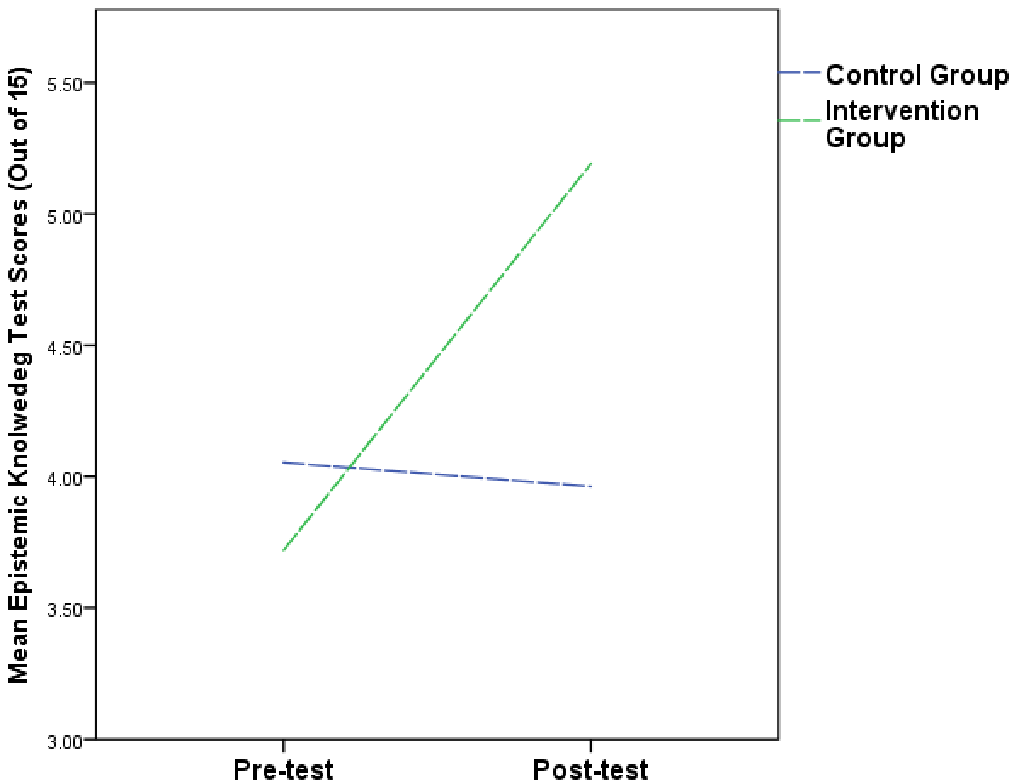


Figure 4.2 Pre-test and post-test mean scores on ten epistemic knowledge items for intervention (n = 239) and control (n = 240) groups

A Mann-Whitney U tests were conducted to determine if there were statistically significant difference between intervention and control groups in their level of epistemic knowledge at their pre-test mean scores. A Mann-Whitney U test revealed that the distribution (mean rank) of the pre-test scores were not statistically significant between intervention and control groups, (U= 27,126.5, z = 1.04, p = 0.299, r = .05). This indicated that Grade 8 students were not different in their epistemic knowledge of science at the beginning of the intervention. For the post-test scores, however, the Mann-Whitney U test (U=35,454, z = 4.5, p < 0.001, r = .19) indicated a statistically significant difference between intervention and control groups in their EKI mean scores. These small to medium effect sizes indicated a substantial difference in level of epistemic knowledge between intervention and control groups in their post-test scores. The small to medium effect size was observed as a consequence to the dialogic pedagogy implemented by the intervention group. The implication is that engagement in dialogic argumentation has significantly raised Grade 8 students' level of epistemic knowledge. The result suggests that transforming physics instructions from didactic to dialogic argumentation improves upper primary school students' epistemic knowledge of science.

In addition, a Wilcoxon Signed Rank Tests were conducted to determine if there were statistically significant difference between the pre-test and post-test mean scores of both the intervention and control groups in their level of epistemic knowledge. For the control group, level of epistemic knowledge were not significantly different on the post-test scores than on pre-test scores, T = 10,080, z = -.208, p = .835, r = -.01. However, the intervention group significant difference between pre-test and post-test scores were observed: level of epistemic knowledge were significantly higher on the post-test scores than the pre-test scores, T = 17,220, z =6.18, p = .000, r = .40. The medium to large effect sizes indicated a substantial difference in level of epistemic knowledge of the intervention group between pre-test and post-test scores.

In summary, the control group did not differ statistically significantly from those of the intervention groups' level of epistemic knowledge in their performance of the pre-test scores. That is, the epistemic gap between both groups can be considered as at similar level of epistemic knowledge. However, for the post-test scores, the level of epistemic knowledge of the intervention group were significantly higher than the level of epistemic knowledge of the control group. Having the evidence that there is no statistically significant difference between the pre-test and post-test scores of the control group and but there is statistically significant mean rank differences in the pre-test and post-test scores of the intervention group can be ascribed to treatment effect.

Table 4.4 presents the percentage of the average EKI scores before and after implementation of dialogic argumentation, the gain in epistemic knowledge based on EKI scores, and the normalized gain. In the dialogic argumentation classroom, intervention group, the gain in epistemic knowledge measure was found to be large (8.40 % gain) compared to that of the traditional instruction classroom, control group (.53 % gain). Even though the students EKI scores were found to be very small (mostly below the minimum expected 50%), we observed a little improvement in students' epistemic knowledge (a low gain of G = .11) for the intervention group as compared to the gain in the control group (G = .01).

Table 4.4 Average normalized gain of students' epistemic knowledge between argumentative and non-argumentative classrooms

Method of Teaching	**Pre-test**	**Post-test**	**Gains**	**G**	**N**
Dialogic Argumentation Classroom*	25.60	34.00	8.40	0.11	239
Traditional Instruction Classroom*	27.60	27.07	(0.53)	(0.01)	240

*Both pre-test and post-test scores given here are found by changing the students' mean scores (given in Figure 4.2) into percentages.

4.1.3 Quality of students' dialogic argumentation

To assess the quality of students' dialogic argumentation, we recorded 28 small group discussions; fourteen videos before and fourteen after intervention. The intervention engaged them in dialogic argumentation for a year. The video records were collected from seven intervention and seven control groups. Assessment of Scientific Argumentation in the Classroom (ASAC), which was developed by Sampson et al. (2012), was used to assess the quality of Grade 8 students' dialogic argumentation. The ASAC observation protocol considered conceptual, epistemic, and social aspects of argumentation as fundamental in the assessment of argumentation and is believed to support researchers to do in-depth analyses and measure the nature and quality of students' argumentations Sampson et al. (2012).

The ASAC tool contains nineteen items. The conceptual and cognitive aspects and the epistemic aspect of the tool are represented by seven items each and the social aspect, by five items. Each item is rated on a 0 (Not at all) to 3 (Often) scale with Item 6 and Item 8 reverse rated. In this paper, the ASAC observation protocol was used to evaluate and compare the progress of Grade 8 students in all three aspects of dialogic argumentation over the one-year intervention period. To ensure the reliability of ASAC in scoring different episodes of argumentation, the first author and a second-rater, who was a physics teacher educator and a PhD candidate in physics education at Addis Ababa University, scored four randomly chosen episodes of argumentative student group discussions. Cohen's kappa (κ = .775) showed acceptable inter-rater reliability. Table 4.5 summarizes the mean scores of the conceptual and cognitive aspects, the epistemic aspects, and the social aspects of argumentation, and the overall ASAC mean scores for each school in this study.

Table 4.5 Mean ASAC scores of both intervention and control group before and after intervention in dialogic argumentation

Items	Item Descriptions and Dimensions of ASAC	Ctrl-Pre Mean(SD)	Ctrl-Post Mean(SD)	Intvn-Pre Mean(SD)	Intvn-Post Mean(SD)
Cca1	The conversation focused on the generation or validation of claims or explanations.	0.43 (.53)	0.71 (.49)	0.71 (.49)	1.43 (.98)
Cca2	The participants sought out and discussed alternative claims or explanations.	0.29 (.49)	1(.82)	1 (.82)	1.14 (.69)
Cca3	The participants modified their claim or explanation when they noticed an inconsistency or discovered anomalous information.	- (-)	0.71 (.49)	0.71 (.49)	0.71 (.49)
Cca4	The participants were skeptical of ideas and information.	0.14(.38)	0.43 (.53)	0.43 (.53)	0.57 (.53)
Cca5	The participants provided reasons when supporting or challenging an idea.	0.57(.79)	1.14 (.69)	1.14 (.69)	1.57 (.98)
Cca6	The participants based their decisions or ideas on inappropriate reasoning strategies.	0.86(1.07)	2 (.58)	2 (.58)	1.86 (.69)
Cca7	The participants attempted to evaluate the merits of each alternative explanation or claim in a systematic manner.	0.29(.49)	0.86 (.69)	0.86 (.69)	1.43 (.98)
	Conceptual and Cognitive Aspects	**3.57**	**4.29**	**6.86**	**8.71**
Ea1	The participants relied on the “tools of rhetoric” to support or challenge ideas.	2.29(.95)	1.29 (.49)	1.29 (.49)	1.29 (.49)
Ea2	The participants used evidence to support and challenge ideas or to make sense of the phenomenon under investigation.	- (-)	0.71 (.76)	0.71 (.76)	1.43 (.53)
Ea3	The participants examined the relevance, coherence, and sufficiency of the evidence.	0.14 (.38)	0.43 (.53)	0.43 (.53)	1.14 (.69)
Ea4	The participants evaluated how the available data was interpreted or the method used to gather the data.	0.29 (.49)	0.43 (.79)	0.43 (.79)	0.86 (.9)
Ea5	The participants used scientific theories, laws, or models to support and challenge ideas or to help make sense of the phenomenon under investigation.	- (-)	0.29 (.49)	0.29 (.49)	0.86 (.38)
Ea6	The participants made distinctions and connections between inferences and observations explicit to others.	0.14 (.38)	0.57 (.53)	0.57 (.53)	1.14 (.9)
Ea7	The participants used the language of science to communicate ideas.	0.14 (.38)	0.57 (.79)	0.57 (.79)	1.57 (.79)
	Epistemic Aspects	**3.00**	**4.29**	**4.29**	**8.29**
Sa1	The participants were reflective about what they know and how they know.	1 (-)	1.14 (.38)	1.14 (.38)	1.43 (.53)
Sa2	The participants respected what each other had to say.	1.43 (.53)	1.43 (.53)	1.43 (.53)	1.57 (.53)
Sa3	The participants discussed an idea when it was introduced into the conversation.	0.43 (.53)	1.14 (.69)	1.14 (.69)	1.86 (.38)
Sa4	The participants encouraged or invited others to share or critique ideas.	0.43 (.53)	1.43 (.53)	1.43 (.53)	1.57 (.53)
Sa5	The participants restated or summarized comments and asked each other to clarify or elaborate on their comments.	0.57 (.79)	1 (.58)	1 (.58)	1.14 (.69)
	Social Aspects	**3.86**	**3.57**	**6.14**	**7.57**
	ASAC Observation Protocol Total Score	**10.43**	**12.14**	**17.29**	**24.57**

Figure 4.3 (and Table 4.5) display the differences in the ASAC mean scores, for each aspect and overall, between groups and across time. A look at the differences in the pre-test and post-test mean scores on Figure 4.2 indicate that the intervention group demonstrated progress in the overall quality of dialogic argumentation compared to the control group. A Wilcoxon Signed Rank test was run to determine if there were statistically significant differences in the quality of the overall and each aspect of dialogic argumentation between the pre-intervention and post-intervention ASAC scores of both intervention and control groups. Here, all differences turned out to be significant ($p < .05$).

For the control group, the mean scores of *Conceptual & Cognitive Aspects* in 1st videoing (Mdn = 3) did not differ significantly from the 2nd videoing (Mdn = 5) of students small group argumentative task, T = 6, z = 1.66, p = .102, $r = .62$. The mean scores of *Epistemic Aspects* in 1st videoing (Mdn = 4) did not differ significantly from the 2nd videoing (Mdn = 4) of students small group argumentative task, T = 17, z = 1.38, p = .167, r = .52. The mean scores of *Social Aspects* in 1st videoing (Mdn = 4) did not differ significantly from the 2nd videoing (Mdn = 3) of students small group argumentative task, T = 6, z= -.412, p = .68, r = .41. The mean ASAC scores in 1st videoing (Mdn = 9) did not differ significantly from the 2nd videoing (Mdn = 10) of students small group argumentative task, T = 11.5, z = 1.084, p = .279, r = .41.

For the intervention group, the mean scores of *Conceptual & Cognitive Aspects* in 1st videoing (Mdn = 8) did not differ significantly from the 2nd videoing (Mdn = 8) of students small group argumentative task, T = 16.5, z = 1.265, p = .206, $r = .48$. The mean scores of *Epistemic Aspects* in 1st videoing (Mdn = 4) did differ significantly from the 2nd videoing (Mdn = 9) of students small group argumentative task, T = 21, z = 2.207, $p = .027$, r = .83. The mean scores of *Social Aspects* in 1st videoing (Mdn = 6) did not differ significantly from the 2nd

videoing (Mdn = 7) of students small group argumentative task, T = 19, z = 1.802, *p* = *.072*, r = .68. The mean ASAC scores in 1st videoing (Mdn = 17) did differ significantly from the 2nd videoing (Mdn = 23) of students small group argumentative task, T = 26.5, z = 2.12, *p* = *.034*, r = .80.

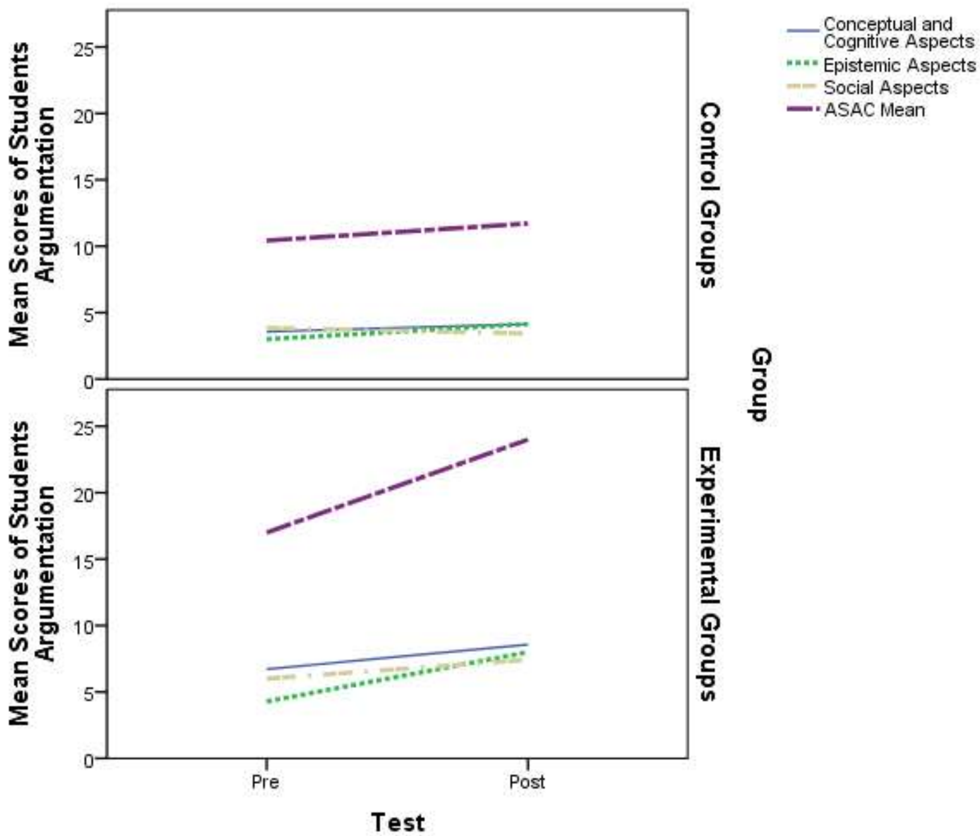


Figure 4.3 Student mean scores on the conceptual and cognitive, epistemic and social aspects of argumentation together with the overall ASAC mean scores for both the intervention and control groups across time (pre-test and post-test)

4.1.4 Correlation between epistemic knowledge and dialogic argumentation

A Pearson correlation test was conducted for fourteen school cases to assess the relation between students' epistemic knowledge of science, as measured by EKI mean scores, and the quality of their dialogic argumentation, as measured by ASAC mean scores. Results of the Pearson correlation indicate a significant positive correlation between EKI and ASAC mean scores, Pearson's r = .558, p = .038, two-tailed. Dialogic argumentation accounts for 31.14 % of the variations in upper primary school students' epistemic knowledge of science.

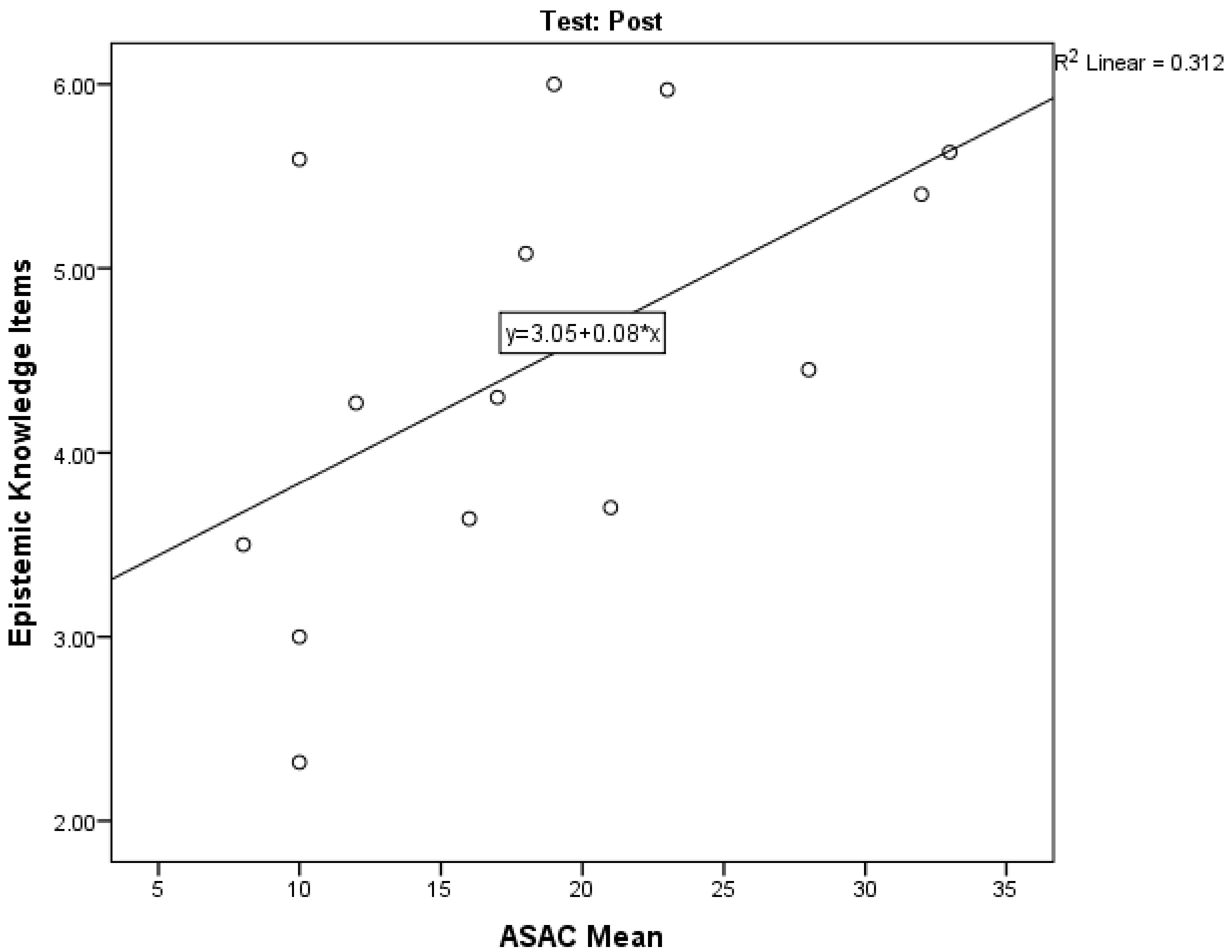


Figure 4.4 A scatter plot of mean scores of epistemic knowledge items and mean overall scores of ASAC observation protocol

Figure 4.4 is a scatter plot with a regression line (R^2 = .312) for EKI and ASAC mean scores. The scatter plot shows that the development of epistemic knowledge and engagement in dialogic argumentation are positively correlated. That is, students who score high on ASAC also score high on the epistemic knowledge items, and vice versa.

4.2 Qualitative analysis

The qualitative analysis aimed to understand the epistemic practices of six Grade-8 physics teachers and to identify their challenges and prospects when implementing argumentative instructions. The epistemic aims and ideals in the physics teachers' instructions provided insight into their epistemic science practices.

4.2.1 Further qualitative analysis of students' argumentation

A qualitative analysis of the video records of small group argumentative discussions on given tasks helped elicit the features of epistemic knowledge regarding science among the students in the intervention and control groups. The groups were compared before the intervention, which was implemented at the beginning of the school year, and after the intervention at the end of the school year. To identify the characteristics of the students' epistemic knowledge, each of their utterances in the video transcriptions was analyzed line by line along the dimensions of "feature of epistemic knowledge of science" and "descriptions about an elicited feature" for each of the following discussion tasks: measuring temperature (pre-intervention task) and force and motion (post-intervention task). Both activities are given in the Appendix B.

As shown in Appendix B, the pre-intervention task discussed the temperature of the boiling of water when measured by five different groups. The *measuring temperature* task required students to reason out why the groups did not get the exact same temperature and to justify their decisions on which result should be used. During the pre-intervention, both groups relied on their prior knowledge in formulating oppositional or supportive arguments. The students were compelled to refer to their textbooks as they raised the claim that the boiling temperature of water is 100°C. Both groups, in most cases, agreed that any deviation from this temperature could have arisen from a reading error or a malfunctioning thermometer. Both groups also failed to recognize that data can be uncertain and anomalous. When the second question (How should they decide which results they should use? Explain which method you think is best. Please see Appendix B) was discussed, the best strategy that the students identified for deciding on which results to use was either to consider 100°C as the boiling point on the grounds of what they had learned or to add up all the measurements to obtain an average on the basis of their experiences in a physics laboratory. Neither group exhibited a significant proportion of features that characterize epistemic knowledge of science in their arguments. Their explorations lacked coherence, as shown in the above-mentioned case, with the students failing to acknowledge the role of replication in generating scientific know-how. Their reasoning was also entirely reliant on what was written in their textbooks or what they were previously taught. The consensus of students about the boiling temperature of water suggested that they do not regard scientific measurements as identical, displaying no uncertainty whatsoever in this respect. Sometimes, the students wondered why a reason was required given that the boiling temperature was known. They seemed to have failed to understand the role of justification in claiming knowledge of science.

The post-intervention task presented the following conception of two students about *force and motion*.

Student 1: You always need a force to keep an object moving.

Student 2: An object can move without any force acting on it.

The question presented to both groups was “Why is the right student right and the wrong student wrong?” (see Appendix B). We found that the intervention group was considerably inclined toward reasoning when they supported/refuted the claims presented above, whereas the control group focused on identifying the correct answer, paying little attention to the justifications expected. Both failed to utilize data to substantiate their reasoning. In the post-intervention, a distinct variation was observed from both the intervention and control groups compared with their pre-intervention performance.

This study uncovered that changing pedagogy from didactic to dialogic improves the features of epistemic knowledge elicited by student discussions to resolve a physics problem. Unlike the students in the control group, those in the intervention group slightly shifted their thinking to assimilate the epistemic elements of scientific reasoning. In the pre-intervention discussion, both groups wondered about questioning a well-known idea (e.g., Water boils at 100 °C). In the post-intervention discussion tasks, however, the intervention group generated more features of epistemic knowledge and recognized the importance of justification in knowledge building in science. Nevertheless, both groups inappropriately used additional information given during the activity in both the pre-intervention and post-intervention discussion tasks. Moreover, the argumentation were inadequately organized, and group members were reluctant to engage in debate. Although this study was conducted in Ethiopia, where the ideas that a teacher teaches are readily accepted and dependence on textbooks is a strongly entrenched classroom norm, this research shows that implementing dialogic argumentation as a teaching strategy positively affects the quality and quantity of the features of epistemic knowledge elicited from students' argumentative discussions.

In certain cases, the discussions contained unintelligible ideas. Overall, the students were unaware of the basic constructs required for scientific knowledge construction and their role in justifying generated scientific knowledge. The students also failed to realize the importance of justifying their claims and did not challenge any views put forward by their colleagues. The group seemed to think that the thermometer suffered from a malfunction and saw no need to argue when competing views occurred. As an example, some of the students said, “The thermometer is wrong,” whereas the others indicated that “uncertainty is part and parcel of any measurement.” The latter reflects the belief that a thermometer does not fail. Both the respondent groups did not see the need to settle their differences through scientific argumentation. Both sides also failed to explain their answers.

Again, justification was insufficiently elaborated to support responses or assertions, with the students seeing no need to provide grounds for their reasoning and back it with scientific evidence. No one challenged answers—which pointed to potential laziness or reluctance among the students. They proceeded to succeeding questions without critically evaluating their answers, and they did not ask for clarification from one another when their peers’ responses differed from theirs.

4.2.2 Qualitative analysis of videotaped teaching

4.2.2.1 Case studies of epistemic practices of teachers in argumentative instructions

This section provides a detailed descriptions and analysis of the argumentation lessons of each of the six teachers. The results of this analysis aims to provide partial answers to the third research question of this dissertation. The third research question was a) how do grade 8 physics teachers’ scaffold, support, and promote dialogic argumentation instruction to create an opportunity for understanding science as epistemic practice, and b), what factors in teachers dialogic argumentation instructions facilitate and constrain grade 8 students’ epistemic knowledge of science. In this section, first, thorough descriptions of teachers’ whole class teaching are explored, and second, analysis of teachers epistemic discourses in the argumentation lesson is provided using the ENA framework. In addition, techniques and moves used to promote epistemic knowledge during argumentation lessons as well as challenges and prospects are identified and discussed.

4.2.2.1.1 Epistemic features observed from Mr. Landabo's argumentative instruction (CS-1)

Figure 4.5 shows the various epistemic features observed during Mr. Landabo's argumentation lesson. Among the twenty-four codes that represent the epistemic aims and ideals of argumentation (see the codes in Table 3.3), only eight features were observed in Mr. Landabo's epistemic discussion. Among these eight observed features, three (*explanations*, *descriptions* and *definitions*) are epistemic aims, three (*propose position*, *prompts for descriptions* and *prompts for definitions)* represent the construction of scientific knowledge claims, one (*justification*) is associated with justifying scientific knowledge claims and one (*compare and contrast*) relates to evaluating scientific knowledge claims.

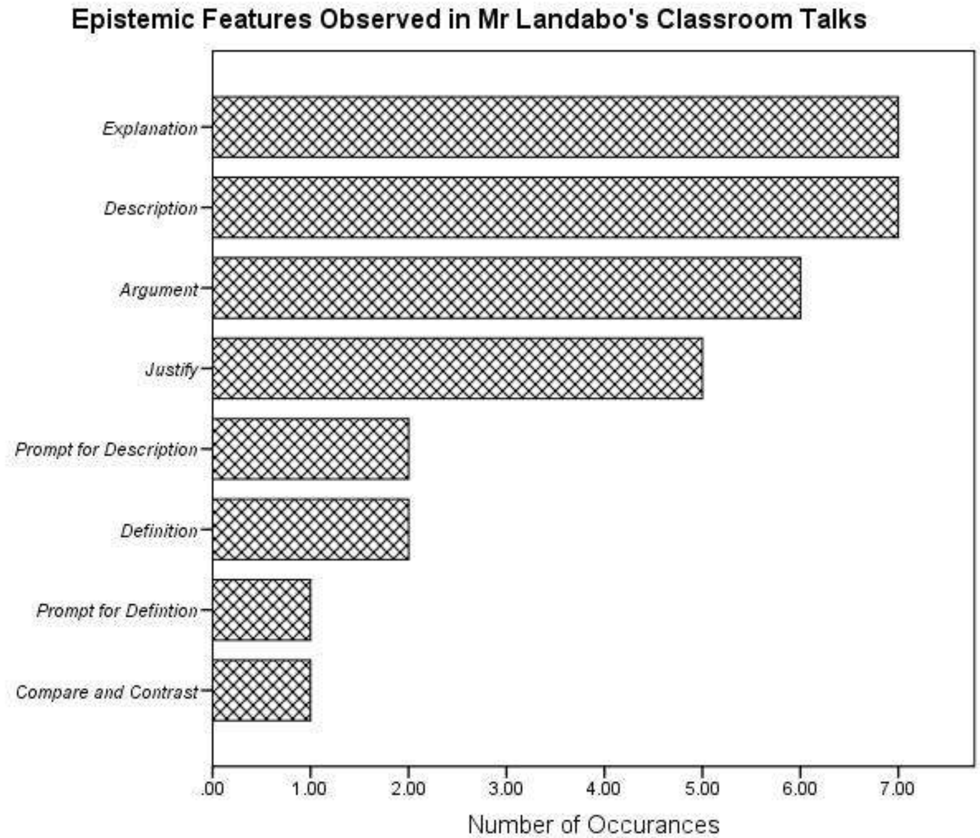


Figure 4.5 Epistemic features observed from Mr. Landabo's classroom talks in argumentation lessons

The epistemic aims of science dominated Mr. Landabo's epistemic talks. The noticeable features included *definitions*, *descriptions*, and *explanations*. *Definitions* are any utterances made by teachers to prompt students to define a physics concept, a physics process, or physics phenomena. The teacher frequently asked students to provide definitions of previously taught concepts during his revision of the previous lesson as illustrated by the following excerpt from the full video transcript:

Example 1: Excerpts that depict *Definition*

4 …What is a generator and what is an electric motor?

29 …What is the transformer? Do you know about the transformer?

83 What is a step-up transformer and what is a step-down transformer?

92 What is a transformer in which the number of turns in the secondary [coil] is

93 greater than the number of turns in primary [coil].

These *prompts for definition* serve to start student small group discussions. *Prompts for definition* were observed not only when the teacher revised the previous lesson, but also when he was about to begin a new topic. Most *prompts for definition* were related to questions such as ‘What is a generator? What is an electric motor? What is the transformer?’ as shown in the excerpted text above. It is clear from the pattern of questioning that this teacher puts a series of redundant *prompts for definitions* to the class, which are not intrinsically useful to instigate argumentative discourses. However, the teacher gave students some time to discuss and organize their definition of these terms and tried to check the progress of the students’ discussion. This teacher’s attempt to develop discursive actions failed due to the nature of his epistemic talks. Rather than focusing on definitions, attempts to describe parts of an electric motor and a generator might have resulted in argumentative interactions in his class. *Providing descriptions* (any utterances in which teacher performs to present a detailed account of a concept or a process) or *prompt for descriptions* of parts of an electric motor and a generator might have contributed to initiating students' argumentative discourses.

Explanations are another feature observed in Mr. Landabo's classroom talk. *Explanations* are utterances in which the teacher provides explicit, in-depth, and interconnected descriptions of a scientific concept or a phenomenon. The following example is excerpted from Mr. Landabo's talks to illustrate his *explanations*:

Example 2: Excerpts that depict *Explanations*

42 Ok! Electromagnetic induction is the process but transformers applies the process

43 of electromagnetic induction. Therefore these transformer is a device which is

44 used to convert electrical energy from one circuit to another circuit by the process
45 of electromagnetic induction for the application of what? Or the transforming
46 system of electric energy from one circuit to another. [Teacher is writing on the board]
47 So transformer is a device.... [Teacher is still writing,] by the
78 process of electromagnetic induction. So what does it use? It uses the process
79 Which process? Teacher: Very good. So what does this transformer do? It transfers the
80 electric power into the power box. When it transfers this electrical energy it uses
81 coil. We refer to them as primary and. secondary coil And based on the numerical
82 value of the primary and secondary are classified as
101 step-up and step-down transformers
102 T: Good. Under the step-up transformer, we have seen that the transformer in
102 which the number of turns in the secondary coil is greater than the number of
103 turns in the primary. But the inverse is true for the step-down transformer

As can be seen from the excerpt above, *explanations* are used when this teacher wants to explain the working principle of a transformer and when he wants to classify transformers into two: step-up and step-down. However, there are problems related to the quality of *explanations* and to content knowledge. As shown in Example 2, this teacher linked the working mechanism of transformers with electromagnetic induction (Example 2: Line 42 - 43). However, this teacher failed to explain the process of electromagnetic induction because he missed the purpose of using *explanations* in this particular instance – to create an understanding of how transformers are used to either increase or decrease the voltage in a circuit without an appreciable loss of power. The teacher also failed to give any description or definition that helps students to distinguish between primary and secondary coils.

The qualitative analysis of Mr. Landabo’s classroom epistemic talk, the epistemic features observed in his lessons (Figure 4.5), and his ENA (Figure 4.11) give insight into how this teacher’s argumentative instructions contributed towards promoting students epistemic knowledge of science. The fact that the observed features are predominantly epistemic aims, not epistemic ideals, inform us that the teacher had focused on the epistemic products, such as knowledge and explanations, rather than on the epistemic processes that lead to the creation of these epistemic products. Mr. Landabo did not engage students in argumentative discourses that promote their epistemic practices. Though this teacher seemed to understand the importance of questions to enhance students' understanding of science and their engagement in the scientific practices, the quality of his questions made his teaching contribute less towards this end. Besides, this teacher did not make strong and frequent connections between epistemic aims, ideals, and processes.

4.2.2.1.2 Epistemic features observed from Mr. Dawud's argumentative instruction (CS-2)

Figure 4.6 shows the various epistemic features observed during Mr. Dawud's argumentation lesson. Among twenty-four codes that represent the epistemic aims and ideals of argumentation (see the codes in Table 3.3), only nine were observed in Mr. Dawud's epistemic talk. Among these nine observed features, three (*explanations*, *descriptions*, and *definitions*) are epistemic aims; four (*propose position, prompt for argument, prompt for description,* and *prompt for definition*) relate to constructing scientific knowledge claims; one (*justification*) relates to justifying scientific knowledge claims; and one (*evaluation*) relates to evaluating scientific knowledge claims.

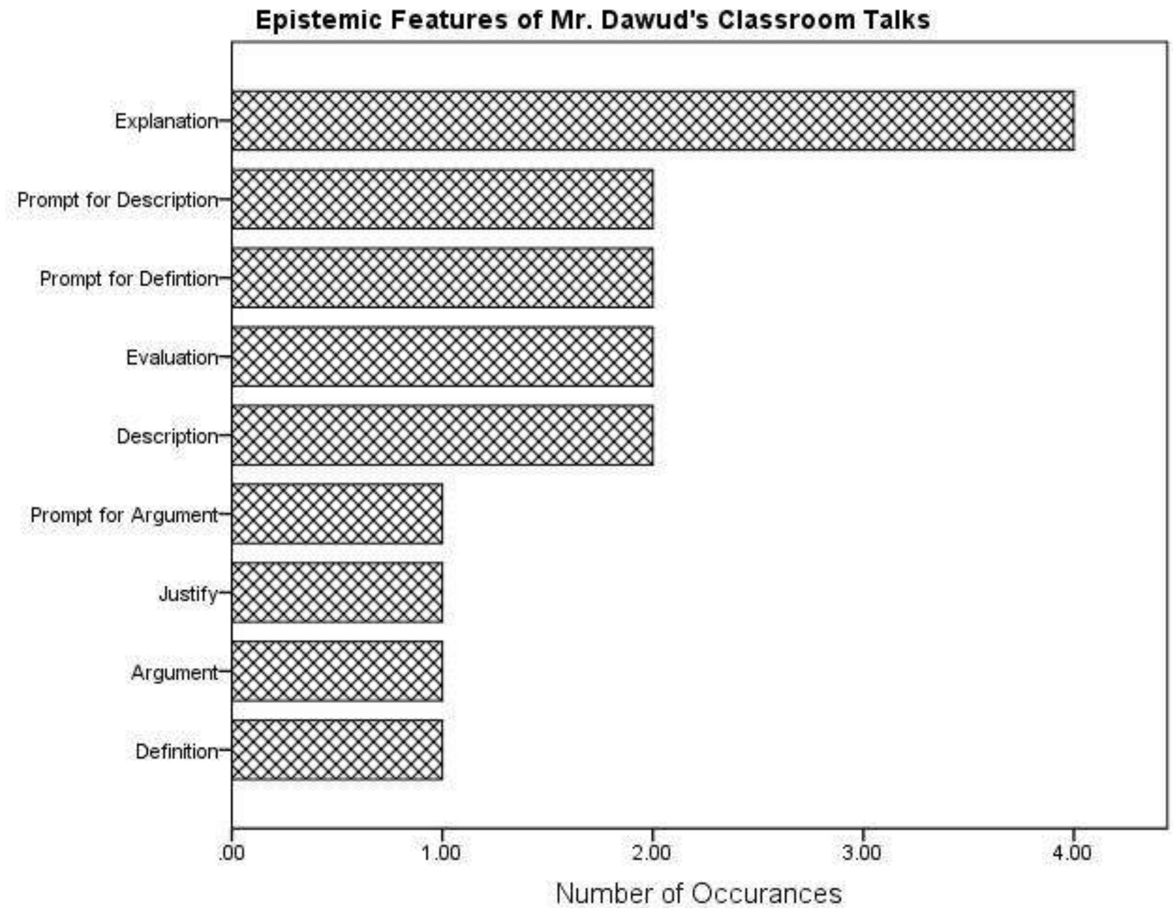


Figure 4.6 Epistemic features observed from Mr. Dawud's classroom talks in argumentation lessons.

The epistemic aims observed in Mr. Landabo's instructions were also observed in Mr. Dawud's instructions. Regarding constructing scientific knowledge, Mr. Dawud's instructions have one more additional feature, *prompt for argument*. Like Mr. Landabo, Mr. Dawud exhibits the epistemic feature of justifying as shown in Figure 4.6. As regards evaluating scientific knowledge claims, Mr. Dawud manifests the feature *evaluation* more often but not practicing *compare and contrast* whereas Mr. Landabo reveals the feature *compare and contrast* once but not practicing *evaluation* at all.

Out of sixteen utterance codes, seven utterances are epistemic aims of argumentation (four utterances of e*xplanations*, and two utterances of *description*, and one utterance of *definition*); six utterances are constructing scientific knowledge claims (two utterances for each of *prompt for definition* and *prompt for description* and one utterance for each of *argument* and *prompt for argument*); and one utterance of justifying (one utterance of j*ustify*) and two utterances of evaluating (two utterances of *evaluation*). This implies that Mr. Dawud attempted to discuss with his students about epistemic aims of science and epistemic features relevant to constructing scientific knowledge. In Mr. Dawud's argumentation-based lesson, the lowest number of epistemic features were observed compared to other teachers.

Figure 4.11 shows that both Mr. Landabo and Mr. Dawud made a single strong connection; Mr. Landabo made relatively strong connections between epistemic aims and constructing knowledge, whereas Mr. Dawud made a relatively strong connection between construction and evaluation of knowledge claims. Excerpts presented in Example 3 and Example 4 illustrates how Mr. Dawud attempted to communicate the epistemic aims of the science activities and to support students to build scientific knowledge.

Two of the common epistemic features seen in Mr. Dawud’s classroom talk is *description*, and *explanation*. In Example 3, from Line 205 to 209, Mr. Dawud describes the category of materials into three based on the criteria whether light can pass through the given matter fully, partially, or not at all. Mr. Dawud describes these three kinds of materials. Mr. Dawud had used various questions to teach issues such as how light travels, what will happen when light meets a shining surface, and also used various examples to explain the reflection of light. In Example 3, the line from 226 to 233 shows these teachers attempt to explain the reflection of light.

Example 3: Excerpts that depict *Description* and *Explanations*

205 There are three types of [materials], one is transparent, second is translucent, third is opaque, thus
207 how to define transparent, the transmission of kinds of light, please read it.
208 Transparent [materials] are said to the medium of light transfers, the second one is translucent
209 which partial transfers of light (Inaudible) opaque not transfers of light, transfers of light is
226 The angle of reflections, this one is beta, this one is 90^{o}, then, this normal angel is to show
227 the normal of (Inaudible) in the mirrors and this is surface area is this, mirrors, show
228 the mirrors and calculate the angle of each depth plus theta 90^{o}, then theta is given as for
229 example, 60^{o} degree or whatever 30^{o}, as given as the angle plus theta=90^{o}, theta is given
230 as 60^{o}, then the angle of depth plus $60^{o} = 90^{o}$ and $90^{o} - 60^{o} =$ is 30^{o}
231 (Inaudible)...the same formula, we have seen in the previous times in the discussion and
232 the reflect angle + theta = 90^{o} as given as, theta + 60 degree = 90 degree, 90 degree - 60
233 degree = reflected angles, so the reflected angle = 30^{o}, and continuing to that, same of

In addition to epistemic aims, Mr. Dawud's classroom talks had few features related to constructing scientific knowledge. The epistemic features observed were *prompt for definition* and *prompt for description* were observed when this teacher begins a new topic and during the discussion. Example 4 gives a few of the excerpts observed in Mr. Dawud's argumentation lesson.

Example 4: Excerpts that depict *prompt for description* and *prompt for definition*

186 What is the source of light? ... Source of light is what? Yes Kaleab
188 T: Yes that is right. New hand? Ekuma, What is the source of light?
197 T: Okay light travels...no one what do we mean by that light travels? Mekedes? Light travels in
199 The other portion is kinds of light transmissions. What are the kinds of light transmission?
201 kinds of light transmissions, the first one, third, second. What are the kinds of light
229 What is the value of angle theta? degree or whatever 30 degrees, as given as the angle plus

As seen in Example 4, Mr. Dawud's *prompt for description* and *definition* were not good enough to produce fruitful argumentative interactions in the classroom. Like Mr.

Landabo, Mr. Dawud's talks had shown a content-related knowledge shortage. Perhaps, the poor quality of the Ethiopian science classrooms might originate from such hindrances.

In Mr. Dawud's argumentation lesson, his classroom talk did not address epistemic aims and epistemic ideals (includes constructing, justifying, and evaluating scientific knowledge claims). The dominant epistemic process observed was knowledge construction. However, Mr. Dawud made much discourse facilitating moves in his lesson. He tried to communicate the epistemic aims of various activities he was doing in the classroom. He also attempted to engage students by *prompt for description* and *prompt for definition*. Overall, his discursive actions did not engaged students in epistemic practices of science. Mostly, he was the initiator of the discussion, then students with many pushes responded to him, and he evaluates the response. When the answers were wrong, he tried to stir students' answers. His communication with students followed an IRE pattern.

The qualitative analysis of this teacher's classroom epistemic talk, the epistemic features observed in his lessons as shown in Figure 4.6, and the ENA of these teachers (presented in Figure 4.6) gives insight into the how this teacher's argumentative instruction contributed towards promoting students epistemic knowledge of science. Mr. Dawud showed the lowest number of epistemic features. Mr. Dawud had attempted to encourage students to participate. However, due to the poor quality of questions raised by him, he could not create cognitive conflict on students' minds and stimulate them to talk. Though this teacher seemed to understand the importance of questions to enhance students' understanding of science and to engage in the scientific practices, the quality of his questions contributed less towards this end. Besides, this teacher did not make strong and frequent connections between epistemic aims, ideals, and processes.

4.2.2.1.3 Epistemic feature observed from Mr. Aregawi's argumentative instruction (CS-3)

In Figure 4.7, we presented the epistemic features observed in Mr. Aregawi's argumentation lesson. The epistemic features observed here are more diverse compared to the epistemic talks of Mr. Landabo and Mr. Dawud. Twenty-one utterances were observed. Out of these twenty-four codes that represent the epistemic aims and ideals of argumentation (see the codes in Table 3.3), thirteen epistemic features were observed on Mr. Aregawi's epistemic talk. Among these thirteen features observed, *explanations* (with four utterances), *descriptions*, *prompt for description*, *propose position*, *justify*, and *evaluation* (with two utterances each) and *provide evidence*, *prompt for model*, *prompt for justification*, *prompt for evaluation*, *prompt for argument*, *model*, and *compare and contrast* (with one utterance each). In other words, *epistemic aims* (with six utterances), *constructing* (with eight utterances), *justifying* (with three utterances), and *evaluating* (with four utterances).

As shown in the mean network of Mr. Aregawi in Figure 4.11, Mr. Aregawi had made connections between epistemic ideas and construction, construction and justification, justification and evaluation, and evaluation and epistemic aims. Nevertheless, the connections are not strong and also are not frequent. Compared to Mr. Landabo and Mr. Dawud, who made only a single connection between the four epistemic features, Mr. Aregawi made four connections. Excerpts presented in the examples given in this section attempt to show the overall nature of Mr. Aregawi's classroom talk in the argumentation lesson.

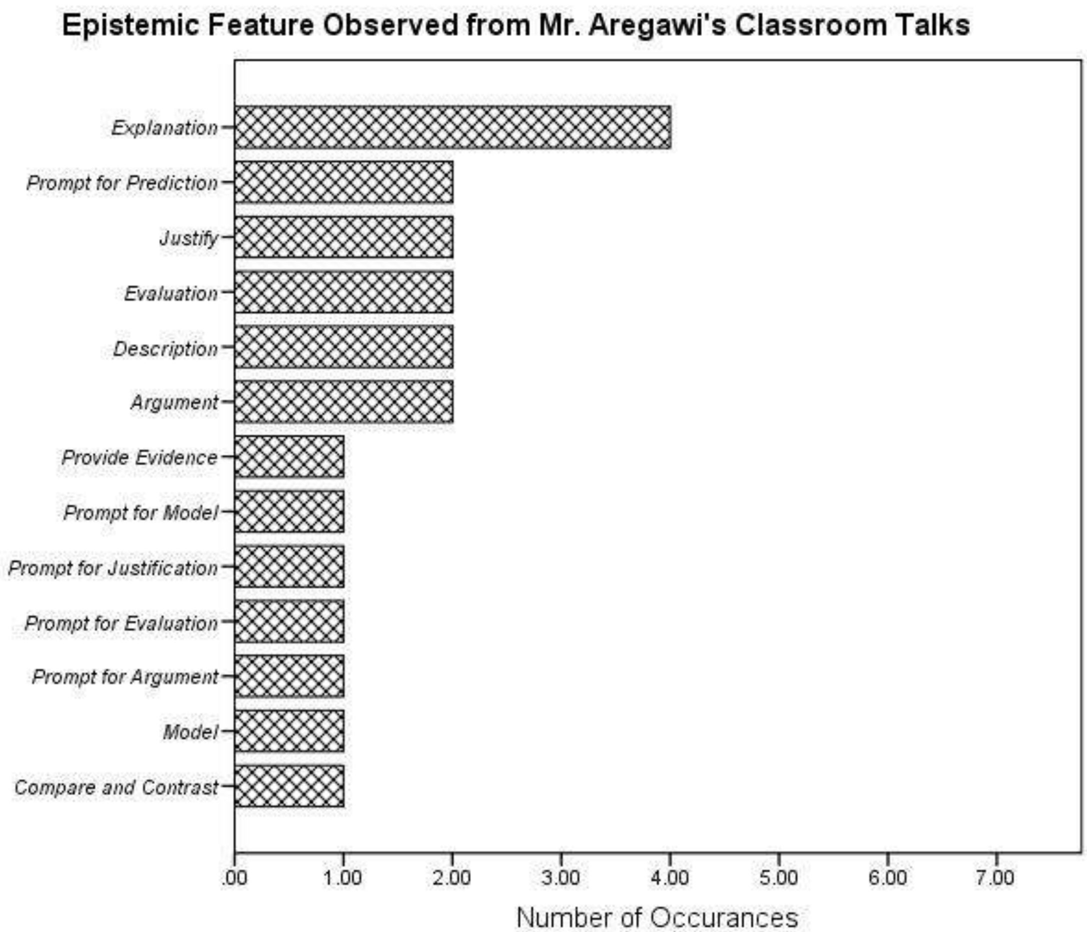


Figure 4.7 Epistemic features observed from Mr. Aregawi's classroom talks in argumentation lessons.

Among many epistemic features observed in Mr. Aregawi's argumentation lesson, *model* and *prompt for model* were observed in his lesson only. *Modelling* is an utterance that is used to reveal abstract physical concepts in Mr. Aregawi's case, image formation. Mr. Aregawi attempted to make clear how images are formed in spherical mirrors. Example 5 presents the excerpts that Mr. Aregawi utterances related to *modelling*. Mr. Aregawi attempted to engage students in *modelling* by discussing important concepts in image formation and their pictorial representations. As a *prompt for modelling*, Mr. Aregawi gave for two students to come to the blackboard and show how images are formed at various locations. Students were using terms like principal axis, focal point, the center of curvature, and incident rays that come parallel to the parallel axis, and line that pass through the center of curvature.

Example 5: Excerpts that depict *Modelling*, and *Prompt for modelling*

288 T: Okay. What if the incident [ray] passes through f [focal point]? What if the
289 the incident is parallel to the x-axis? Okay. This one is an incident and this one is reflected
290 Therefore, these two rays are showing us the reflection. What about the
291 one that passes through C, It comes back? Uhh. If It goes through C,
292 It will reflect through C. This helps us to know the image formed

Another important epistemic feature observed in Mr. Aregawi's classroom talks was *compare and contrast*, that shows the evaluating scientific knowledge in Mr. Aregawi's argumentation lesson. Mr. Aregawi used to compare the characteristics of images formed at five various points: between the focal point and the vertex, at the focal point, between the focal point and the center of curvature, at the center of curvature, and beyond the center of curvature. Example 6 presents the excerpts of this teacher-related to *compare and contrast*.

Example 6: Excerpts that depict *Compare and Contrast*

371 To sum it up... All of you, pay attention. We have seen this before. Uhh. If it is.
372 beyond C, where will the image be formed? Uh. Yes. What else will happen to the
373 image? It will be smaller. It will be smaller than the object. What number is this?
374 Number one. The one at C will remain at C. (Yes). The same size.
375 What about the one between C and F? It will be beyond C. Beyond C.
376 It will be larger than the object. Right. What about when it is at F?
377 No image. There will be no image. What about here? Behind the mirror?
378 Uhh. Erected? Uhh. Larger than the object. This is number five.
379 Why? Yes. Both the reflected rays do not have an Intersection.
380 They are parallel. Therefore, they cannot form an image. One, two, three.
381 It is opposite. Three, two, one. They are all inverted. Uhh. The one that was the.
382 farthest will get closer and the closest one will get farther.
383 Where should we put It? Right here. Right here. It will come right here. Yes.

384 I mean. No. No. No. This one was the closest therefore, It will go farther.
385 Yes. They are equal right here. The one
386 that is farthest will increase in size. Okay. Do any of you have a question?
387 Something that is not clear. Is there any question? Uhh. Is it clear? Uhh.
388 Five images were not formed. The reflected rays are parallel. We have seen this.
389 The reflected rays from an image, the other could not form an intersection.
390 Therefore, an image could not be formed. The image at infinity. Is there any question?

As excerpts from Line 371 to 390 in Example 7 shown, Mr. Aregawi tried to compare image formation at five different positions. Besides, this teacher draws each of the images for the compared five positions of the object. In Mr. Aregawi's argumentation lesson, his classroom talk seemed to depict more epistemic features compared to Mr. Landabo and Mr. Dawud's argumentation lesson. Mr. Aregawi attempted to touch epistemic aims and epistemic ideals (includes constructing, justifying, and evaluating scientific knowledge claims). The epistemic process observed includes *epistemic aims* (6 utterances), *constructing* knowledge (eight utterances), *justifying* knowledge (three utterances), and *evaluating* knowledge (four utterances). Moreover, Mr. Aregawi made a lot of science-related moves and discourse facilitating moves in his lesson to engage students. Like Mr. Dawud, Mr. Aregawi initiates the discourse, and sometimes the IRE pattern of talks was visible in his lesson.

4.2.2.1.4 Epistemic feature observed from Mr. Teshome's argumentative instructions (CS-4)

Figure 4.8 presents the epistemic features observed during Mr. Dawud's argumentation lesson. Among twenty-four codes that represent the epistemic aims and ideals of argumentation (see the codes in Table 3.3), only ten were observed on Mr. Dawud's epistemic talk. Among these ten features observed, *explanations* (three utterances), *descriptions* (one utterance), and *definitions* (one utterance) are epistemic aims; *prompt for argument* (one utterance), *prompt for prediction* (one utterance), and *prompt for description* (three utterances) are constructing scientific knowledge claims; *justify* (two utterances) and *prompt for justification* (two utterances) are with justifying scientific knowledge claims; and *prompt for evaluation* (one utterance) and *prompt for counter* (one utterance) is with evaluating scientific knowledge claims. In Mr. Teshome's case, *epistemic aims* (four utterances), *constructing* (five utterances), and *justifying* (four utterances), knowledge seemed balanced, whereas *evaluating* knowledge was with two utterances.

As shown in the mean network of Mr. Teshome in Figure 4.11, Mr. Teshome had made one connection between epistemic aims and evaluation and another connection between construction and justification. The first connections are relatively stronger when compared with the second one. Mr. Teshome’s classroom talk presents better connectedness among epistemic features of science compared to Mr. Landabo and Mr. Dawud’s classroom talk. When compared with Mr. Aregawi, Mr. Teshome’s classroom talk presents better connectedness among epistemic features of science.

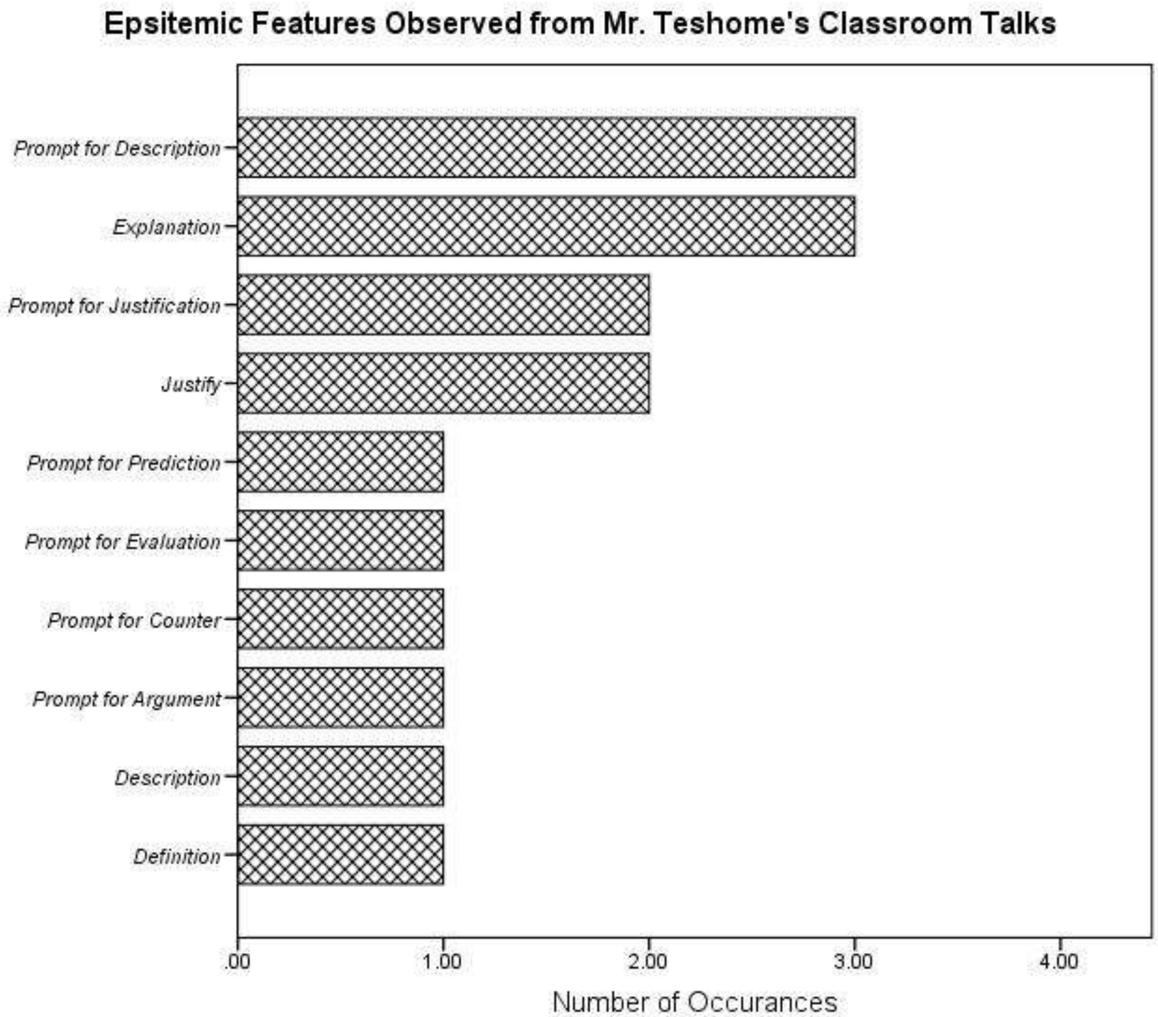


Figure 4.8 Epistemic features observed from Mr. Teshome's classroom talks in argumentation lessons

As shown in Figure 4.8, Mr. Teshome made few connections between various epistemic features. This teacher also made continuous engagement with his students. He also frequently encourage students to involve in the classroom. He continuously asked students to justify their answers. As shown in the excerpts given in Example 7, utterances (line 509) such as "how do you show that they are equal?" depicted that in Mr. Teshome's classroom talk *prompt for justification* had been observed. *Prompts for justification* is linked with utterances that encourage someone to provide their justifications for the answer they had forwarded or the views that they had accepted. *Prompt for justification* pushes students to provide their reasoning or justification for how they used data as evidence or how their reasoning is the correct explanation of the phenomena under investigation. It provides an opportunity for students to justify why their evidence supports their claims and to connect evidence and reason logically.

Moreover, Example 7 shows one of the classroom dialogue between Mr. Teshome and his students. The communication seemed different from an IRE pattern. In this example, the question Mr. Teshome utters in Line 509 of Example 6 tells the emphasis Mr. Teshome has for justification to one's claims to knowledge.

Example 7: Excerpts that depict *Prompt for Justification*

502 S: then, the angle of reflection and theta are added to give 90 degrees. then since
503 the angle of incidence and angle of reflection are equal, the angle of reflection is equal
504 to 50 degrees. Subtracting from 90 degrees 50 degrees, we get 40 degrees for theta.
505 T: what is ninety minus 40?
506 S: 50...no fifty is subtracted from 90...40.
507 T: like this...this means 40 degrees...ee...
508 S: [inaudible]...if that one is 40 degree, then that one also be 40 degrees.
509 T: so, how do you show that they are equal? For example... the law of reflection.

In Mr. Teshome's classroom talks, *explanations* were observed. When students attempt to construct scientific explanations, engaging in argumentation is inevitable. In such scientific practices, students understand to evaluate the validity of others' claims and to support their claims with evidence. Example 8 presents excerpts that depict *explanations* in Mr. Teshome epistemic talk. Mr. Teshome was explaining to students about the law of reflection.

Example 8: Excerpts that depict *Explanations*

T: the law of reflection says that the angle of incidence and angle of reflection are equal. it is not that the angle between the mirror and the reflected ray, theta, and this one [pointing to these angle on the blackboard] are equal. But we called this N and this one O. ON is perpendicular to what? To MM'. then, $\beta+\theta=90^o$, 40^o plus alpha equals 90^o relative to the normal. it is because the mirror is perpendicular to the normal, not because this one passes to here and makes it 40^o. Now incidence ray strikes the surface of the mirror at an angle of…what? 40^o. If it was 30^o [angle of incidence], this one would also be 30^o [angle of reflection]. What about this?

Overall, Mr. Teshome has made so many complete dialogues with his students. In Mr. Teshome's argumentation lesson, his classroom talk seemed to depict more epistemic features compared to Mr. Landabo and Mr. Dawud's argumentation lesson but less epistemic features compared to Mr. Aregawi. In this teacher's talk, we observed epistemic aims (five utterances), constructing knowledge (five utterances), justifying knowledge (four utterances), and evaluating knowledge (two utterances). Moreover, Mr. Teshome's classroom talk was different from the traditional IRE model.

4.2.2.1.5 Epistemic feature observed from Mr. Megerissa's argumentative instructions

Figure 4.9 shows epistemic features observed during Mr. Megerissa's argumentation lesson. Among twenty-four codes that represent the epistemic aims and ideals of argumentation (see the codes in Table 3.3), only eight types of epistemic features were observed on Mr. Dawud's epistemic talk. This was the smallest, as in the case of Mr. Landabo. Among these eight features observed, *explanations* (six utterances), *descriptions* (four utterances), and *definitions* (one utterance) are epistemic aims; *prompt for prediction* (one utterance), and *prompt* *for description* (one utterance) are constructing scientific knowledge claims; *justify* (one utterance) are justifying scientific knowledge claims, and *counter* (one utterance) and *prompt for counter* (one utterance) is with evaluating scientific knowledge claims. In Mr. Megerissa's case, epistemic aims (eleven utterances), constructing (two utterances), justifying (one utterance), and evaluating (one utterance). This reveals that Mr. Megerissa's epistemic talk was significantly dominated by epistemic aims. Other features of epistemic practices of science were not properly addressed, whereby constructing, justifying, and evaluating knowledge were observed in only five utterances.

As shown in the mean network of Mr. Megerissa in Figure 4.11, Mr. Megerissa had made a single and relatively less frequent connection between epistemic aims and construction. Mr. Megerissa's classroom talk presents poor connectedness among epistemic features of science compared to Mr. Teshome and Mr. Aregawi's classroom talk. The mean network diagram reveals that Mr. Landabo, Mr. Dawud, and Mr. Megerissa were not presenting different epistemic practices features of science in their classroom talk during argumentation lessons. Since in Mr. Megerissa's classroom talk, 'Explanations' and 'Descriptions' are the dominant one, we will discuss these two using excerpts taken this teacher discursive action. In example 9, line 583 to line 587 presents Mr. Megerissa's explanation about uniformly accelerated motion, whereas line 568 to line 574 presents, this teacher's description of problem-solving strategies

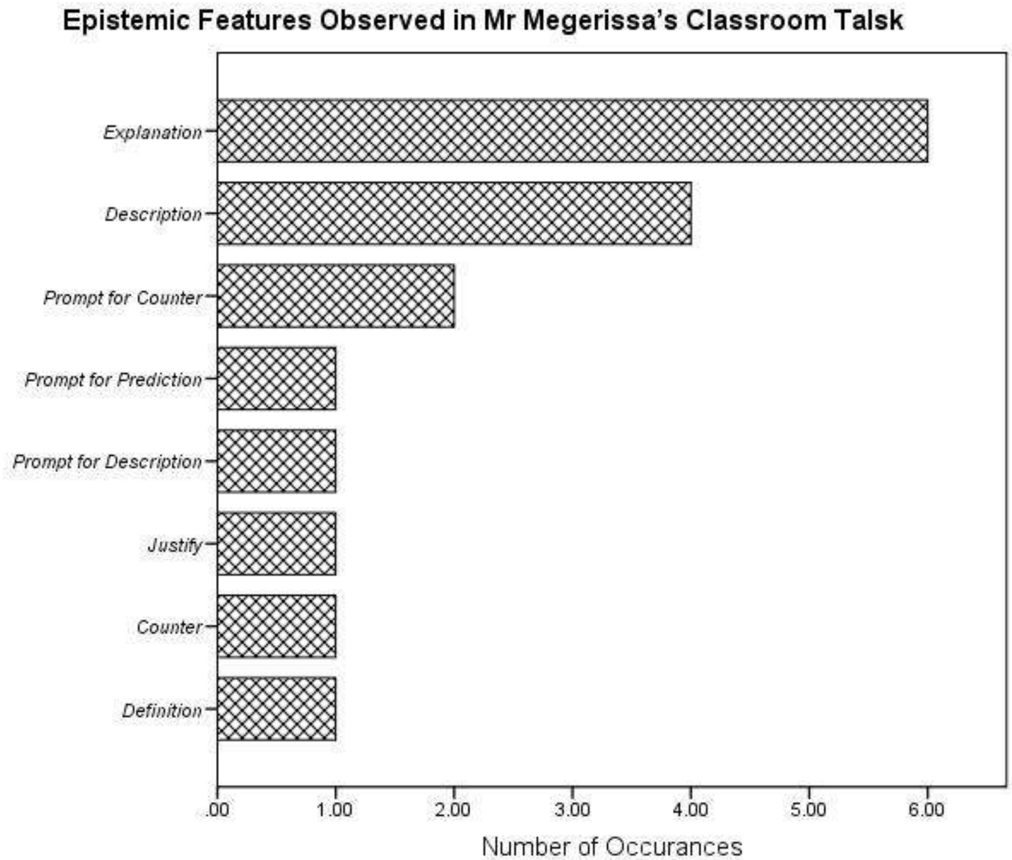


Figure 4.9 Epistemic features observed from Mr. Megerissa's classroom talks in argumentation lessons.

Example 9: Excerpts that depict *Description* and *Explanations*

583 T: It is uniform? motion, so in uniform motion velocity is constant, acceleration
584 is zero, so the answer is what C, constant velocity means? Vi=Vf the
585 starting velocity and the final velocity becomes the same, acceleration is what?
586 change in velocity/change in time, now here we have the same numbers, the
587 difference between the same number becomes what? 0, 0/any number is what?
588 0, so acceleration becomes 0.
568 T: 126, we could say 126.0 or 126km/hr, so when you do these types of
569 the calculation, what did I tell you to do, remove the decimal point right? you
570 pretend as if there is no point, to multiply the numbers just like we know it, so
571 35 multiplied by 36, isn't it? 6*5=30, 0 we with this 21, 3*5=15, 5 we have 1,
572 3 times 3 equals 9 with this 10, are you paying attention? So we sum the two numbers, 0 is

excluded because we cannot sum up 0, 6, 2 we have 1, now the decimal point is after one digit here from right to left side, so we put our point, what would it be? 126 km/hr. This is the first question, is it clear?

Mr. Megerissa attempted to engage students in their science learning. However, most of the questions this teacher raised were not argumentative. Most of the important epistemic processes related to epistemic practices of science were either absent or minimally addressed. The elements related to constructing, justifying, and evaluating knowledge were not practiced much. These elements of epistemic practices of science are important to the development of students' epistemic knowledge of science.

4.2.2.1.6 Epistemic feature observed from Mrs. Ethiopia's argumentative instructions

In Mrs. Ethiopia's argumentation lesson, her classroom discourse was dominated by giving explanations. Explanations are any utterances that teachers made to clarify reasons and principles related to the phenomena discussed. As shown in Figure 4.11, the most common discursive actions of Mrs. Ethiopia also included epistemic aims of science, justifying scientific knowledge claims, and evaluating scientific knowledge claims. This would imply that Mrs. Ethiopia has focused and balanced all aspects of epistemic features in her classroom talks. In Mrs. Ethiopia's lesson, seven utterances of *explanation* were observed. The functions of most of these explanations were to clarify and describe a physical phenomenon. These *explanations* were also used to initiate and instigate arguments in the classroom. (See Figure 4.10). One of the questions raised in her lesson was:

"We only see the moon and stars at night. Why?"

To support students to construct scientific knowledge of physics concepts and phenomenon, elements of constructing scientific knowledge claims such as *propose positions*, *description, analogy, providing evidence, prompts to description* and *arguments* also took place in Mrs. Ethiopia discursive actions.

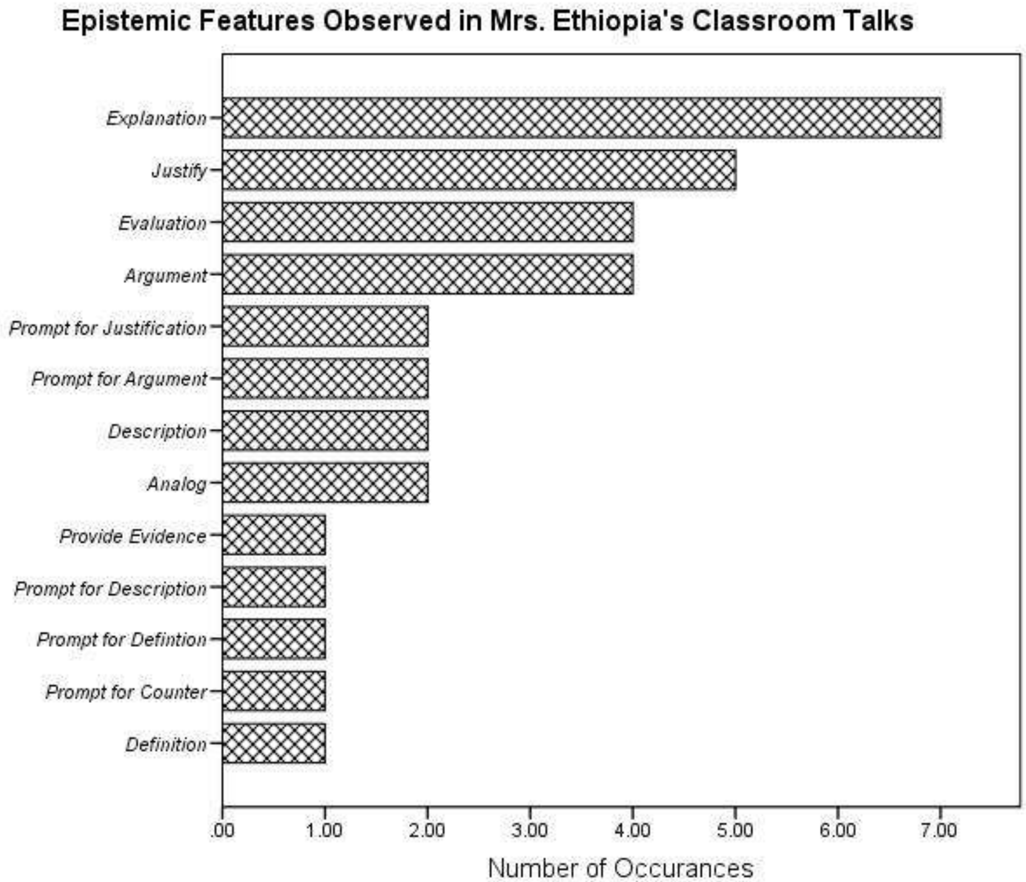


Figure 4.10 Epistemic features observed in Mrs. Ethiopia's classroom talks in an argumentation lesson

4.2.2.2 Cross-case Analysis of teachers' epistemic feature observed from argumentation lessons

4.2.2.2.1 Epistemic practices of teachers in argumentative instructions

The overarching goal of any science instruction should be to help students develop the skills necessary to criticize scientific claims and effectively use evidence (Osborne, 2010). The qualitative analysis of classroom teaching videos investigated how six Grade-8 physics teachers used argumentation to achieve this primary goal of science education. Thus, it is important to understand the ways these teachers deliver instructions to enhance their students' epistemic knowledge of science, such as using critique and evaluating evidence (Berland & Reiser, 2009). The epistemic network analysis (ENA) of the video transcripts of six whole-class teachings, which included teachers' argumentative instructions, generated a mean network of each teacher's epistemic practices of science. The qualitative evidence was used to better understand the challenges teachers face when they promote the knowledge building process in Grade-8 science classrooms, which also supported the ENA results. Both ENA and qualitative excerpts provide the complete picture, as well as a fully comprehensive description of the epistemic practice of teachers who used argumentative instruction. Examining and understanding their challenges is a natural extension of these analyses.

Figure 4.11 presents the mean network of the six teachers in this study. The mean network plots show the frequencies of various connections among epistemic aims and ideals in each teacher's classroom discourse. The weight of the line represents the number of connections that teachers made between aims and ideals. Thus, thicker lines indicate those teachers who made more frequent and stronger connections. Based on the mean network plot presented in Figure 4.11, a subtle difference in overall strength and frequency of connections is evident, particularly the connections that each teacher made in their discussions with students. Mrs. Ethiopia's thicker lines are an indication that she made strong connections between epistemic aims and ideals compared to the other teachers, and her connections were also frequent. Mr. Aregawi seemed to make connections between various epistemic features, but the thinner lines in his mean networks implied that the connections were not as strong and frequent.

Both Mrs. Ethiopia and Mr. Aregawi made strong and frequent connections between epistemic aims of science, constructions, justifications, and evaluations of scientific knowledge claims compared to the other teachers. Nonetheless, the other four teachers also made connections between various epistemic features of science. For example, Mr. Landabo made strong connections between epistemic aims and construction of scientific knowledge claims but no connection between the other components. Mr. Megerissa made connections between epistemic aims and construction of scientific knowledge claims, though they were not as strong as those of Mr. Landabo. Like Mr. Landabo, Mr. Megerissa also made no connection between the other components. Mr. Dawud made a strong connection between constructions and the evaluation of scientific knowledge claims. Again, like Mr. Landabo and Mr. Megerissa, Mr. Dawud did not make any connection between epistemic aims of science and justification of scientific knowledge claims, but the mean networks for both Landabo and Megerissa did not show any connection with constructing or evaluation of scientific knowledge claims. Mr. Teshome made connections between constructions and justification of scientific knowledge claims, as well as between epistemic aims of science and evaluating knowledge claims in his argumentative instructions. Mr. Teshome made no further connections across the various epistemic features of science.

Excerpts taken from each of the teacher’s classroom discussions revealed that Mrs. Ethiopia’s and Mr. Aregawi's instructions had produced relatively strong and frequent connections between various epistemic features. The other teachers’ (i.e., Mr. Teshome, Mr. Landabo, Mr. Megerissa, and Mr. Dawud) instructions resulted in weak connections between various epistemic features of science (see Figure 4.11). These excerpts, depictions of teachers’ trends related to talking about epistemic aims and ideals, and teacher interviews were used to shed light on the opportunities and challenges that the physics teachers faced in their efforts to promote the epistemic knowledge of students.

Figure 4.11 Mean networks for six grade 8 physics teachers showing connections made between epistemic aims, constructing, justifying, and evaluating scientific knowledge claims. (These teachers used argumentation as a pedagogy.)

Figure 4.11 reflects the nature of epistemic practices of science using epistemic networks. The ENA revealed that the physics teachers' EPS was weak.

- Mrs. Ethiopia made strong connections between *Constructing* and *Justification, Epistemic Aims* and *Constructing,* and *Evaluation* and *Justification.*
- Mr. Aregawi made weak connections between *Constructing* and *Justification, Epistemic Aims* and *Constructing, Evaluation* and *Justification,* and *Epistemic Aims* and *Evaluation*.
- Mr. Teshome made two weak connections between constructing and *Justification*, and *Epistemic Aims* and *Evaluation* and *Justification.*
- Mr. Landabo, Mr. Megerissa and Mr. Dawud also made weak connections between *Constructing* and *Epistemic Aims, Constructing* and *Epistemic Aims,* and *Constructing, Aims* and *Evaluation,* respectively.

Most of the physics teachers made weak and less frequent connections between *Epistemic Aims* and *Constructing*, *Justification* and *Evaluation* in their argumentative instructions. The strength and frequency of connections between *Epistemic Aims* and *Constructing*, *Justification* and *Evaluation* illustrate the nature of teachers' epistemic practices of science during argumentation lessons.

4.2.2.2.2 Epistemic features observed during argumentation instructions

This section presents the features of epistemic knowledge of science observed during argumentation lesson and also discusses these epistemic practices in terms of the component dimensions of epistemic aims, constructing, justifying, and evaluating scientific knowledge claims. Table 4.6 summarizes these observed features of epistemic knowledge of science from the six teachers' dialogic instructions.

Table 4.6 Features of epistemic knowledge of science observed during video recorded argumentation instructions

	Codes	Code counts	Percentage (%)
	Sub codes of epistemic aims	56	42.80%
1	Analogy	2	1.50%
2	Description	16	12.20%
3	Examples		0.00%
4	Explanation	31	23.70%
5	Summary		0.00%
6	Modelling ()	1	0.80%
7	Definition	6	4.60%
	Sub codes of constructing SKC	38	29.00%
8	Propose Position (Argument)	13	9.90%
9	Prompt for Argument	5	3.80%
10	Prompt to Define	4	3.10%
11	Prompt to Describe	9	6.80%
12	Provide Evidence	1	.80%
13	Request Evidence		0.00%
14	Prompt to Modeling ()	1	0.80%
15	Prediction/ Hypothesize		0.00%
16	Prompt to Prediction/ Hypothesize	5	3.80%
	Sub codes of justifying SKC	21	16.00%
17	Justify	16	12.20%
18	Prompts to Justify	5	3.80%
	Sub codes of evaluating SKC	17	13.00%
19	Compare & Contrast	2	1.50%
20	Prompt to Compare & Contrast		0.00%
21	Provide Counter-argument	4	3.10%
22	Consider Alternatives	1	0.80%
23	Evaluation	8	6.10%
24	Request to Evaluate	2	1.50%

In Table 4.6, the number of codes (and its percentages) of the transcripts are presented across both the major features of epistemic knowledge of science and its sub codes. Next analysis and interpretation of the results of Table 4.6 are aligned with the four components of epistemic knowledge of science and described in details.

4.2.2.2.2.1 Epistemic aims

Epistemic aims are the dominant discursive actions found in the six teachers' argumentation lessons. It was found that 42.8 % of the features of epistemic knowledge of science observed lies under epistemic aims. Some of the reasons for the dominance of epistemic aims on teachers classroom talk are teachers' discourses had focused on providing relevant information or evidence so that students can construct and utilize their scientific knowledge. As reported earlier, students are poor, hence they require a large amount of factual information and content knowledge. This situation might force teachers talk towards *descriptions* and *explanations.* As a matter of fact *explanations, descriptions* and *definitions* are observed frequently in these six teachers argumentation lessons.

4.2.2.2.2.2 Constructing scientific knowledge claims

The second important epistemic knowledge observed in intervention groups to promote students' epistemic knowledge of science was *constructing* SKC. *Propose position (argument), prompt to describe, prompt for argument, prompt to define, prompt to prediction* and *provide evidence* were observed in order from much frequent to less frequent. The component of *constructing* SKC such as *request evidence* and *prediction/ hypothesize* were not observed.

4.2.2.2.2.3 Justifying scientific knowledge claims

Both *justify* (more frequent) and *prompt to justify* (less frequent) were present in most of the argumentation lessons. Justifying SKC covered 16.0 % of the overall epistemic features observed. Most argumentation lessons failed to make students ideas explicit by asking them to justify their claims. In the argumentation lessons, the function of justification was both procedural and epistemic in nature. Justification served for the procedural function when the teachers provided directions and for epistemic purpose when the teacher supported for a particular SKC. In constructing and reconstructing scientific knowledge, asking students how do they know and why it is right or wrong initiated arguments.

4.2.2.2.2.4 Evaluating scientific knowledge claims

This is the smallest portion of features of epistemic knowledge (13.0 % of the total epistemic features) observed in the intervention groups argumentation lessons. Most of the dimensions of evaluating SKC were not present in the observed argumentation lessons.

4.2.3 Qualitative analysis of interviews

Qualitative analysis of interview transcripts resulted in further elaborations of the challenges and prospects physics teachers faced in promoting epistemic knowledge of students in argumentation lessons (see Appendix C for the teachers' interview protocol). These text data were coded using open coding and inductive categorization (Corbin & Strauss, 2014). In the open coding, forty-six teachers' practices that are related to the epistemic climate in promoting student's epistemic knowledge in argumentative instructions were identified. Then in the second coding, these core challenges were condensed into three major categories. The qualitative analysis of teachers' interviews include triangulation with the other data sources such as videotaped classroom teaching.

To ensure the reliability during coding, two raters (the author and another Ph.D. candidate in physics education at Addis Ababa University) coded the six teachers' interview transcripts. The value of Cohen's kappa (κ = .824) confirmed inter-rater reliability.

To establish validity further, we quote teachers' utterances verbatim from original interview transcripts in addition to our interpretations of teachers' argumentative instructions.

These steps ascertained the validity and reliability of the qualitative analysis of interviews using the trustworthiness criteria, namely credibility, dependability, and confirmability. The multiple-phases of coding allowed the raters to make sense of teachers' pedagogical practices and, therefore, ensured credibility by minimizing any possible distortions in understanding teachers' challenges to promote students' epistemic knowledge of science. The raters' expertise ascertained dependability, whereas the interview transcripts and verbatim depicted to support interpretation addressed confirmability. Table 4.7 presents the major codes and the description of these codes that emerged from analyses of teacher interview transcripts. Next, a description of the analysis of each category is given.

Table 4.7 Coding Schemes for the qualitative analysis of teachers' interviews

Codes	Description of Codes
Implementation Characteristics	Discuss the extent of argumentation lessons in their physics teaching
Challenges Faced	Discuss the main challenges faced during these argumentation lessons
Strategies to Promote Students Talks	Discuss strategies implemented to promote students talk in these argumentation lessons

4.2.3.1 Implementation characteristics

Qualitative analysis of teacher interview transcripts revealed a wide range in implementation characteristics of argumentation lessons with responses varying from 'used frequently' (Mr. Landabo, Mr. Megerissa, and Mr. Dawud) to 'used only when the topic taught is suitable' (Mr. Aregawi, Mrs. Ethiopia and Mr. Teshome). In the interview, teachers also described how they used argumentation in their lessons. The following excerpts show teachers' responses.

…from the three periods allocated for physics, we used it [argumentation lessons] in the two of these periods. I used argumentation to probe students' prior knowledge of the topic and to brainstorm their understandings. I had found that argumentative activities are motivating students. [Mr. Landabo]

Mainly, I had used argumentative activities during the laboratory sessions. … I also used argumentation lessons when the [activities in the] material [i.e., TPSS Talking Physics Manual] are related to the topics of my lesson. [Mr. Megerissa]

The above excerpts indicated that many of the teachers used argumentation when the topic is suitable for argumentative instructions. Furthermore, teachers confirmed that they had used dialogic argumentation in various physics topics; acceleration (one teacher), force (one teacher), pressure (two teachers), light (three teachers), and topics in electromagnetism (four teachers). This suggests that teachers considered argumentation suitable for few topics of physics. Mrs. Ethiopia added that argumentation lessons provided their instruction more explanatory power and enabled them to ask the 'why' questions in their discussions.

4.2.3.2 Challenges faced

Teachers' responses also revealed the many challenges they face in implementing argumentation in their Grade 8 physics classrooms. Here are some illustrative excerpts from teachers' interview transcripts.

The students do not participate. Student participation is low. (They do not participate) Uhh. This is one of the problems. Besides, similar responses forwarded from different groups during argumentative tasks made it difficult to initiate argumentative interactions. Had they forwarded different answers, instigating arguments might be easy….It was hard to cover the portions of the book. It was hard to make the two go together because we did not have enough time. I have three periods a week, and I had found that hard covering the portions of the book, let alone something else. There was a challenge with the periods. [Mr. Megerissa]

The challenge that I faced is that only a few students were willing to do things. Most of them are not willing. [Another challenge I had faced is] uhh... in time aspect, shortage of time for the discussion... It takes time. That is for sure.

Sometimes when we think that it takes much time, we leave it [teaching using dialogic argumentation] and start teaching as usual. Nevertheless, we use it [teaching using dialogic argumentation] when we have spare time. [Mr. Aregawi]

One of the challenges I have faced is a large number of students. (Ok!). The second is, the students are accustomed to one way of [traditional teacher-centered] science teaching approaches; hence, they usually tended to disturb. These were the main challenge that I had faced. [In addition] Their discussions are largely dependent on one person. That is one of the main challenges, and the other one is their large number. [Moreover] another one is that the materials are not easily available. Specially In physics, not everything is available. [Mr. Dawud]

I think there is a barrier of language for any student as well as a way of communication. (Way of communication). How to communicate or explain the lesson? (Ok!). This is one challenge. What I face when I teach dialogic teaching. [Mr. Teshome]

These teachers' responses indicated that the main challenges arise from student, teacher, and external parameters. Student-related challenges included poor content knowledge of physics, low level of participation, and unwillingness to engage fruitfully during argumentative discourses. Teachers' claim of students' poor knowledge of science supports the quantitative results which show low post-test scores (5.1 out of a total of fifteen points). Students' poor knowledge of physics is one reason for the low preparedness to engage in arguments, to support their claims with evidence, and to openly critique others' scientific claims (Berland & Reiser, 2009; Sampson & Blanchard, 2012). In general, the low level of students' content knowledge of science is the main challenge in these teachers' attempts to implement dialogic argumentation and to promote epistemic knowledge of science.

Teacher-related challenges include the ability to prepare and lead argumentative instructions. Teachers' responses focused on challenges everywhere but themselves. Teachers did not consider their limitations in their epistemic talks, which was observed in the analysis of their whole-class teaching as presented in Section 4.2.2. Perhaps the low level of students' participation might be related to teachers' inability and lack of understanding of the nature of science and the nature of scientific argumentation.

Teachers' responses also pinpointed a third kind of challenge originated from external agents, mainly from curriculum and school norms. Shortage of time to cover the vast school curriculum and large class sizes are frequently mentioned. In summary, the major challenges included poor level of students' participation, poor content knowledge of students, shortage of time, large class size, communication, and group characteristics.

4.2.3.3 Strategies to promote students' talks

Physics teachers used various strategies to promote students' talks. Most of these teachers recognized the importance of talking science to construct and develop students' scientific knowledge. *Asking questions* was identified as the primary strategy to promote argumentation. Other strategies included asking students individually and providing reinforcements as shown in the following responses excerpted from the interview transcripts:

> *During group discussions, students are given points every time they state their opinion. The students, who forwarded clear opinions, get more marks out of five. … When they are given marks, they try the question even though [their answers] are wrong. [Mr. Megerissa]*
>
> *Asking questions. In addition, I asked them to observe the pictures and to reflect on what they understood. [Mr. Aregawi]*
>
> *I usually ask them for their opinions. I ask them to clarify their opinions. (You invite them to talk.) When they are invited to talk, they state their opinions, even though their opinions are wrong. … [However,] They are not always wrong; sometimes, they give the right answers. They usually gave the right answer. [Mr. Dawud]*
>
> *When students did not participate or were not willing, I asked them individually. Individually calling their names and asking to forward their answers to the given questions. [Mr. Teshome]*
>
> *In general, I give them something [questions] that make them discuss 'why' questions. What I tell them is that if you say the answer is true, put your*

reasons and justifications. If you say it is false, justify why it is false. [Mrs. Ethiopia]

These teachers' responses indicate that their strategies are not successful. Mrs. Ethiopia recognized the need to justify claims. Claims should be supported or refuted based on evidence. This qualitative analysis of teachers' interview juxtaposed with teachers discursive practices were central to answer research question three.

4.3 Summary of chapter

In this chapter, we presented a comprehensive analysis of Grade 8 students' progress in their epistemic knowledge of science and changes in their teachers' epistemic practices over the yearlong intervention of argumentative instructions. The quantitative analyses indicated that prolonged engagement of Grade 8 students in argumentation lessons improved students' epistemic knowledge of science. The qualitative analyses also revealed that the argumentation quality of Grade 8 students correlates with their level of epistemic understanding of science. Moreover, the qualitative analyses of teachers' videotaped classroom teachings and interviews identified poor trends of teachers' epistemic discourses during argumentation lessons and various challenges to promote the epistemic knowledge of their students.

Grade 8 students mean test scores on EKIs showed that the intervention groups' level of epistemic knowledge of science increased from pre-test (3.84 ± 1.89) to post-test (5.10 ± 2.48). On the other hand, the control groups' level of epistemic knowledge was a little lower in the post-test (4.06 ± 2.35) compared to their pre-test Scores (4.14 ± 2.28). Further analysis revealed that the intervention group showed statistically significant improvements in their level of epistemic knowledge ($T = 17{,}220$, $z = 6.18$, $p = .000$, $r = .40$), whereas control groups did not show statistically significant improvements ($T = 10{,}080$, $z = -.208$, $p = .835$, $r = -.01$). In addition, there was a strong positive correlation observed between students' epistemic understanding and the quality of their argumentation. The Pearson's product-moment correlation analysis indicated a strong positive correlation between mean scores of epistemic knowledge items and mean ASAC scores, Pearson's $r = .558$, $p = .038$. Dialogic argumentation accounts for 31.14 % of the variations in upper primary school students' epistemic knowledge of science.

Analyses of pre-intervention and post-intervention videotaped students' small group argumentative tasks revealed no substantial difference between the groups in the (nature of) epistemic knowledge features they elicited. Both groups have shown only a few features of epistemic knowledge of science in their talks.

One part of the qualitative analysis of the interview provided more detailed thematic discussion of the post-intervention videotaped classroom teaching in the intervention group. Another part of the qualitative analysis of the interview provided detailed accounts of the challenges faced by teachers to promote students' epistemic knowledge of science. The qualitative results revealed that in argumentation lessons, teachers faced challenges that mainly originated from student- and teacher-related problems and external agents. In the next chapter, the research questions will be discussed in light of the results presented in this chapter.

Chapter 5 Discussion

5.1 Introduction

The purpose of this study was to investigate the effect of dialogic argumentation on epistemic knowledge of Grade-8 physics students. Three questions guided the study:

1) To what extent and in what ways do engagement in dialogic argumentation affect grade eight students' epistemic knowledge?

2) Is there a relationship between the quality of dialogic argumentation generated by grade eight students and their level of epistemic knowledge?

3) What are the nature and characteristic of teachers' epistemic practices as well as constraints faced to promote students' epistemic knowledge through dialogic argumentation? Particularly
   a) What are the features of epistemic practices observed in teachers' discursive action during dialogic argumentation lessons?
   b) What are the challenges teachers' have faced when implementing dialogic argumentation?

The physics reasoning test that contains EKIs was administered at two time points, pre-test and post-test, for both intervention and control groups to measure the epistemic knowledge of students. The quality of student argumentations in small group discussion tasks, video recorded near the beginning and end of intervention, was analyzed using ASAC for both intervention and control groups. The students' discussed in their local languages which were translated into and transcribed in English before analysis. Teachers in the intervention group received a three-day training on scientific reasoning and argumentation.

EKIs (10 items) were developed based on Grade 7 and Grade 8 physics curricula designed for Ethiopian primary schools. These items were selected by experts from the physics reasoning test based on the type of knowledge the items were supposed to represent – content, procedural, epistemic knowledge. The ASAC observation protocol, developed by Sampson et al. (2012), contains nineteen items organized under three aspects: seven items for the cognitive aspect, five, for the epistemic aspect and seven, for the social aspect. A total of 495 students and fourteen teachers from twelve primary schools participated in this study. The schools were sampled from three regional states in Ethiopia.

Data were collected at two time points, pre- and post-intervention. The data included pre- and post-tests, video records of small group student discussions, video records of teachers' whole class teaching, and audio records of teacher interviews. The pre-intervention and post-intervention small group discussions were guided by two different argumentative scaffolding activities – *measuring temperature* and *force and motion*.

5.2 Discussion of findings

5.2.1 Research question one

The main purpose of the first research question was to investigate whether learning physics through dialogic argumentation would change grade-8 students' epistemic knowledge of science. Pre-test and post-test scores on EKIs quantitatively determined students' level of epistemic knowledge. The pre-test results indicated a low level of epistemic knowledge for both the intervention (M = 3.85, SD = 1.89) and control (M = 4.14, SD = 2.28) groups. Moreover, the Mann-Whitney U Test (a non-parametric equivalent of independent sample t-test) results indicated the mean pre-test scores were not statistically significant difference between both groups, (U= 27,126.5, z = 1.04, p = 0.299, r = .05). This, however, assumes that the students' level of epistemic knolwedge, from intervention and control group, was at similar level. Furthermore, this result serves as a benchmark to compare their level of epistemic knolwedge with their post-test scores. After the intervention, the Mann-Whitney U Test revealed that the intervention groups showed small but significant improvement in their level of epistemic knowledge of science compared to the control group (U=35,454, z = 4.5, p < 0.001, r = .19). In other words, the mean EKIs score for the intervention group was higher in the post-test than in the pre-test. Moreover, the Wilcoxon Signed Rank tests (a non-parametric equivalent of repeated measures t-test) of the control group indicated that there was no change between the pre-test and post-test scores (T = 10,080, z = -.208, p = .835, r = -.01). For the intervention groups, the Wilcoxon Signed Rank tests revealed that the mean post-test scores of the intervention group increased statistically significantly compared to their mean pre-test scores (T = 17,220, z =6.18, p = .000, r = .40). In addition, the observed 'medium to large' effect sizes signaled a considerable difference in level of epistemic knowledge between pre-test and post-test scores of the intervention group. The Mann-Whitney U test revealed that the post-test scores of the intervention group was significantly higher compared to that of the control group. No such significant difference was observed in the pre-test comparison of both groups. Moreover, the Wilcoxon Signed Rank tests revealed that the post-test scores of the intervention was significantly higher compared to its pre-test scores. No such statistically significant difference was observed between the mean pre-test and the mean post-test scores for the control group; actually, the mean score was a little lower in the post-test. This indicates a positive impact of dialogic argumentation on students' epistemic knowledge of science. The average normalized gain for the intervention group was .11 whereas the average normalized gain for the control group was .00. Even though, the average normalized gain for the intervention groups was a low gain (G =.11), it is still better when compared to the average normalized gain for the control groups (G = .00). Perhaps, this might be another indication to claim dialogic argumentation enhanced epistemic knowledge of science.

In summary, pre-test and post-test scores of students' level of epistemic knowledge was used to compare the effectiveness of argumentation instructions from intervention and control groups. A non-parametric test showed that both groups were not statistically significantly different before the intervention, which suggested both groups are at the same level of epistemic knowledge of science after a yearlong engagement in dialogic argumentation, the level of epistemic knowledge of students' in the intervention group was statistically significantly higher compared to their pre-test scores as well as when compared with the post-test scores of students' in the control groups. Hence, students, who engaged in dialogic argumentation pedagogy for a year, had progressed in their epistemic understanding of science compared to their pre-intervention status and compared to their peers who did not engaged in dialogic argumentation. Though the non-parametric tests indicated that there was a statistically significant difference in the level of epistemic knowledge of students between intervention and control groups, the raw scores were still low. The low level of epistemic understanding of students implies that that students' have difficulties in understanding the way of knowing in science, such as supporting claims with evidence and making plausible inferences. Other researchers who noted that students are unfamiliar with the "norms of scientific argumentation" and misunderstand what counts as good evidence and reasoning in science reported similar problems (Sampson & Clark, 2008; Simon et al., 2006; Walker & Sampson, 2013).

To the best of the knowledge of the author of this study, previous studies did not provide empirical evidence on the effect of dialogic argumentation on middle school students' level of epistemic knowledge of science, particularly in a sub-Saharan context. The current study found that dialogic argumentation did facilitate the growth of student's epistemic understanding of science. Similar positive effects of argumentation on students' epistemic cognition have been reported in the literature (e.g., Greene & Yu, 2014; Kuhn & Udell, 2003; Mason & Scirica, 2006; Nussbaum & Asterhan, 2016; Sinatra & Chinn, 2012). Consistency with previous findings shows that argumentation could provide a powerful context for improving students' epistemic knowledge of science (Kuhn, Arvidsson, Lesperance, & Corprew, 2017; Osborne, 2010).

5.2.2 Research question two

The main purpose of the second research question was to investigate whether continuous engagement in dialogic argumentation would improve the quality of student-generated dialogic argumentations and whether the level of students' epistemic knowledge would correlate with the quality of their dialogic argumentation. The quality of dialogic argumentations generated by the intervention and control groups was assessed using the ASAC observation protocol. Video recordings of twenty-eight episodes of dialogic argumentation were evaluated to get ASAC scores. For ease of comparison, mean ASAC scores of the pre-intervention and post-intervention videoing for both intervention and control groups were calculated (see Table 4.5).

Generally, both groups showed improvements in the quality of dialogic argumentations produced in the post-intervention stages compared to the pre-intervention stages (Mean ASAC scores of Ctrl-Pre = 10.43, Mean ASAC scores of Ctrl-Post = 12.14, Mean ASAC scores of Intvn-Pre = 17.29, and Mean ASAC scores of Intrvn-Post = 24.57). The higher mean scores of the intervention group in their 1st videoing were understandably not due to the treatment effect. It may be attributed to random selection of students in the group, and/or other reasons not investigated in this study.

Further comparisons across various aspects of ASAC for the control groups indicated that the quality of argumentation between the 1st videoing and the 2nd videoing remained very low and did not show significant progress for all aspects of ASAC and the mean ASAC scores (for the mean scores of Conceptual & Cognitive Aspects, $T = 6$, $z = 1.66$, $p = .102$, $r = .62$; for the mean scores of Epistemic Aspects, $T = 17$, $z = 1.38$, $p = .167$, $r = .52$; for the mean scores of Social Aspects, $T = 6$, $z= -.412$, $p = .68$, $r = .41$; and for the mean ASAC scores, $T = 11.5$, $z = 1.084$, $p = .279$, $r = .41$). However, comparisons between the 1st videoing and 2nd videoing of intervention groups indicated that the quality of argumentation showed significant improvement for the mean scores of Epistemic Aspects ($T = 21$, $z = 2.207$, $p = .027$, $r = .83$) and the mean ASAC scores ($T = 26.5$, $z = 2.12$, $p = .034$, $r = .80$), whereas no significant difference was observed for the mean scores of Conceptual & Cognitive Aspects ($T = 16.5$, $z = 1.265$, $p = .206$, $r = .48$) and the the mean scores of Social Aspects ($T = 19$, $z = 1.802$, $p = .072$, $r = .68$). The signficiant progress the mean scores of Epistemic Aspects seems responsible to the significant improvement observed in the overall improvement of students quality of argumentation. However, though the quality of the epistemic aspect of argumentation was still low, statistically significantly higher scores were observed in the intervention group compared to the control group. The observed significant difference was mainly due to the poor performance of students' in the control group in almost all items of the epistemic criteria (Items 9, 10, 11, 12, 13, and 14) in the ASAC observation protocol. The control group tended to use common sense reasoning to support or challenge claims rather than the rational use of available evidence such as principles, laws, theories, and formulas. In addition, the control group was naïve and intuitive in their attempt to use evidence. No attempt was observed to examine the relevance, coherence, and sufficiency of the evidence to the physical phenomenon being discussed (*Measuring Temperature* and *Force and Motion*). Also, students in the control group frequently make vague inferences.

Few but a growing number of studies relate epistemologies with argumentation (Greene & Yu, 2014; Kuhn & Udell, 2003; Mason & Scirica, 2006; Nussbaum et al., 2008; Ryu & Sandoval, 2012; Sinatra & Chinn, 2012). These studies generally focus on the impact of epistemology of science on students' argumentation abilities. For instance, Mason and Scirica (2006) found that the quality of students’ argument, counter-argument, and rebuttal responses correlated with their level of epistemological sophistication (Kuhn, Black, Keselman, & Kaplan, 2000). The current study also found strong relations between students' epistemic knowledge and the quality of their argumentation. Pearson's product-moment correlation conducted to assess the relationship between the level of grade eight students' epistemic knowledge (as determined by mean EKI scores) and the quality of dialogic argumentation (as determined by mean ASAC scores), showed a strong positive correlation between EKI and ASAC scores, Pearson’s r =.558, p =.038. Besides the quality of dialogic argumentation explains 31% of the variation in grade eight students' level of epistemic knowledge of science.

By and large, comparison between the quality of argumentation in the intervention groups’ 1st and 2nd videoing had shown progress, whereas no such improvement was observed in the comparison of control groups’ 1st and 2nd videoing. This progress was expected. Kuhn (2010) demonstrated that engaging in dialogic argumentation helps students to develop their ability to participate in scientific practices and, as a consequence, to understand the epistemic nature of science. Thus, it can be inferred from this result that extended engagement in dialogic argumentation has a positive impact on the quality of argumentation. This is consistent with the observation of Osborne et al. (2004) that students can significantly improve their ability to argue if provided with appropriate instructional conditions.

To sum up, this study clearly shows improvements in the quality of student dialogic argumentations as a result of a yearlong engagement in dialogic argumentation. Similarly, the study also shows not only the existence of a relationship between students' level of epistemic knowledge and the quality of dialogic argumentations they generated but that this relation was strong. Though the relationship between student argumentation and their epistemic knowledge continues to be a debatable issue, the findings in the present study provide further evidential support for the existence of a positive relation between epistemic knowledge and quality of dialogic argumentation.

5.2.3 Research question three

Research question 3 explores the nature and characteristics of teachers epistemic practices in their classroom discourse i.e., how teachers scaffold, support and promote students epistemic knowledge of science and investigates the challenges and prospects physics teachers faced when promoting epistemic knowledge of students in a dialogic argumentation physics classroom. Based on data collected from video recorded whole class teaching and interview of teachers, the qualitative analysis used the analytical tool developed for use in quantitative ethnography and thematic analysis respectively. ENA of teachers videotaped whole class teaching was used to show the various features of epistemic practices of science observed in teachers epistemic discourse when attempted to support and promote students epistemic knowledge of science in argumentation lessons. The thematic analysis of teachers' interviews were used to identify the nuance constraints and opportunities teachers had to enhance students epistemic knowledge in their argumentation lessons.

5.2.3.1 Part 'a' of research question three

The first part of research question three explored the features of epistemic practices observed in teachers' discursive when attempting to scaffold and support students during dialogic argumentation lessons. To answer this question, i.e., to understand the nature and character of teachers epistemic discourse during dialogic argumentation, this study had used six teachers videotaped classroom teaching, that recorded at the end of the intervention year. The transcripts of teachers whole class teaching was coded using thematic coding. The thematic coding, which was presented in Table 3.3 was developed based on theoretical underpinnings of epistemic operations (such as Christodoulou & Osborne, 2014; Fischer et al., 2014) and the apt-AIR framework (Barzilai & Chinn, 2018; Chinn et al., 2016). The process of coding resulted in four major themes, namely *Epistemic Aims, Constructing SKC, justifying SKC,* and *evaluating SKC*, and further twenty-four sub codes under these four major themes. For the qualitative analysis, in addition to thematic analysis, this study used ENA analytic tool to understand the nature of connection between these four major themes.

The qualitative analysis of videotaped whole class teaching indicated that teachers depicted various features of epistemic knowledge, the frequently observed being *epistemic aims, then constructing, justifying,* and *evaluating SKC* in the order from more to less frequent. The connections made between these features of epistemic knowledge were also not strong and less frequent. This informed that many teachers when used dialogic argumentation focused on the lower level features of epistemic knowledge of science. Furthermore, *explanation, description, justify*, and *argument* were the dominant sub codes observed on teachers' talks. These findings supported the idea that most of the components of *epistemic aims, constructing, justifying,* and *evaluating SKC* were not represented consistently and sufficiently on teachers' talks. Perhaps, this might indicate that teachers did not implemented dialogic argumentation pedagogy properly and successfully. In addition, the less frequent and weak connections between the four epistemic features might reveal teachers had issues in building students understanding of science and its epistemic knowledge. In the meantime, the small but significant improvement of students' epistemic knowledge of science in the quantitative study was a promising change to advocate the change of STEM pedagogy toward dialogic argumentation.

Results from the qualitative analysis of teachers interview provided useful insights into how six Grade-8 physics teachers' implemented their argumentation lessons. Majority of teachers had used dialogic argumentation for various topics of Grade-8 physics. However, teachers mentioned only few topics of Grade-8 physics. For example, teachers claimed that they had used argumentation when teaching the topics of *acceleration, force, pressures, light*, and *electromagnetism*. Most of teachers shared the opinion that dialogic argumentation suits few topics of their physics lessons. Provided that, the *Talking Physics Students Activities* manual contains fifty-two activities, which are developed to be used in all Grade 7 and 8 physics lessons, these teachers arguments is unconvincing. Furthermore, most of the teachers said that they had used *Asking Questions* as a strategy to promote students understanding of the nature of science. However, the videotaped analysis indicated that teachers questions did not enhance students to involve into argumentative interactions with each other and with their teacher. This study also further revealed that teachers did not use various successful support mechanisms to promote students scientific reasoning in general and epistemic knowledge of science in particular.

The findings of the current study, which points out the importance of teachers epistemic practices in dialogic argumentation pedagogy, are consistent with previous findings (Christodoulou & Osborne, 2014; Greene, Cartiff, & Duke, 2018). In addition, dialogic argumentation might shape teachers and students understandings of the nature of science as well as epistemology of science. Transforming STEM pedagogy towards dialogic argumentation is a key step in enhancing upper primary school students' epistemic knowledge of science. Thus, understanding how upper primary school science teachers implement dialogic argumentation intertwined with the epistemic practices of science is important.

As mentioned elsewhere, recent reforms in science education have prioritized epistemic practices of science as the primary goal of science education at the K-12 level. These reforms also put argumentation as an epistemic practice of science to develop in students an appreciation of scientific processes and procedures, the conception of the practices of the scientific community, and eventually the internalization of the epistemic practices of science. Constructing, justifying, and evaluating knowledge claims are interconnected aspects of argumentation used as an epistemic practice to critique and evaluate knowledge claims in science. These aspects are also important to develop explanations. To learn epistemic practices, students must understand how, in science, epistemic processes and knowledge construction are linked and related with each other (Bauer et al., 2019; Shaffer, 2017). Even more, science education researchers have emphasized that students' understanding of scientific practices should be coherent, connected, and associated with successful engagement in such practices (Berland et al., 2016; Erduran & Dagher, 2014; Ford, 2015; Lehrer & Schauble, 2015). Stroupe (2015) stressed that the alignment of classroom science teaching with the epistemic practice of science enables students to understand the epistemic agency of science as well as to participate in scientific practices. Lehrer and Schauble (2015) agree with Stroupe and call for an emphasis on the goals of science education. Berland et al. (2016) mention the challenge to bring the practices of scientists into school science classrooms and recommend to align teaching training to prepare teachers who know the knowledge production epistemic processes in science. Science education scholars proposed many instructional strategies to achieve these goals of science.

Thus, argumentation as epistemic practice of science is of paramount importance to portray the epistemic aims of science, and the norms and values acknowledged in science's epistemic processes. However, science taught in schools results in students seeing scientific knowledge as fragmented and incoherent (diSessa, 1988; Erduran & Dagher, 2014). Using concepts of network analysis, science education studies has begun to investigate various aspects of epistemic practices of science as interconnected (see Arastoopour et al., 2016; Arastoopour, Swiecki, Chesler, & Shaffer, 2015; Bauer et al., 2019; Martin, 2019). Students' epistemic knowledge of science can be promoted only when students understand the goals of the activities in argumentative instructions and get opportunities to practice the epistemic criteria cherished by the scientific community.

5.2.3.2 Part 'b' of research question three

There are several problems teachers may face while implementing dialogic argumentation. According to the findings obtained from the qualitative analyses of teachers interview, this study had revealed that teachers had faced many challenges such as students lack of preparedness to make argumentative discourses, students low level conceptual understanding of physics concepts, teachers' skill gaps in preparing and executing argumentative activities, and the content loaded nature of grade 8 physics textbook. This throws clear picture as to why content loaded textbooks lead teachers to emphasize on content transmission. Though, dialogic argumentation focuses on knowledge construction, it is considered as a time-consuming pedagogy. In this regard, as teachers said, using dialogic argumentation to cover such voluminous school curricula creates problems. On top of this, Ethiopian school classrooms are characterized by large class sizes. When using argumentation lessons in such large class sizes, teachers failed to organize group activities, to manage, to supervise and to stimulate students small group discussions, and to summarize group discussions efficiently in whole class discussions by asking each group to give their answers and when needed to arbitrate group differences. Teachers should help students to see why a wrong answer is wrong and finish the discussion with correct answers.

Yun and Kim (2015) reported that students low conceptual and epistemological understating of science are barriers for students engagement in argumentative practice, and hence impedes teachers epistemic discourses. Dialogic argumentation is discursive in nature, for this reason it requires students to notice competing views and ask for evidence and justifications for the claims. This corroborated with this study's observation during the qualitative analysis of students' small group discussion that is students were lenient to argue with their peers, even when their peers opposed their claims. This reveals that this could one of the challenges teachers faced during argumentation lessons. Another formidable challenge worth mentioning is that the textbook does support teachers to present the epistemic practice of science and to portray the epistemic aims of science, and the norms and values acknowledged in science's epistemic processes.

5.3 Summary of chapter

In this chapter, we organized the results found from both quantitative and qualitative findings and attempted to answer the research questions of this study. In a general sense, the quantitative and qualitative results indicated that dialogic argumentation contributed positively towards the development of grade eight students' epistemic knowledge of science. One significant finding from this study is that continuous engagement of students in argumentation lessons helped Grade-8 intervention students to improve their epistemic understanding of science compared to students in the non-argumentation lessons. The small but statistically significant epistemic progress of students in argumentation lessons implied that dialogic argumentation is one of the key teaching strategies in the attempt to bring the ways of knowing and practices of scientists into school science classrooms. The results of this investigation also show that students' quality of argumentation correlates positively and strongly with their level of epistemic knowledge.

The second major finding was the epistemic practices of teachers during argumentation lessons were not effective to support, scaffold students' knowledge building process. The weak and less frequent connections between *Epistemic Aims* and *Constructing, Justification and Evaluation* made by most teachers illustrated the poor nature of teachers' epistemic practices of science during argumentation lessons. In addition to their poor epistemic practices, teachers in the argumentation lessons faced many challenges to promote epistemic knowledge of their students. The challenges mainly originated from teachers themselves, their students, and external agents such as textbooks. Teacher-related challenges include mainly the ability to prepare and lead argumentative instructions. Student–related challenges included poor knowledge of the physics contents, low level of participation, and unwillingness to engage fruitfully during argumentative discourses. Curriculum-related challenges are mainly ascribed to content-crammed school curriculum, shortage of time to cover the curriculum and large class sizes.

Chapter 6 Conclusion and Implications

6.1 Introduction

This chapter provides a brief overview of the study with its limitations, the conclusions made based on the findings and the recommendations and critical issues that require the immediate attention of science teachers, science education researchers and science curriculum experts. Finally, future research directions will be suggested.

6.2 Overview of the study

An extensive search of relevant science education and learning science literature revealed that the effect of students' engagement with dialogic argumentation on epistemic knowledge or vice versa appeared to be not thoroughly examined so far, both in elementary and high school physics as well as in physics teacher training settings. Also, to the best knowledge of the researcher, there is no finding that links the quality of dialogic argumentation to the development of epistemic knowledge. Enhancing the epistemic knowledge of Grade-8 students using dialogic argumentation and aligning the epistemic practices in the science classrooms with the epistemic practices of the scientific community has been a necessary but daunting task (Bauer et al., 2019; Berland et al., 2016). This study was among the few studies that investigated the impact of dialogic argumentation on epistemic knowledge, and as such it makes a unique contribution to the field of argumentation research in general and physics education research in particular. The study will also make a unique contribution to the field of science education research in Ethiopia in that it is the first rigorous empirical study that has investigated the impact of dialogic argumentation on Grade-8 students' knowledge in a natural classroom setting.

Fourteen upper primary schools from three regional states of Ethiopia (Addis Ababa, Amhara, and South Peoples) participated in this study. The study was part of the TPSS project carried from 2016 to 2018. Data were collected through administration of physics reasoning tests that consist of epistemic knowledge items (EKIs), video records of students' small group discussions, video records of whole class teaching, and audio records of teacher interviews before and after intervention. A 3-day training on dialogic argumentation was given to teachers in the intervention groups. During the training these teachers were introduced to the *Talking Physics* manual (prepared by the TPSS project) with follow-up discussions on ways of using the activities in the manual.

In order to answer the research questions, a quasi-experimental mixed methods approach was adopted. A quantitative pre-post design and a qualitative case study design were utilized to investigate the effect of dialogic argumentation on students' epistemic knowledge of science, and the correlation between the two variables; and also to explore challenges and opportunities faced by Grade-8 physics teachers to promote their students' epistemic knowledge. Drawing on the experimental nature of this study, we analyzed the pre-test and post-test EKI scores for both the control and intervention groups. We also analyzed the quality of argumentation in the first and second video records for both the control and intervention groups using ASAC observation protocol. The results indicated that, compared to the control groups (-.01 or -.53% average normalized gain), the intervention groups showed small but significant improvements (.11 or 8.4% average normalized gain) in students' level of epistemic knowledge and the quality of their argumentation.

In a nutshell, this study has found that students' engagement in argumentative instructions resulted in significant improvements in their level of epistemic knowledge and quality of argumentation. Furthermore, the analysis revealed that the significant change in the quality of argumentation, based on ASAC scores, is linked to the significant change in students' scores of the epistemic aspects of ASAC. We observed no significant changes in other two aspects of ASAC, namely conceptual and cognitive aspects and social aspects.

To understand the constraints and drivers in promoting epistemic knowledge using argumentative instructions, we used the apt-AIR framework as an analytic framework to identify epistemic features in teachers' classroom discourse. Martin (2019) recommends understanding the epistemic practices of science that can only be practical when students begin to see scientific practices as naturally connected. Using the apt-AIR framework, we identified epistemic aims, construction, justification, and evaluation as a lens to conceptualize knowledge building in science through dialogic argumentation. This has enabled us to investigate how teachers' argumentative instructions promote students' epistemic knowledge of science and how teachers talk about various epistemic features of science.

The qualitative analysis of teachers' whole class teaching using dialogic argumentation showed that physics teachers portrayed various features of epistemic practices of science in their talks. However, the connections made between different features of epistemic knowledge were weak and not frequent. The weak and less frequent connections across features of epistemic knowledge imply that students were not given a learning environment that mirrors the practices of scientists. This might be the reason for the below-average post-test scores of students in the argumentative instructions.

6.3 Limitation of the study

Some limitations may be raised in connection with the current study. One limitation could be the selection of students participated in the video recorded small group discussion tasks. The selected group may not be representative of the classroom. To address this limitation, teachers were informed to compose a representative group and we use teachers' verdicts to improve the trustworthiness of data collected from the selected representative group.

The other limitation could be related to the evaluation of PhD candidates, from science and mathematics education department, to categorize the physics reasoning test as conceptual, procedural, and epistemic knowledge. In order to identify items that assess epistemic knowledge, it would be more appropriate to recruit established scholars in epistemology and science education. There are few scholars in science education in general and epistemology of science in particular in Ethiopia, moreover, it was not feasible to recruit such scholars around the globe. Thus, validity of the selected EKIs to measure epistemic knowledge is in question. Therefore, care should be taken when interpreting the findings in this study that showed improvement of students' epistemic knowledge as a result of dialogic argumentation pedagogy.

The third limitation is related to the character of students. In most of students' small group argumentative tasks, students' argumentation were dominated by few students and focused on providing the correct answer to the argumentative activities. As a result, the time various groups spent on these tasks ranges from 5 minutes to 30 minutes. Besides, most of the students were shy and spent much on providing the correct answer to the argumentative activities rather than developing their arguments. This may have potentially impeded their argumentation processes, and perhaps it might not depict the true nature of students' argumentation.

6.4 Conclusion

The goal of science education in the 21st century is to create citizens who can develop and solve various societal problems that require informed decisions. In order to achieve these goals, science education research findings urge to make a shift from traditional science classroom practices to practicing the knowledge-building culture of the science community, focusing on the epistemology of science (Berland et al., 2016; Lehrer & Schauble, 2015). The goal of science education should be to help students understand the epistemic practices of science and to provide a classroom learning environment that mimics the epistemic practices of scientists in the laboratory and research fields. Dialogic argumentation was one of the ways of building knowledge practiced by scientists. Dialogic argumentation shifts the nature and source of scientific knowledge production in the classroom from the teacher to the students. To put it in perspective, teachers are responsible for creating authentic activities and for guiding students' participation in the practice of science (Alemu et al., 2019; Lehesvuori, 2013; Lehesvuori et al., 2011; Tadesse, 2015). This study has focused on the effect of dialogic argumentation on the epistemic knowledge of Grade-8 students and on the challenges teachers face in promoting students’ epistemic knowledge using dialogic argumentation. The purpose was to explore (1) the extent and ways in which engagement in dialogic argumentation affects upper primary school students’ epistemic knowledge and (2) the nature and characteristic of teachers’ epistemic practices as well as constraints teachers had faced promote students’ epistemic knowledge through dialogic argumentation in the physics classroom.

We integrated theoretical foundations from learning theory, philosophy of science, and cognitive history of science to conceptualize epistemic knowledge, dialogic argumentation, and associations between them. Besides, we deployed the apt-AIR framework as an analytic framework to analyze whole class teaching and teachers' epistemic talks in the classroom. The analytic framework also paved ways to identify features of epistemic knowledge apparent in dialogic argumentation instructions. Apt-AIR framework situated the epistemic practices of science and enabled the establishment of entities of knowledge building acts in argumentative instructions.

The findings of this study attested that dialogic argumentation indeed was effective in improving Grade-8 students' epistemic knowledge in physics as well as their ability to generate scientific reasoning during arguments. The significant correlation between the progress in epistemic knowledge and the progress in the quality of dialogic argumentation was supported by the result that dialogic argumentation enhanced Grade-8 students' epistemic knowledge in physics. The quasi-experimental nature of the study further ensures dialogic argumentation has a differential impact on students epistemic knowledge. The findings of the current study were also found to be consistent with similar results in the argumentation literature, strengthening empirical research evidence that argumentation practices in the science classrooms improve students' epistemology. The present study provided evidential support that, even without explicit teaching of argumentation or without the explicit integration of argumentation into a science course, simply providing opportunities for argumentative talks in the science classroom would result in some changes in students' epistemic knowledge. In particular, the current study showed that upper primary school students involved in dialogic argumentation benefited more in improving their epistemic knowledge (as measured by means scores on EKIs) and the epistemic aspects of scientific argumentation (as measured by means scores on ASAC).

This study brought forth evidence to support engaging students in argumentative tasks in physics classrooms improves the level of epistemic knowledge acquired by the students and the quality of argumentations they produce. Exposure to argumentative tasks, even without explicitly introducing the features of dialogic argumentation and integrating dialogic argumentation with the school science curriculum, usually produces a remarkable distinction in enhancing the construction of scientific knowledge in science classrooms. Furthermore, this study indicated that engagement in dialogic argumentation helped upper primary school students to understand what science is and how scientific knowledge is generated and developed.

This is consistent with global efforts to promote student-centered practices through methodological shifts in science instructions. It is to be noted that the positive results in the current study were obtained against strong, persistent prior knowledge students acquired through the transmission method of teaching, still practiced in Ethiopia. The positive changes found in this research agreed with other findings that the transmission method of teaching cannot help to promote science teaching and learning and, therefore, should be replaced by student-centered methods such as dialogic argumentation. Dialogic argumentation helps students develop an epistemic understanding of the role of scientific evidence and how science works. In this way, students are better equipped to make informed judgments about various scientific knowledge claims and their applications.

6.5 Recommendations and suggestions for future research

It is valuable to note that engaging upper primary school students into argumentative discourses may contribute towards the improvement of students' level of epistemic knowledge of science. However, it was found that when students engage in argumentative practices, they often fail to recognize the givens (implicit or explicit), to notice contradictory conceptions, to make sense of argumentative tasks, and to use alternative approaches and apply rational thinking to evaluate their sense making processes. Dialogic argumentation provides a learning environment for students to understand how science works and its ways of knowing in the sciences. Based on our observation, improvements in the level of epistemic knowledge relate linearly to enhance conceptual understanding of physics concepts. Argumentation also promotes active learning through motivating students. It was seen that students from argumentative instructional groups were more interested and eager to participate in discussion tasks.

This study reports the positive impact of dialogic argumentation on students' epistemic knowledge of science. However, there are still open questions about how students make sense of scientific arguments using alternative strategies and scientific reasoning. To support physics teachers to have a paradigm shift in science teachings, investigations about how teachers view science and its practices, how to amalgamate students and teachers indigenous ways of knowing and ways of knowing in science, and thinking about teaching scientific practices are needed in science education, particularly in an African context.

This study used physics reasoning test items that probe content, procedural, and epistemic knowledge of Grade-8 students. Future studies could involve the preparation of test items that measure epistemic knowledge of students in primary, secondary, or tertiary level physics classrooms. Such tests can be further tailored to address epistemic knowledge of students in various topics of physics, such as mechanics, waves, thermodynamics, electromagnetism, optics, and modern physics.

In science education, epistemology is intertwined with metacognition and self-regulated learning. Metacognition and self-regulation play a paramount role in shaping students' scientific literacy, conceptual understanding, and views of the nature of science. Thus, the connections of epistemic knowledge to meta-cognitive supports and self-regulated learning strategies while doing laboratory activities and solving physics problems could be one direction of future studies.

In the current study, a gender issue was not raised regarding the level of epistemic knowledge within the argumentative groups and between the control and intervention groups. Additional studies are needed to explore further the difference in the level of epistemic knowledge between male and female students.

References

Aikenhead, G. (2006). *Science education for everyday life: Evidence-based practice*. New York, NY: Teachers College Press.

Alemu, M., Kind, P., Tadesse, M., Atnafu, M., & Michael, K. (2017). Challenges of Science Teacher Education in Low-income Nations - The Case of Ethiopia *PART 13: STRAND 13*, 1782.

Alemu, M., Kind, V., Tadesse, M., Michael, K., Atnafu, M., Kind, P., & Rajab, T. (2019). The knowledge gap between intended and attained curriculum in Ethiopian teacher education: identifying challenges for future development. *Compare: A Journal of Comparative and International Education*. Retrieved from https://doi.org/10.1080/03057925.2019.1593107.

Alexander, R. (2008). *Towards dialogic teaching: Rethinking classroom talk*. Cambridge, UK: Dialogos York.

Alexander, R. (2013). *Essays on pedagogy*. London, UK: Routledge.

Alexopoulou, E., & Driver, R. (1996). Small-group discussion in physics: Peer interaction modes in pairs and fours. *Journal of Research in Science Teaching, 33*(10), 1099-1114.

Allen, M. (2014). *Misconceptions in Primary Science* (2nd ed.). Berkshire, England: Open University Press.

Arastoopour, G., Shaffer, D., Swiecki, Z., Ruis, A., & Chesler, N. (2016). Teaching and assessing engineering design thinking with virtual internships and epistemic network analysis. *International Journal of Engineering Education, 32*(2), 1492-1501. Retrieved from https://tigerprints.clemson.edu/cgi/viewcontent.cgi?article=1004&context=ed_human_dvlpmnt_pub.

Arastoopour, G., Swiecki, Z., Chesler, N., & Shaffer, D. (2015). *Epistemic network analysis as a tool for engineering design assessment.* Paper presented at the 122nd ASEE Annual Conference & Exposition, Seattle, WA: July 14-17, 2015.

Archila, P. A. (2015). Using History and Philosophy of Science to Promote Students' Argumentation. *Science & Education, 24*(9), 1201-1226. Retrieved from https://doi.org/10.1007/s11191-015-9786-2.

Asterhan, C., & Schwarz, B. (2007). The effects of monological and dialogical argumentation on concept learning in evolutionary theory. *Journal of educational psychology, 99*(3), 626–639. Retrieved from https://doi.org/10.1037/0022-0663.99.3.626.

Avraamidou, L., & Zembal-Saul, C. (2005). Giving priority to evidence in science teaching: A first-year elementary teacher's specialized practices and knowledge. *Journal of Research in Science Teaching, 42*(9), 965-986. doi: https://doi.org/10.1002/tea.20081

Barzilai, S., & Chinn, C. A. (2018). On the goals of epistemic education: Promoting apt epistemic performance. *Journal of the Learning Sciences, 27*(3), 353-389. doi:10.1080/10508406.2017.1392968

Bauer, E., Sailer, M., Kiesewetter, J., Schulz, C., Pfeiffer, J., Gurevych, I., . . . Fischer, F. (2019). *Using ENA to Analyze Pre-service Teachers' Diagnostic Argumentations: A Conceptual Framework and Initial Applications.* Paper presented at the Advances in Quantitative Ethnography: First International Conference, ICQE 2019, Madison, WI, USA, October 20–22, 2019.

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The Qualitative Report, 13*(4), 544-559.

Berland, K., & Reiser, J. (2009). Making sense of argumentation and explanation. *Science Education*, *93*(1), 26 - 55. doi:10.1002/sce.20286

Berland, L., & Hammer, D. (2012a). Framing for scientific argumentation. *Journal of Research in Science Teaching*, *49*(1), 68-94. doi: https://doi.org/10.1002/tea.20446

Berland, L., & Hammer, D. (2012b). Students' framings and their participation in scientific argumentation. In M. Khine (Ed.), *Perspectives on Scientific Argumentation* (pp. 73-93). Dordrecht, The Netherlands: Springer.

Berland, L., Schwarz, V., Krist, C., Kenyon, L., Lo, S., & Reiser, J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching*, *53*(7), 1082–1112.

Bleicher, R. E., Tobin, K. G., & McRobbie, C. J. (2003). Opportunities to talk science in a high school chemistry classroom. *Research in Science Education, 33*(3), 319-339.

Boulter, C. J., & Gilbert, J. K. (1995). Argument and science education. In P. Costello & S. Mitchell (Eds.), *Competing and consensual voices: The theory and practice of argumentation* (pp. 84-98). Clevedon, UK: Multilingual Matters.

Braaten, M., & Windschitl, M. (2011). Working toward a stronger conceptualization of scientific explanation for science education. *Science Education, 95.*(4), 639–669.

Braten, I., Muis, K. R., & Reznitskaya, A. (2017). Teachers' epistemic cognition in the context of dialogic practice: A question of calibration? *Educational Psychologist, 52*(4), 253-269.

Braund, M., Scholtz, Z., Sadeck, M., & Koopman, R. (2013). First steps in teaching argumentation: A South African study. *International Journal of Educational Development, 33*(2), 175-184.

Bryman, A. (2012). *Social Research Methods* (4th ed.). Oxford: Oxford University Press.

Buehl, M. M., & Fives, H. (2016). The role of epistemic cognition in teacher learning and praxis. In J. Greene, W. Sandoval, & I. Braten (Eds.), *Handbook of epistemic cognition* (pp. 247-264). New York, NY: Routledge.

Cavagnetto, A. (2010). Argument to foster scientific literacy: A review of argument interventions in K-12 contexts. *Review of Educational Research, 80*(3), 336-371. doi:10.3102/0034654310376953

Chen, Y.-C., Hand, B., & Norton-Meier, L. (2017). Teacher roles of questioning in early elementary science classrooms: A framework promoting student cognitive complexities in argumentation. *Research in Science Education, 47*(2), 373-405. doi:https://doi.org/10.1007/s11165-015-9506-6

Chin, C. (2007). Teacher questioning in science classrooms: Approaches that stimulate productive thinking. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 44*(6), 815-843.

Chin, C., & Osborne, J. (2008). Students' questions: a potential resource for teaching and learning science. *StudieS in Science education, 44*(1), 1-39.

Chin, C., & Osborne, J. (2010). Students' questions and discursive interaction: Their impact on argumentation during collaborative group discussions in science. *Journal of Research in Science Teaching, 47*(7), 883-908.

Chinn, C., Duncan, R. G., Hung, L. C.-C., & Rinehart, R. W. (2016). *Epistemic criteria and reliable processes as indicators of argument quality in science students' argumentation*. Paper presented at the the Annual Meeting of the American Educational Research Association, Washington, DC. https://www.aera.net/Publications/Online-Paper-Repository/AERA-Online-Paper-Repository

Chinn, C., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education, 86*(2), 175-218.

Chinn, C., & Rinehart, R. (2016). Epistemic cognition and philosophy: Developing a new framework for epistemic cognition. In J. Greene, W. Sandoval, & I. Braten (Eds.), *Handbook of epistemic cognition* (pp. 460-478). New York, NY: Routledge.

Chinn, C., & Sandoval, W. (2018). Epistemic cognition and epistemic development. In F. Fischer, C. E. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *International handbook of the learning sciences* (pp. 24-33). Abingdon, UK: Routledge.

Choi, A., Klein, V., & Hershberger, S. (2015). Success, difficulty, and instructional strategy to enact an argument-based inquiry approach: Experiences of elementary teachers. *International Journal of Science and Mathematics Education, 13*(5), 991-1011.

Christodoulou, A., & Osborne, J. (2014). The science classroom as a site of epistemic talk: A case study of a teacher's attempts to teach science based on argument. *Journal of Research in Science Teaching, 51*(10), 1275-1300.

Corbin, J., & Strauss, A. (2014). *Basics of qualitative research. Techniques and procedures for developing grounded theory.* (4th ed.). Thousand Oaks, CA: Sage.

Creswell, J., & Clark, V. (2018). *Designing and conducting mixed methods research* (3rd ed.). Los Angeles, CA: Sage.

Creswell, J., & Guetterman, T. (2019). Educational research: Planning, conducting, and evaluating quantitative and qualitative research In. New York, US: Pearson.

Creswell, J., & Poth, C. (2018). *Qualitative Inquiry & Research Design Choosing Among Five Approaches* (4th ed.). Los Angeles, CA: Sage Publications.

Cruz-Guzmán, M., García-Carmona, A., & Criado, A. M. (2017). An analysis of the questions proposed by elementary pre-service teachers when designing experimental activities as inquiry. *International Journal of Science Education, 39*(13), 1755-1774. Retrieved from https://doi.org/10.1080/09500693.2017.1351649.

Denscombe, M. (2017). *The good research guide, for small-scale social research projects* (6th ed.). Cambridge, UK: Open University Press.

Ding, L., & Mollohan, K. N. (2015). How college-level introductory instruction can impact student epistemological beliefs. *Journal of College Science Teaching, 44*(4), 19-27.

diSessa, A. (1988). Knowledge in pieces. In G. Forman & P. Pufall (Eds.), *Constructivism in the computer age* (pp. 35-60). Hillsdale, NJ: Erlbaum.

diSessa, A. (1993). Towards an epistemology of physics. *Cognition and Instruction, 10* (2/3), 105-225. Retrieved from https://www.jstor.org/stable/3233725.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*, 287 – 312.

Duschl, R. A. (1990). *Restructuring science education: The importance of theories and their development*. New York, NY: Teachers College Press.

Duschl, R. A. (2008a). Quality argumentation and epistemic criteria. . In S. Erduran & M. P. Jimenez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 159 – 175). Dordrecht, The Netherlands: Springer.

Duschl, R. A. (2008b). Science education in three-part harmony: balancing conceptual, epistemic, and social learning goals. *Review of Research in Education, 32*(1), 268 - 291. doi: 10.3102/0091732X07309371

Duschl, R. A., & Grandy, R. (2008). *Teaching scientific inquiry: Recommendations for research and implementation*. Rotterdam, The Netherlands: Sense Publishers.

Duschl, R. A., & Grandy, R. (2011). Demarcation in science education: Toward an enhanced view of scientific method. In R. S. Taylor & M. Ferrari (Eds.), *Epistemology and Science Education: understanding the evolution vs. intelligent design controversy* (pp. 3-19). New York, NY: Routledge.

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *StudieS in Science education, 38*(1), 39-72. doi:10.1080/03057260208560187

Eagan, B., & Hamilton, E. (2018). *Epistemic network analysis of an international digital makerspace in Africa, Europe, and the US.* Paper presented at the Annual Meeting of the American Education Research Association, New York, NY.

Elby, A., Macrander, C., & Hammer, D. (2016). Epistemic cognition in science. In J. Greene, W. Sandoval, & I. Braten (Eds.), *Handbook of epistemic cognition* (pp. 125-139). New York, NY: Routledge.

Erduran, S. (2014). Beyond Nature of Science: The Case for Reconceptualising ‘Science’ for Science Education. *Science Education International, 25*(1), 93 - 111.

Erduran, S., & Dagher, Z. (2014). *Reconceptualizing the Nature of Science for Science Education: Scientific Knowledge, Practices and Other Family Categories*. Dordrecht, The Netherlands: Springer.

Erduran, S., Ozdem, Y., & Park, J.-Y. (2015). Research trends on argumentation in science education: a journal content analysis from 1998–2014. *International Journal of STEM Education, 2*(5). doi:10.1186/s40594-015-0020-1

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education, 88,* 915 – 933.

Eshach, H. (2010). An analysis of conceptual flow patterns and structures in the physics classroom. *International Journal of Science Education, 32*(4), 451-477.

Evans, M., Legare, C., & Rosengren, K. (2011). Engaging Multiple Epistemologies: Implications for Science Education In R. Taylor & M. Ferrari (Eds.), *Epistemology and Science Education: Understanding the Evolution vs. Intelligent Design Controversy* (pp. 111 - 139). New York, NY: Routledge.

Fensham, P. J. (1985). Science for all: A reflective essay. *Journal of Curriculum Studies, 17*(4), 415-435.

Feucht, F., & Bendixen, L. (2010). Personal epistemology in the classroom: a welcome and guide for the reader In L. Bendixen & F. Feucht (Eds.), *Personal Epistemology in the Classroom: Theory, Research, and Implications for Practice* (pp. 3 - 28). Cambridge, UK: Cambridge University Press

Fischer, F., Kollar, I., Ufer, S., Sodian, B., Hussmann, H., Pekrun, R., . . . Fischer, M. (2014). Scientific Reasoning and Argumentation: Advancing an Interdisciplinary Research Agenda in Education. *Frontline Learning Research, 2*(3), 28-45.

FMoE. (2010). *Action Plan for Improving the Teaching and Learning of Science and Mathematics in Ethiopia*. Addis Ababa, Ethiopia: FDRE Ministry of Education.

FMoE. (2015). *Education Sector Development Programme V (ESDP V) 2015/16 - 2019/20*. Addis Ababa, Ethiopia Retrieved from https://planipolis.iiep.unesco.org/sites/planipolis/files/ressources/ethiopia_esdp_v.pdf.

Ford, M. (2008). 'Grasp of practice'as a reasoning resource for inquiry and nature of science understanding. *Science and Education, 17*(2-3), 147-177.

Ford, M. (2015). Educational implications of choosing "practice" to describe science in the Next Generation Science Standards. *Science Education, 99*(6), 1041–1048.

Ford, M., & Wargo, B. M. (2012). Dialogic framing of scientific content for conceptual and epistemic understanding. *Science Education, 96*(3), 369-391.

Frost, M., & Little, A. W. (2014). Children's learning practices in Ethiopia: observations from primary school classes. *Oxford Review of Education, 40*(1), 91-111.

Gilbert, J. K., & Justi, R. (2016). *Modelling-based Teaching in Science Education*. Cham, Switzerland: Springer.

GPE. (2019). *Analysis of National Learning Assessment Systems [ANLAS] ANLAS Ethiopia: Country Report*. Melbourne, Australia: ACER.

Gray, R., & Kang, N.-H. (2014). The Structure of Scientific Arguments by Secondary Science Teachers: Comparison of experimental and historical science topics. *International Journal of Science Education, 36*(1), 46-65. doi:10.1080/09500693.2012.715779

Greene, J., & Yu, S. (2014). Modeling and measuring epistemic cognition: A qualitative re-investigation. *Contemporary Educational Psychology, 39*, 12-28. doi:http://dx.doi.org/10.1016/j.cedpsych.2013.10.002

Greene, J. A., Cartiff, B. M., & Duke, R. F. (2018). A meta-analytic review of the relationship between epistemic cognition and academic achievement. *Journal of Educational Psychology, 110*(8), 1084-1111.

Hagos, B., & Tefera, B. (2015). School Readiness Programs in Ethiopia: Practices, Challenges and the Way Forward. *The Ethiopian Journal of Education, 35*(1), 99-154.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*(1), 64 - 74.

Halloun, I. (2004). *Modeling theory in science education* (Vol. 24). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Halloun, I. (2007). Mediated modeling in science education. *Science & Education, 16*(7-8), 653-697.

Halloun, I., & Hestenes, D. (1985). The initial knowledge state of college physics students. *American Journal of Physics, 53*(11), 1043-1055.

Hammer, D. (1994). Epistemological beliefs in introductory physics. *Cognition and Instruction, 12*(2), 151-183.

Hammer, D. (2000). Student resources for learning introductory physics. *American Journal of Physics, 68*(S1), S52-S59.

Hammer, D., & Elby, A. (2003). Tapping epistemological resources for learning physics. *Journal of the Learning Sciences, 12*(1), 53-90.

Harlen, W. (2013). Inquiry-based learning in science and mathematics. *Review of science, mathematics and ICT education, 7*(2), 9-33.

Herrenkohl, L. R., & Cornelius, L. (2013). Investigating elementary students' scientific and historical argumentation. *Journal of the Learning Sciences, 22*(3), 413-461.

Hofer, B., & Pintrich, P. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67*(1), 88-140.

Hundal, S., Levin, D. M., & Keselman, A. (2014). Lessons of researcher–teacher co-design of an environmental health afterschool club curriculum. *International Journal of Science Education, 36*(9), 1510-1530.

Hutchins, E. (1995). *Cognition in the Wild*. Cambrifge, MA: MIT press.

Iordanou, K., & Constantinou, C. P. (2015). Supporting use of evidence in argumentation through practice in argumentation and reflection in the context of SOCRATES learning environment. *Science Education, 99*(2), 282-311. doi:https://doi.org/10.1002/sce.21152

Iordanou, K., Kendeo, P., & Beker, K. (2016). Argumentative reasoning. In J. Greene, W. Sandoval, & I. Braten (Eds.), *Handbook of epistemic cognition* (pp. 39-53). New York, NY: Routledge.

Iwuanyanwu, P., & Ogunniyi, M. (2020). Effects of Dialogical Argumentation Instructional Model on Pre-service Teachers' Ability to Solve Conceptual Mathematical Problems in Physics. *African Journal of Research in Mathematics, Science and Technology Education, 24*(1), 129-141. doi:10.1080/18117295.2020.1748325

Jensen, D. (2008a). Confirmability. In L. M. Given (Ed.), *The Sage encyclopedia of qualitative research methods* (Vol. 1 & 2, pp. 112). Los Angeles, CA: SAGE Publications.

Jensen, D. (2008b). Credibility. In L. M. Given (Ed.), *The Sage encyclopedia of qualitative research methods* (Vol. 1 & 2, pp. 138-139). Los Angeles, CA: SAGE Publications.

Jensen, D. (2008c). Transferability. In L. M. Given (Ed.), *The Sage encyclopedia of qualitative research methods* (Vol. 1 & 2, pp. 886). Los Angeles, CA: SAGE Publications.

Jimenez-Aleixandre, M. (2002). Knowledge producers or knowledge consumers? Argumentation and decision making about environmental management. *International Journal of Science Education, 24*(11), 1171-1190.

Jimenez-Aleixandre, M. (2014). Determinism and underdetermination in genetics: Implications for students' engagement in argumentation and epistemic practices. *Science & Education, 23*(2), 465-484.

Jiménez-Aleixandre, M., & Erduran, S. (2007). Argumentation in Science Education: An Overview. In S. Erduran & M. Jiménez-Aleixandre (Eds.), *Argumentation in science education-Perspectives from classroom-Based Research.* (pp. 3-27). Dordrecht, The Netherlands: Springer.

Jimenez-Aleixandre, M., Mortimer, E. F., Silva, A., & Diaz, J. (2008). *Epistemic practices: an analytical framework for science classrooms.* Paper presented at the the Annual Meeting of the American Educational Research Association, New York, NY; March 24-28, 2008.

Jimenez-Aleixandre, M., Rodríguez, A., & Duschl, R. A. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. *Science Education, 84*(6), 757-792.

Johnson, B., & Onwuegbuzie, A. (2004). Mixed methods research: A research paradigm whose time has come. *Educational researcher, 33*(7), 14-26.

Johnson, B., Onwuegbuzie, A., & Turner, L. (2007). Toward a Definition of Mixed Methods Research. *Journal of Mixed Methods Research, 1*(2), 112-133. doi:10.1177/1558689806298224

Kanari, Z., & Millar, R. (2004). Reasoning from data: How students collect and interpret data in science investigations. *Journal of Research in Science Teaching, 41*(7), 748-769.

Kelly, G. (2008). Inquiry, activity and epistemic practice. In R. Duschl & R. Grandy (Eds.), *Teaching Scientific Inquiry: Recommendations for Research and Implementation* (pp. 99-117). Rotterdam, The Netherlands: Sense Publishers.

Kelly, G., & Green, J. (2019). *Theory and methods for sociocultural research in science and engineering education*. New York, NY: Routledge.

Kelly, G., & Licona, P. (2018). Epistemic practices and science education. In M. Matthews (Ed.), *History, philosophy and science teaching: New research perspectives* (pp. 139 – 165). Cham, Switzerland: Springer.

Kelly, G., McDonald, S., & Wickman, P.-O. (2012). Science Learning and Epistemology. In B. Fraser, K. Tobin, & C. McRobbie (Eds.), *Second International Handbook of Science Education* (Vol. 24 pp. 281-291). Dordrecht, The Netherlands: Springer.

Kelly, G., & Takao, A. (2002). Epistemic levels in argument: An analysis of university oceanography students' use of evidence in writing. *Science Education, 86*(3), 314-342.

Khine, M. S. (2012). Development of argumentative knowledge in science education. In M. S. Khine (Ed.), *Perspectives on Scientific Argumentation* (pp. 283-287). Dordrecht, The Netherlands: Springer.

Kind, P., & Osborne, J. (2017). Styles of Scientific Reasoning: A Cultural Rationale for Science Education? *Science Education, 101*(1), 8–31.

Ko, M., & Krist, C. (2019). Opening up curricula to redistribute epistemic agency: A framework for supporting science teaching. *Science Education, 103*, 979 - 1010. doi:https://doi.org/10.1002/sce.21511

Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education*, *77*(3), 319-337.

Kuhn, D. (2010). Teaching and learning science as argument. *Science Education, 94*(5), 810 - 824.

Kuhn, D., Arvidsson, S., Lesperance, R., & Corprew, R. (2017). Can Engaging in Science Practices Promote Deep Understanding of Them? *Science Education, 101*(2), 232-250.

Kuhn, D., Black, J., Keselman, A., & Kaplan, D. (2000). The Development of Cognitive Skills To Support Inquiry Learning. *Cognition and Instruction, 18*(4), 495-523. Retrieved from https://doi.org/10.1207/S1532690XCI1804_3.

Kuhn, D., & Udell, W. (2003). The development of argument skills. *Child Development, 74*(5), 1245-1260.

Kuhn, T. (1970). *The Structure of Scientific Revolutions* (2nd ed.). Chicago, IL: University of Chicago Press.

Larrain, A., Freire, P., & Howe, C. (2014). Science teaching and argumentation: One-sided versus dialectical argumentation in Chilean middle-school science lessons. *International Journal of Science Education, 36*(6), 1017-1036.

Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science Education, 84*(1), 71-94.

Leach, J., Hind, A., & Ryder, J. (2003). Designing and evaluating short teaching interventions about the epistemology of science in high school classrooms. *Science Education, 87*(6), 831-848.

Leach, J., & Scott, P. (2003). Individual and sociocultural views of learning in science education. *Science & Education, 12*(1), 91-113.

Leavy, P. (2017). *Research Design: Quantitative, Qualitative, Mixed Methods, Arts-Based, and Community-Based Participatory Research Approaches*. New York, NY: The Guilford Press.

Lederman, N., & Gess-Newsome, J. (1999). Reconceptualizing Secondary Science Teacher Education. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining Pedagogical Content Knowledge: The Construct and its Implications for Science Education* (pp. 199-213). Dordrecht, The Netherlands: Springer

Leech, N., & Onwuegbuzie, A. (2008). Debriefing. In L. M. Given (Ed.), *The Sage encyclopedia of qualitative research methods* (Vol. 1 & 2, pp. 199-201). Los Angeles, CA: SAGE Publications.

Lehesvuori, S. (2013). *Towards dialogic teaching in science: Challenging classroom realities through teacher education (Unpublished doctoral dissertation).* University of Jyvaskyla, Jyvaskyla, Finland.

Lehesvuori, S., Viiri, J., & Rasku-Puttonen, H. (2011). Introducing dialogic teaching to science student teachers. *Journal of Science Teacher Education*, *22*(8), 705-727.

Lehrer, R., & Schauble, L. (2005). Developing modeling and argument in elementary grades. In T. Romberg, T. Carpenter, & F. Dremock (Eds.), *Understanding mathematics and science matters* (pp. 29–53). Mahwah, NJ: Lawrence Erlbaum.

Lehrer, R., & Schauble, L. (2015). The development of scientific thinking. In L. Liben, U. Muller, & R. Lerner (Eds.), *Handbook of Child Psychology and Developmental Science* (Vol. 7th, pp. 671- 714). Hoboken, NJ: Wiley.

Lemke, J. (1990). *Talking science: Language, learning, and values*. Westport, CT: Ablex Publishing.

Lidar, M., Lundqvist, E., & Östman, L. (2006). Teaching and learning in the science classroom: The interplay between teachers' epistemological moves and students' practical epistemology. *Science Education, 90*(1), 148-163.

Lin, T.-C., Hsu, Y.-S., Lin, S.-S., Changlai, M.-L., Yang, K.-Y., & Lai, T.-L. (2012). A Review of Empirical Evidence on Scaffolding for Science Education. *International Journal of Science and Mathematics Education, 10*, 437 - 455.

Lincoln, Y., & Guba, E. (1985). *Naturalistic Inquiry*. London, UK: Sage.

Linn, M. C., Eylon, B.-S., & Davis, E. A. (2013). The knowledge integration perspective on learning. In *Internet environments for science education* (pp. 57-74): Routledge.

Lising, L., & Elby, A. (2005). The impact of epistemology on learning: A case study from introductory physics. *American Journal of Physics, 73*(4), 372-382.

Longino, H. (2002). *The fate of knowledge*. Princeton, NJ: Princeton University Press.

Louca, L. T., & Zacharia, Z. C. (2012). Modeling-based learning in science education: cognitive, metacognitive, social, material and epistemological contributions. *Educational Review, 64*(4), 471-492.

Louca, L. T., Zacharia, Z. C., & Tzialli, D. (2012). Identification, interpretation—Evaluation, response: An alternative framework for analyzing teacher discourse in science. *International Journal of Science Education, 34*(12), 1823-1856.

Lubben, F., Sadeck, M., Scholtz, Z., & Braund, M. (2010). Gauging Students' Untutored Ability in Argumentation about Experimental Data: A South African case study. *International Journal of Science Education, 32*(16), 2143-2166. Retrieved from https://doi.org/10.1080/09500690903331886.

Lunn Brownlee, J., Ferguson, L. E., & Ryan, M. (2017). Changing teachers' epistemic cognition: A new conceptual framework for epistemic reflexivity. *Educational Psychologist, 52*(4), 242-252.

Manz, E. (2015). Representing student argumentation as functionally emergent from scientific activity. *Review of Educational Research, 85*(4), 553-590.

Martin, A., & Hand, B. (2009). Factors affecting the implementation of argument in the elementary science classroom. A longitudinal case study. *Research in Science Education, 39*(1), 17-38.

Martin, N. (2019). *Teaching Science as Epistemic Practice: Examining Teachers' Conceptions and Instruction in Middle School Science Classrooms.* (Unpublished PhD Dissertation), University of Wisconsin – Madison, Madison, WI.

Mason, L., & Scirica, F. (2006). Prediction of students' argumentation skills about controversial topics by epistemological understanding. *Learning and Instruction, 16*, 492 - 509.

Matthews, M. (2015). *Science teaching: the contribution of history and philosophy of science, 20th anniversary revised and expanded edition* (2nd ed.). New York, NY: Routledge.

Mazur, E. (1997). *Peer Instruction: A User's Manual*. Upper Saddle River, NJ: Prentice–Hall.

McDermott, L. C. (1991). Millikan Lecture 1990: What we teach and what is learned—Closing the gap. *American Journal of Physics, 59*(4), 301-315.

McDonald, C., & McRobbie, C. (2012). Utilising Argumentation to Teach Nature of Science. In B. Fraser, K. Tobin, & C. McRobbie (Eds.), *Second International Handbook of Science Education* (pp. 969-986). Dordrecht, The Netherlands: Springer.

McDonald, C. V. (2010). The influence of explicit nature of science and argumentation instruction on preservice primary teachers' views of nature of science. *Journal of Research in Science Teaching, 47*(9), 1137-1164.

McNeill, K. (2009). Teachers' use of curriculum to support students in writing scientific arguments to explain phenomena. *Science Education, 93*(2), 233–268.

McNeill, K., & Knight, A. (2013). Teachers' pedagogical content knowledge of scientific argumentation: The impact of professional development on K–12 teachers. *Science Education, 97*(6), 936-972.

McNeill, K., & Pimentel, D. S. (2010). Scientific discourse in three urban classrooms: The role of the teacher in engaging high school students in argumentation. *Science Education, 94*(2), 203-229.

Mercan, F. Ç. (2012). Epistemic beliefs about justification employed by physics students and faculty in two different problem contexts. *International Journal of Science Education, 34*(9), 1411-1441.

Mercer, N. (2002). *Words and minds: How we use language to think together*. London, UK: Routledge.

Mertens, D. (2010). *Research and evaluation in education and psychology: Integrating diversity with quantitative, qualitative, and mixed methods* (3rd ed.). Los Angeles, CA: Sage.

Mhakure, D., & Otulaja, F. (2017). Culturally-Responsive Pedagogy in Science Education: Narrowing the Divide between Indigenous and Scientific Knowledge In F. S. Otulaja & M. B. Ogunniyi (Eds.), *The World of Science Education: Handbook of Research in Science Education in Sub-Saharan Africa*. Rotterdam, The Netherlands: Sense Publishers.

Millar, R., & Osborne, J. (1998). Beyond 2000: Science education for the future. http://www.kcl.ac.uk/content/1/c6/01/32/03/b2000.pdf.

MoE. (2009). *Curriculum Framework for Ethiopian Education (KG - Grade 12)*. Addis Ababa, Ethiopia: Ministry of Education.

MoE & JICA. (2016). *Strategic Policy for National Science, Technology and Mathematics Education*. Addis Ababa, Ethiopia: MoE & JICA. Retrieved from http://www.moe.gov.et/documents/20182/42694/Strategic+Policy+for+National+Science+Technology+and+Mathematics+Education_Full.pdf/ef372bc1-8bc3-430a-b561-b6535e95419a?version=1.0.

Mortimer, E., & Machado, A. H. (2000). Anomalies and conflicts in classroom discourse. *Science Education, 84*(4), 429-444.

Mortimer, E., & Scott, P. (2003). *Meaning Making in Secondary Science Classrooms*. Maidenhead, England: Open University Press.

Mulder, Y. G., Bollen, L., de Jong, T., & Lazonder, A. W. (2016). Scaffolding learning by modelling: The effects of partially worked-out models. *Journal of Research in Science Teaching, 53*(3), 502-523.

Murphy, P., Greene, J., Allen, E., Baszczewski, S., Swearingen, A., Wei, L., & Butler, A. (2018). Fostering high school students' conceptual understanding and argumentation performance in science through Quality Talk discussions. *Science Education, 102*(6), 1239 – 1264.

NAE. (2010). *Ethiopian First National Learning Assessment (EFNLA) of Grades 10 and 12 Students*. Addis Ababa, Ethiopia: FDRE Ministry of Education.

Neber, H., & Schommer-Aikins, M. (2002). Self-regulated science learning with highly gifted students: The role of cognitive, motivational, epistemological, and environmental variables. *High ability studies, 13*(1), 59-74.

Neidorf, T., Arora, A., Erberber, E., Tsokodayi, Y., & Mai, T. (2020). *Student Misconceptions and Errors in Physics and Mathematics: Exploring Data from TIMSS and TIMSS Advanced*. Cham, Switzerland: Springer.

Newton, P. N., Driver, R., & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education, 21*(5), 553 – 576.

Niaz, M. (2017). *Evolving Nature of Objectivity in the History of Science and Its Implications for Science Education*. Cham, Switzerland: Springer.

NRC. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: National Academies Press.

NRC. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

Nussbaum, M., & Asterhan, C. (2016). The psychology of far transfer from classroom argumentation. In F. Paglieri, L. Bonelli, & S. Felletti (Eds.), *The psychology of argument: Cognitive approaches to argumentation and persuasion* (pp. 407-423). London, UK: College Publications

Nussbaum, M., Sinatra, G. M., & Poliquin, A. (2008). Role of epistemic beliefs and scientific argumentation in science learning. *International Journal of Science Education, 30*(15), 1977-1999.

Öberg, G., & Campbell, A. (2019). Navigating the divide between scientific practice and science studies to support undergraduate teaching of epistemic knowledge. *International Journal of Science Education, 41*(2), 230 - 247. doi:10.1080/09500693.2018.154

OECD. (2013). *Draft PISA 2015 Science Framework*. Paris, France: OECD Publishing Retrieved from http://www/oecd.org/pisa/pisaproducts/pisa2015draftframeworks.htm.

Ormrod, J. (2011). *Human learning*. Boston, MA: Pearson Education Inc.

Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science, 328*(5977), 463 – 466.

Osborne, J. (2012). The Role of Argument: Learning How to Learn in School Science. In B. Fraser, K. Tobin, & C. McRobbie (Eds.), *Second International Handbook of Science Education* (pp. 933-949). Dordrecht, The Netherlands: Springer.

Osborne, J. (2014). Teaching scientific practices: Meeting the challenge of change. *Journal of Science Teacher Education, 25*(2), 177-196.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching, 41*(10), 994 - 1020.

Osborne, J., Rafanelli, S., & Kind, P. (2018). Toward a more coherent model for science education than the crosscutting concepts of the next generation science standards: The affordances of styles of reasoning. *Journal of Research in Science Teaching, 55*(7), 1-20.

Papadouris, N., & Constantinou, P. (2014). An Exploratory Investigation of 12-Year-Old Students' Ability to Appreciate Certain Aspects of the Nature of Science through a Specially Designed Approach in the Context of Energy. *International Journal of Science Education, 36*(5), 755-782.

Pizzolato, N., Fazio, C., Mineo, R., & Adorno, D. (2014). Open-inquiry driven overcoming of epistemological difficulties in engineering undergraduates: A case study in the context of thermal science. *Physical Review Special Topics in Physics Education Research, 10*(1), 010107. doi:10.1103/PhysRevSTPER.10.010107

Pontecorvo, C., & Girardet, H. (1993). Arguing and Reasoning in Understanding Historical Topics. *Cognition and Instruction, 11*(3/4), 365-395. Retrieved from www.jstor.org/stable/3233745.

Rapanta, C. (2019). *Argumentation strategies in the classroom*. Wilmington, DE: Vernon Press.

Richmond, G., & Striley, J. (1996). Making meaning in classrooms: Social processes in small-group discourse and scientific knowledge building. *Journal of Research in Science Teaching, 33*(8), 839-858.

Roberts, D. (2013). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 729-780). New York, NY: Routledge.

Ruiz-Primo, M. A. (2011). Informal formative assessment: The role of instructional dialogues in assessing students' learning. *Studies in Educational Evaluation, 37*(1), 15-24.

Ryu, S., & Sandoval, W. (2012). Improvements to Elementary Children's Epistemic Understanding From Sustained Argumentation. *Science Education, 96*(3), 488-526. doi:10.1002/sce.21006

Sampson, V., & Blanchard, M. R. (2012). Science teachers and scientific argumentation: Trends in views and practice. *Journal of Research in Science Teaching, 49*(9), 1122-1148.

Sampson, V., & Clark, D. (2008). Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions. *Science Education, 92*, 447 – 472.

Sampson, V., & Clark, D. (2011). A comparison of the collaborative scientific argumentation practices of two high and two low performing groups. *Research in Science Education, 41*(1), 63-97.

Sampson, V., Enderle, P., & Walker, J. (2012). The development and validation of the assessment of scientific argumentation in the classroom (ASAC) observation protocol: A tool for evaluating how students participate in scientific argumentation. In M. S. Khine (Ed.), *Perspectives on scientific argumentation: Theory, Practice and Research* (pp. 235-264). Dordrecht, The Netherlands: Springer.

Sandoval, W. (2003). Conceptual and epistemic aspects of students' scientific explanations. *Journal of the Learning Sciences, 12*(1), 5-51.

Sandoval, W. (2005). Understanding students’ practical epistemologies and their influence on learning through inquiry. *Science Education, 89*(4), 634 - 656.

Sandoval, W. (2014). Science education's need for a theory of epistemological development. *Science Education, 98*(3), 383-387.

Sandoval, W., Greene, J., & Bråten, I. (2016). Understanding and promoting thinking about knowledge: Origins, issues, and future directions of research on epistemic cognition. *Review of Research in Education, 40*(1), 457-496.

Sandoval, W., Kawasaki, J., Cournoyer, N., & Rodriguez, L. (2016). Secondary teachers ’emergent understanding of teaching science practices. In C. Looi, J. Polman, U. Cress, & P. Reimann (Eds.), *Transforming Learning, Empowering Learners: The International Conference of the Learning Sciences (ICLS) 2016* (pp. 737–744). Singapore: International Society of the Learning Sciences.

Sandoval, W. A., & Morrison, K. (2003). High school students' ideas about theories and theory change after a biological inquiry unit. *Journal of Research in Science Teaching, 40*(4), 369-392.

Schwarz, C., Passmore, C., & Reiser, B. J. (2017). *Helping students make sense of the world using next generation science and engineering practices*. Arlington, Virginia: NSTA Press.

Semela, T. (2010). Who Is Joining Physics and Why? Factors Influencing the Choice of Physics among Ethiopian University Students. *International Journal of Environmental and Science Education, 5*(3), 319-340.

Settlage, J., & Southerland, S. A. (2019). Epistemic tools for science classrooms: The continual need to accommodate and adapt. *Science Education, 103*(4), 1112-1119.

Shaffer, D. (2003). Pedagogical praxis: using technology to build professional communities of practice. *ACM SIGGROUP Bulletin, 24*(3), 39-43.

Shaffer, D. (2006a). Epistemic frames for epistemic games. *Computers & Education, 46*(3), 223-234.

Shaffer, D. (2006b). *How computer games help children learn*. New York, NY: Palgrave Macmillan.

Shaffer, D. (2012). Models of situated action: Computer games and the problem of transfer. In C. Steinkuehler, K. Squire, & S. Barab (Eds.), *Games, learning, and society: Learning and meaning in the digital age* (pp. 403-431). New York, NY: Cambridge University Press.

Shaffer, D. (2017). *Quantitative Ethnography*. Madison, WI: Cathcart Press.

Shaffer, D. (2018). Epistemic network analysis: Understanding learning by using big data for thick description. In F. Fischer, C. E. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *International handbook of the learning sciences* (pp. 520-531). New York, NY: Routledge.

Shaffer, D., Collier, W., & Ruis, A. (2016). A tutorial on epistemic network analysis: Analyzing the structure of connections in cognitive, social, and interaction data. *Journal of Learning Analytics, 3*(3), 9-45.

Shaffer, D., Hatfield, D., Svarovsky, G. N., Nash, P., Nulty, A., Bagley, E., . . . Mislevy, R. (2009). Epistemic network analysis: A prototype for 21st-century assessment of learning. *International Journal of Learning and Media, 1*(2), 33-53. doi:10.1162/ijlm.2009.0013

Shaffer, D., & Ruis, A. (2017). Epistemic network analysis: A worked example of theory-based learning analytics. In C. Lang, G. Siemens, A. Wise, & D. Gašević (Eds.), *Handbook of learning analytics*. New York, NY: Society for Learning Analytics Research.

Sharpe, T. (2008). How can teacher talk support learning? *Linguistics and Education, 19*(2), 132-148.

Shemwell, J. T., Chase, C. C., & Schwartz, D. L. (2015). Seeking the general explanation: A test of inductive activities for learning and transfer. *Journal of Research in Science Teaching, 52*(1), 58-83.

Siebert-Evenstone, A. L., Arastoopour, G., Collier, W., Swiecki, Z., Ruis, A., & Shaffer, D. (2017). In Search of Conversational Grain Size: Modelling Semantic Structure Using Moving Stanza Windows. *Journal of Learning Analytics, 4*(3), 123-139.

Simon, S., Erduran, S., & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education, 28*(2-3), 235-260.

Sinatra, G. M., & Chinn, C. A. (2012). Thinking and reasoning in science: Promoting epistemic conceptual change. In K. R. Harris, S. Graham, T. Urdan, A. G. Bus, S. Major, & H. L. Swanson (Eds.), *APA educational psychology handbook, Vol. 3. Application to learning and teaching* (pp. 257–282). Washington, DC: American Psychological Association.

Smith, P. (2013). *Improving classroom discourse in inquiry-based primary science education (Unpublished doctoral dissertation).* Edith Cowan University, Perth, Australia. Retrieved from https://ro.ecu.edu.au/theses/591

Sober, E. (1993). Epistemology for empiricists. *Midwest studies in philosophy, 18*, 39-61.

Stake, R. E. (2005). Qualitative case studies. In N. K. Denzin & Y. S. Lincoln (Eds.), *The Sage handbook of qualitative research* (3rd ed., pp. 443 - 466). Thousand Oaks, CA: Sage Publications Ltd.

Stake, R. E. (2013). *Multiple case study analysis*. New York, NY: Guilford press.

Stroupe, D. (2015). Describing "science practice" in learning settings. *Science Education, 99*(6), 1033-1040.

Stroupe, D., Moon, J., & Michaels, S. (2019). Introduction to special issue: Epistemic tools in science education. *Science Education, 103*, 948 - 951. Retrieved from https://doi.org/10.1002/sce.21512.

Sullivan, S., Warner-Hillard, C., Eagan, B., Thompson, R. J., Ruis, A., Haines, K., . . . Jung, H. S. (2018). Using epistemic network analysis to identify targets for educational interventions in trauma team communication. *Surgery, 163*(4), 938-943.

Tadesse, M. (2015). *Dialogic Argumentation as Pedagogy: Impact on Preservice Physics Teachers' Conceptual Understanding of Mechanical Waves A Mixed Methods Study (Unpublished doctoral dissertation).* Addis Ababa University, Addis Ababa, Ethiopia.

Taibu, R., Schuster, D., & Rudge, D. (2017). Teaching weight to explicitly address language ambiguities and conceptual difficulties. *Physical Review Physics Education Research, 13*(1), 010130. doi:10.1103/PhysRevPhysEducRes.13.010130

Toulmin, S. (1958). *The uses of argument*. Cambridge, UK: Cambridge University Press.

Tracy, S. J. (2013). *Qualitative Research Methods Collecting Evidence, Crafting Analysis, Communicating Impact*. West Sussex, UK: Wiley-Blackwell.

Tsai, C.-C. (2002). Nested epistemologies: science teachers' beliefs of teaching, learning and science. *International Journal of Science Education, 24*(8), 771-783.

Von Aufschnaiter, C., Erduran, S., Osborne, J., & Simon, S. (2008). Arguing to learn and learning to argue: Case studies of how students' argumentation relates to their scientific knowledge. *Journal of Research in Science Teaching, 45*(1), 101-131.

Vosniadou, S. (2012). Reframing the Classical Approach to Conceptual Change: Preconceptions, Misconceptions and Synthetic Models. In B. Fraser, K. Tobin, & C. McRobbie (Eds.), *Second International Handbook of Science Education* (pp. 119-130). Dordrecht, The Netherlands: Springer.

Vygotsky, L. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.

Walker, J., & Sampson, V. (2013). Learning to argue and arguing to learn: Argument-driven inquiry as a way to help undergraduate chemistry students learn how to construct arguments and engage in argumentation during a laboratory course. *Journal of Research in Science Teaching, 50*(5), 561-596.

Wilcox, B. R., & Lewandowski, H. (2017). Developing skills versus reinforcing concepts in physics labs: Insight from a survey of students' beliefs about experimental physics. *Physical Review Physics Education Research*, *13*(1), 010108.

Wooldridge, A. R., Carayon, P., Shaffer, D., & Eagan, B. (2018). Quantifying the qualitative with epistemic network analysis: a human factors case study of task-allocation communication in a primary care team. *IISE transactions on healthcare systems engineering, 8*(1), 72-82.

Yang, F.-Y., Liu, S.-Y., Hsu, C.-Y., Chiou, G.-L., Wu, H.-K., Wu, Y. T., . . . Tsai, C.-C. (2018). High-School Students' Epistemic Knowledge of Science and Its Relation to Learner Factors in Science Learning. *Research in Science Education, 48*(2), 325-344. doi:10.1007/s11165-016-9570-6

Yin, R. (2014). *Case Study Research Design and Methods* (5th ed. Vol. 5). Thousand Oaks, CA: Sage.

Yin, R. (2017). *Case study research and applications: Design and methods* (6th ed.). Los Angeles, CA: Sage publications.

Yin, R. K., & Campbell, D. T. (2018). *Case study research and applications : design and methods* (6th ed.). Thousand Oaks, CA: SAGE Publications.

Yun, S. M., & Kim, H.-B. (2015). Changes in students' participation and small group norms in scientific argumentation. *Research in Science Education, 45*(3), 465-484.

Zimmerman, C. (2007). The development of scientific thinking skills in elementary and middle school. *Developmental review, 27*(2), 172-223.

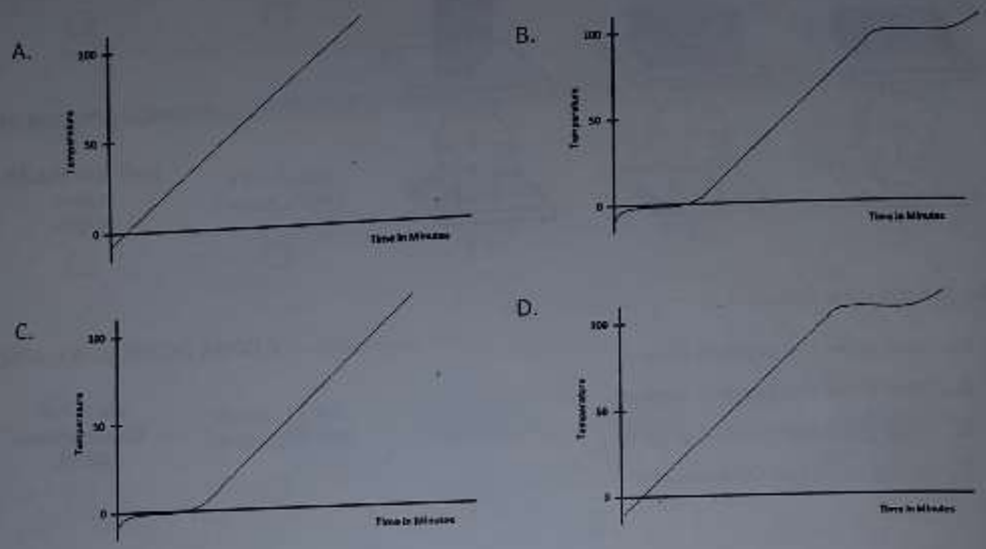
Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39*(1), 35-62.

Appendix A: Epistemic knowledge items from physics reasoning test

Item 3

Scientists claim the temperature does <u>not</u> change when ice is melting or when water is boiling

Which graph below supports their claim?



Item 4

Scientists say matter can turn from **solid** to **liquid**.

How do we know they are right?

A. Because ice can melt to water
B. Because ice can be crushed to powder
C. Because ice expands when it freezes
D. Because ice can be hard as rock

Item 5

Scientists say sound is caused by **vibrations**

How do we know they are right?

A. Because vibrations can make things break
B. Because you can feel vibrations in the strings of a guitar or a kirar
C. Because we can hear sound coming from a guitar or a kirar

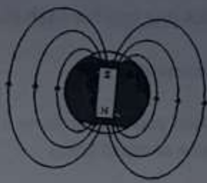
6

D. Because loud sound can make the ears hurt

Item 6

Scientists say the Earth has a **magnetic field**

How do we know they are right?



A Because we can find magnetic stones in nature

B. Because we can see magnets attract each other

C. Because we can see that the Sun attracts the Earth

D. Because we can see the needle on a compass always pointing to the North

Item 7

Some students think sound travels **faster** than light.

How do we know they are <u>wrong</u>?

A. Because you can see a lightning before you can hear the thunder

B. Because light travels all the way from the Sun to the Earth

C. Because you can still hear sounds when it is dark

D. Because sound travels faster in water than in air

Item 8

Some students think the Moon, like the Sun, is producing its own light.

How do we know they are <u>wrong</u>?

A. Because the Moon is seldom seen at daytime

B. Because we feel no heat from the Moon

C. Because shadows caused by moonlight are very weak

D Because the part of the Moon not lit by sunlight is dark

Item 9

Debre thinks boats float because they are made of light material.

Decide if the observations below <u>support</u> or <u>oppose</u> what Debre thinks
(tick <u>one box</u> for each observation)

Observation	Supports Debre	Oppose Debre
When you drop a stone in water it sinks, but a piece of wood floats	☐	☐
Some boats are made of steel, but still float	☐	☐
Some stones are very light, but still sinks	☐	☐

Item 10

The table shows average temperature at different places in Ethiopia

Location	Average Temperature (°C)	Altitude (Meters above sea level)
Arba Minch	21.8	1278
Dilla	20.6	1572
Bahir Dar	19.6	1797
Hawassa	19.2	1710
Gondar	19.1	1966
Addis Ababa	15.9	2324
Debre Markos	15.9	2462
Dessie	15.2	2491

a. What is the average temperature in Gondar ______________ °C

b. How does temperature change with altitude?

A. Higher altitude has higher temperature

B. Higher altitude has lower temperature

C. There is no clear pattern between altitude and temperature

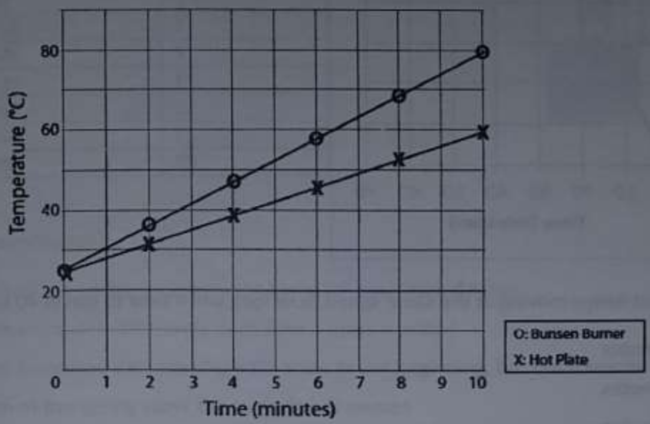
8

Item 11

Some students investigated two ways of heating water. One way was hot plate and the other was Bunsen burner.

They heated the same amount of water and measured temperature every 2 minutes

The measurements are presented in the graph:



a) Which heat source (hot plate or Bunsen burner) heated the water fastest?

____

b) What was the difference in temperature after 10 minutes?

____

Item 12

The table compares properties of three materials: **Wood, rock** and **iron**

Property	Material 1	Material 2	Material 3
Sinks in water?	Yes	No	Yes
Burns easily?	No	Yes	No
Attracted by a magnet?	Yes	No	No

Decide which materials are wood, rock and iron (write the number)

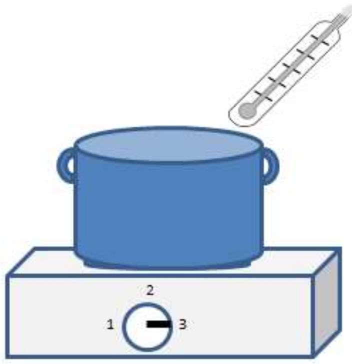
Wood is material number __________

Rock is material number __________

Iron is material number __________

9

Appendix B: Scaffolding activities for video recorded students' discourse
Activity for 1st videoing: Measuring Temperature



A school class did an experiment to find the temperature of boiling water. They had five groups of students that each made the measurement.
Here are their results:

Group	Temperature ºC
Group 1	99
Group 2	100
Group 3	99
Group 4	101
Group 5	98

Why did the groups not get the exact same temperature?

Here are some possible reasons:

- They did not read the temperature accurately from the thermometer
- There must have been something wrong with some of the thermometers
- Measurements are never exactly the same – there will always be uncertainty

Explain what you think is the most likely reason:

____

____

____

How should they decide which results they should use?

A. Add up all measurements and divide by five to get an average
B. Choose the two measurements that are the same
C. Choose 100 degrees, because this is in the textbook
D. Choose ninety-eight because this is the lowest

Explain which method you think is best:

____

____

____

____

____

____

Activity for 2nd videoing: Force and Motion

FORCE AND MOTION

Two students had a discussion about force and motion.

- **Student 1** said: *You always need a force to keep an object moving.*
- **Student 2** said: An object *can move without any force acting on it.*

Which student do you think is *right*? (Tick your choice like ☑)

Student 1 ☐ **Student 2** ☐

Why is the right student right and the wrong student wrong?

Here are some possible reasons to support or oppose the students' ideas:

- When throwing a stone, it keeps moving after it has left your hand
- Satellites move around the Earth without being pushed by an engine
- A bike does not move unless you push on the pedals
- When skidding on mud, a bicycle just keeps moving
- When pushing a heavy cart, it always stops when you stop pushing

Discuss in groups and write your agreed upon reasons why a student is right or wrong.

Student 1 is ______________________

Because ____

____

____

____

____

Student 2 is ______________________

Because ____

____

____

____

____

Appendix C: Interview protocol for school teachers

Teacher Interviews
(Try to keep the interview shorter than 15 minutes)

1. To what extent have you used the provided teaching material this semester? (Every lesson, every week…)
2. Can you give one or two particular examples of how you used the TPSS material?
3. What do you regard as the main challenges for using dialogic argumentation in your lessons?
4. More generally, what strategies do you prefer for making students talk in your lessons?
5. If more training was available, what would you like to learn to become a better teacher?

Appendix D: Assessment of Scientific Argumentation in the Classroom (ASAC)

ASSESSMENT OF SCIENTIFIC ARGUMENTATION IN THE CLASSROOM OBSERVATION PROTOCOL OBSERVATION INFORMATION

Teacher: ______________________ School: ______________________

Subject: ______________________ Grade: ______________________

Observer: ______________________ Date: ______________________

Duration of the episode: ______________________

GROUP CHARACTERISTICS

Size:
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6 or More
- ☐ Whole Class

Number of times that these students have been placed into this same group before:
- ☐ Never
- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4 or more
- ☐ Unknown

Assignment to the Group:
- ☐ Random
- ☐ Self-Selected
- ☐ Achievement – Mixed
- ☐ Achievement – High
- ☐ Achievement – Low
- ☐ Teacher choice – Other
- ☐ Unknown

Gender Composition:
- ☐ All Male
- ☐ All Female
- ☐ # of Males > # of Females
- ☐ # of Females > # of Males
- ☐ # of Females = # Males

Racial/Ethnic Composition: ______________________

Native Language Composition:

ACTIVITY DESIGN

Provide a brief description of (a) the way the activity or lesson was designed in an effort to promote and support argumentation and (b) the way the teacher encouraged students to engage in argumentation.

RECORD OF EVENTS

In the space provided keep a running record of the events that occurred as the participants interacted with each other, the materials, and ideas.

Time	Description of Event

CONCEPTUAL AND COGNITIVE ASPECTS OF SCIENTIFIC ARGUMENTATION

How the group attempts to negotiate meaning or develop a better understanding

<table>
<tr><td rowspan="2">1. The conversation focused on the generation or validation of claims or explanations.</td><td>0</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>Not at all</td><td>Once or Twice</td><td>A few times</td><td>Often</td></tr>
<tr><td colspan="5">Description: The emphasis on the generation or validation of claims or explanations indicates that there were some significant claims or explanations at the heart of discussion. Groups that score high on this item maintain the focus of their talk and efforts on understanding or solving the problem rather than the best way to finish their work quickly or with the least amount of effort. Note: Groups that stay on topic but never go engage in an in-depth discussion about what is happening should be scored low on this item.</td></tr>
<tr><td colspan="5">Comments:</td></tr>
<tr><td rowspan="2">2. The participants sought out and discussed alternative claims or explanations.</td><td>0</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>Not at all</td><td>Once or Twice</td><td>A few times</td><td>Often</td></tr>
<tr><td colspan="5">Description: Divergent thinking is an important part of scientific argumentation. A group that meets this criterion would talk about more than one claim, explanation, or solution. Individuals that valued alternative modes of thinking would respect and actively solicit new or alternative claims, explanations, or solutions from the other participants. Note: Groups that discuss multiple types of grounds or support for a claim, explanation, or solution but only one claim, explanation, or solution should be scored low on this item.</td></tr>
<tr><td colspan="5">Comments:</td></tr>
<tr><td rowspan="2">3. The participants modified their claim or explanation when they noticed an inconsistency or discovered anomalous information.</td><td>0</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>Not at all</td><td>Once or Twice</td><td>A few times</td><td>Often</td></tr>
<tr><td colspan="5">Description: Inconsistencies between claims or explanation and the phenomenon under investigation are common in science. A group that modified their claim or explanation when they noticed inconsistencies or anomalies would not ignore “things that do not fit” or attempt to discount them once they are noticed by one of the participants. Groups that score high on this item try to modify their claim or explanation (not just their reasons) in order to account for an inconsistency or an anomaly rather than attempting to “explain them away” or simply deciding that something “doesn’t matter.”</td></tr>
<tr><td colspan="5">Comments:</td></tr>
<tr><td rowspan="2">4. The participants were sceptical of ideas and information.</td><td>0</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>Not at all</td><td>Once or Twice</td><td>A few times</td><td>Often</td></tr>
<tr><td colspan="5">Description: During scientific argumentation, allowing a variety of ideas to be presented, but insisting that challenge and negotiation also occur would indicate that group members were sceptical. Accepting ideas without accompanying reasons would result in a low score because it is a sign of credulous thinking. In other words, students must be willing to ask, “how do you know?” or “Are you sure?” Groups that respond to the ideas of others with comments such as “ok”, “that sounds good to me”, or “whatever you think is right” would score low on this item.</td></tr>
<tr><td colspan="5">Comments:</td></tr>
<tr><td>5. The participants provided</td><td>0</td><td>1</td><td>2</td><td>3</td></tr>
</table>

reasons when supporting or challenging an idea.	Not at all	Once or Twice	A few times	Often
Description: Providing reasons to support or challenge a claim, conclusion, or explanation is a crucial characteristic of argumentation. Claims must have some support provided for them beyond simply restating the claim itself. Making claims without support would result in a low score on this item and including any reason like "that's what I think", "it doesn't make sense", "the data suggests…" or "but that doesn't fit with…" would result in a higher score. *Note:* Personal or past experiences count as a reason for this item.				
Comments:				
6. The participants based their decisions or ideas on inappropriate reasoning strategies.	**3**	**2**	**1**	**0**
	Not at all	Once or Twice	A few times	Often
Description: When people are trying to support ideas they often: (a) jump to hasty generalizations, (b) attribute causality to random events, (c) insist that a correlation is evidence of causality, and (d) exhibit a confirmation bias (for example saying, "now we need some data to prove this"). Groups that avoid inappropriate reasoning strategies or recognize them when they occur would score high on this item. Groups where these types of reasoning strategies are common would score low on this item.				
Comments:				
7. The participants attempted to evaluate the merits of each alternative explanation or claim in a systematic manner.	**0**	**1**	**2**	**3**
	Not at all	Once or Twice	A few times	Often
Description: This addresses the tentative or responsive nature of science. The idea that there is often more than one way to interpret data or evidence and that only through careful analysis can an idea be accepted or eliminated. This gets at the "gut" response factor. Conclusions are not based on opinion or inference.				
Comments:				

EPISTEMIC ASPECTS OF SCIENTIFIC ARGUMENTATION

How consistent the process is with the culture and norms of science

<table>
<tr><td rowspan="2">8. The participants relied on the “tools of rhetoric” to support or challenge ideas.</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td>Not at all</td><td>Once or Twice</td><td>A few times</td><td>Often</td></tr>
<tr><td colspan="5">Description: “Tools of rhetoric” refer to tricks or strategies used to win a debate. Tool of rhetoric include: (a) claiming that if someone cannot disprove a claim it must be true, (b) using emotive words and false analogies, (c) directing the focus of the discussion from thinking about a claim or an explanation to thinking about the person holding or proposing a claim or an explanation, (d) over relying on authorities, (e) dichotomizing issues so that if you discredit one position, then the observer is forced to accept the other view, and (f) making claims that are a simple restatement of one of the premises. Groups that avoided using the tools of rhetoric would score high on this item. Note: This item focuses on how the content of a discussion is presented or supported (i.e., how they are saying it) rather than the content of the discussion (i.e., what they are saying).</td></tr>
<tr><td colspan="5">Comments:</td></tr>
<tr><td rowspan="2">9. The participants used evidence to support and challenge ideas or to make sense of the phenomenon under investigation.</td><td>0</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>Not at all</td><td>Once or Twice</td><td>A few times</td><td>Often</td></tr>
<tr><td colspan="5">Description: A goal of scientific argumentation is the use of data as evidence to defend a claim, conclusion, or explanation. This item implies that students were attempting to use evidence in their arguments. This should more than an opinion; they must include data. Statements like “that’s what I think” or “it doesn’t make sense” would result in a low score. Statements like “the data we found suggests that …” or “our evidence indicates…” would result in a higher score.</td></tr>
<tr><td colspan="5">Comments:</td></tr>
<tr><td rowspan="2">10. The participants examined the relevance, coherence, and sufficiency of the evidence.</td><td>0</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>Not at all</td><td>Once or Twice</td><td>A few times</td><td>Often</td></tr>
<tr><td colspan="5">Description: This item draws attention to the amount and kinds of evidence used to support a claim or explanation. Groups that attempt to (a) determine the value of a piece of evidence (e.g., “does that matter?”), (b) look at links or the relationship between multiple pieces of evidence (e.g., “This supports X and Y but this only supports X”), or (c) attempt to determine if there is enough evidence to support an idea (e.g., “We do not have any evidence to support that”) would score higher on this item.</td></tr>
<tr><td colspan="5">Comments:</td></tr>
</table>

11. The participants evaluated how the available data was interpreted or the method used to gather the data.	0	1	2	3
	Not at all	Once or Twice	A few times	Often

Description: The evidence provided for a claim or explanation should be evaluated based on how well the data was gathered and interpreted. A question such as "Why is that evidence included?" or
"How did they gather their data?" or "Where did that data come from?" indicates that the participants are assessing methods or an interpretation of data and would result in a higher score.

Comments:

12. The participants used scientific theories, laws, or models to support and challenge ideas or to help make sense of the phenomenon under investigation.	0	1	2	3
	Not at all	Once or Twice	A few times	Often

escription: Science is theory-laden. In other words, scientists rely on broad, well-supported ganizing ideas to frame their arguments and claims. Students should also employ these radigmatic ideas in providing warrants for the evidence and claims they make or use to fute others' claims. Explicit reference to these "big ideas" will result in a higher score on is item.

Comments:

13. The participants made distinctions and connections between inferences and observations explicit to others.	0	1	2	3
	Not at all	Once or Twice	A few times	Often

Description: The structure of scientific arguments includes evidence involving both empirical (such as quantitative measurements and systematic observations) and inferential (noting of trends and logical connections among observations) aspects. Making these distinctions and their connections explicit to others enhances the quality of the argumentation and thus results in a higher score.

Comments:

14. The participants used the language of science to communicate ideas.	0	1	2	3
	Not at all	Once or Twice	A few times	Often

Description: This item stresses the importance of the accurate use of scientific language by students. The adoption and use appropriate terms (e.g., condensation, force, etc.), phrases (e.g., "it supports" rather than "it proves") or ways of describing information is a characteristic of argumentation that is scientific. *Note:* Ideas may be explicated before being labelled with the correct terminology.

Comments:

SOCIAL ASPECTS OF SCIENTIFIC ARGUMENTATION
How the participants interact with each other

	0	1	2	3
15. The participants were reflective about what they know and how they know.	Not at all	Once or Twice	A few times	Often
Description: It is important for members of the group to agree on what they know and to be specific about how they know. Statements such as, "do we all agree?" or "is there anything else we need to figure out?" or "can we be sure?" indicate that participants are monitoring their progress and have an end goal in mind.				
Comments:				
16. The participants respected what each other had to say.	**0** Not at all	**1** Once or Twice	**2** A few times	**3** Often
Description: Respecting what others have to say is more than listening politely or giving tacit agreement. Respect also indicates that what others had to say was actually heard and considered (e.g., "that is a good point", interesting idea", or "I hadn't thought of that"). A group that scored high on this would allow everyone to present their ideas and express their opinions without censure or ridicule.				
Comments:				
17. The participants discussed an idea when it was introduced into the conversation.	**0** Not at all	**1** Once or Twice	**2** A few times	**3** Often
Description: To be a participating and contributing member of the group, it is important to feel valued. Ideas and opinions need to be critically acknowledged. This means they are considered and given weight by the group. Groups that ignore ideas when they are proposed (results in the same idea being mentioned over and over) would earn a low score on this item.				
Comments:				
18. The participants encouraged or invited others to share or critique ideas.	**0** Not at all	**1** Once or Twice	**2** A few times	**3** Often
Description: Good argumentation comes from considering and comparing competing ideas from multiple individuals to construct the most robust explanation of the phenomenon under study. Groups that consist of individuals that invite others to share (e.g., "what do you think"), critique (e.g., "do you agree" or "it is ok to disagree with me"), or discuss an idea (e.g., "let's talk about this some more") would score higher that a group with an alienating leader that dominates the conversation and the work of the group.				
Comments:				
19. The participants restated or summarized comments and asked each other to clarify or elaborate on their comments.	**0** Not at all	**1** Once or Twice	**2** A few times	**3** Often
Description: The depth of discussion will be enhanced by not making implicit judgments or assumptions about another person's ideas or views, and it demonstrates that their point of view is valued and is furthering the discussion. Communication provides students with opportunities to identify the strengths and weaknesses of their understanding.				
Comments:				

Total: /57

Declaration

I, the undersigned candidate declare that this dissertation entitled: *Effect of dialogic argumentation on grade eight students' epistemic knowledge: A mixed methods design* is an original research I conducted under the supervision of *Prof. Jonathan Osborne and Dr. Mesfin Tadesse*. The full or any part of this dissertation has not been submitted for any degree or examination in this or any other university and therefore, it is not by any means a replication of a work already done by no one. Further, I declare that all the sources I have used or quoted have been indicated and acknowledged as complete references in this dissertation.

Candidate name: ___Getachew Tarekegn____________________________

Id Number: ___GSR/3623/07_____________________

Signature __________________________ Date: __________________________

I (we), Getachew Tarekegn's dissertation supervisors testify that this dissertation has been developed under my (our) supervision and I (we) approved it to be submitted to the department for evaluation as a fulfillment of the requirements for the degree of Doctor of Philosophy.

Main Supervisor:

Name: **Professor Jonathan Osborne_**____________________________

Signature: ____________________________ Date: ________________________

Co-Supervisor:

Name: **Dr. Mesfin Tadesse**____

Signature: ____________________________ Date: ________________________