The Effect of Dialogic-Practical Work Approach on Secondary School Students' Physics Learning outcomes

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This is to certify that this dissertation prepared by Ewonetu Bantie Belay, entitled: “***The effect of Dialogic Practical Work Approach on Secondary School Students’ Physics Learning outcomes***” and submitted in fulfilment of the requirements for the Degree of Doctor of Philosophy (in Physics Education) complies with the regulation of the University and meets the accepted standards with respect to originality and Quality.

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Declaration

I, the undersigned candidate declare that this dissertation entitled: "*The Effect of Dialogic - Practical Work Approach on Secondary School Students' Physics Learning Outcomes"* is my original work and it is not a replication of a work already done by no one. Furthermore, all the sources I have cited or quoted herein have been acknowledged and referenced.

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Abstract

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The purpose of this study was to investigate the effects of the dialogic-practical work approach on secondary school students' physics learning outcomes. A mixed method, concurrent research design was used to collect and analyze data before, during, and after the dialogic-practical work approach sessions. In this study, 91 participants from two governmental secondary schools in Bahir Dar City, Amhara, Ethiopia were involved. The treatment group and the comparison group conducted a dialogic-practical work approach and a recipe-based practical work approach respectively in secondary school physics laboratories. Quantitative data was collected through multiple choice test items, questionnaires, and observation checklist rubrics. Video recordings of small group discussions and semi-structured interviews were used as qualitative data. To analyze the quantitative data t-tests, Pearson correlation coefficient, and multiple regression were performed. Video recordings and semi-structured interviews were transcribed, coded, and analyzed. Results indicated that the dialogic-practical work approach significantly improved secondary school students' mechanics achievement, science process skills, attitudes toward physics, and epistemic beliefs about physics compared to the recipe-based practical work approach. Moreover, the dialogic-practical work approach improved female and male students' physics learning outcomes irrespective of gender differences observed between them. The results also revealed that the dialogic-practical work approach significantly and progressively improved students' scientific argumentation skills from the beginning to the final session. The results from the qualitative analysis showed that students' dialogic talk moves focused on cumulative and exploratory talks. They showed improvements in their exploratory talks. These results revealed that the dialogic-practical work approach has a positive impact on students' physics learning outcomes. The results, however, revealed that students had difficulties providing evidence, arguments, and counterarguments to the expected level during the dialogic-practical work approach. Students struggled with changing a claim when encountering inconsistent information. Applying dialogic-practical work approach can help secondary school students develop physics learning outcomes.

***Keywords**: Attitudes towards physics; Dialogic-Practical work approach; Epistemic Beliefs about Physics; Mechanics Achievement; Recipe-based practical work; Scientific argumentation skills; Science process skills.*

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CHAPTER 1: INTRODUCTION

1.1 Background of the study

In this era of rapid technological advances, physics is an essential science that helps people make sense of natural phenomena. Studying physics has the potential to generate the fundamental knowledge, skills, and attitudes needed for economic development (Musasia et al., 2016). It is also vital to prepare future scientists who are scientifically literate. It promotes students' critical thinking, problem-solving skills, and creativity, allowing them to take advantage of scientific advances and innovations. In the history of physics education, physicists began to study the discipline rigorously and scientifically in the past four decades (Chambers, 2014; Hodson, 1991). They started researching to identify students’ knowledge gaps, difficulties, and challenges encountered while learning physics. This problem-initiated physics education research. Physics education research provides research-based evidence on student learning and reorients curricular content and instruction accordingly. Physics educators started to document difficult content areas and misconceptions held by students while learning physics.

A growing body of PER findings concluded that students’ academic performance was declining in physics (Amin et al., 2014; Babajide et al., 2018). Most students failed to understand physics concepts and were unable to grasp concepts related to mechanics (Bani-Salameh, 2016; Husin et al., 2019). Similarly, studies indicated that students’ attitudes toward physics are declining continuously (Osborne & Dillon, 2008; Potvin & Hasni, 2014). Several physics educators indicated that the predominantly practiced traditional instructional methods did not address students' needs and interests (Baloyi, 2017; Otero & Meltzer, 2016; Teo, 2019). In addition, these studies indicated that the lecture method had little impact on students' understanding of fundamental physics concepts but did not help them avoid misconceptions and naïve thinking.

In this regard, physics educators implemented alternative instructional strategies in physics education to maximize students' learning. Furthermore, physics teachers tried to support classroom teaching with demonstrations and practical work activities in laboratories (Cramman et al., 2019). However, the way laboratory sessions were delivered was not enough to enhance students’ physics learning (Holmes et al., 2017). Therefore, the present study implemented a dialogic-practical work approach as a pedagogy in physics laboratory and investigated its effect on secondary school students’ physics learning outcomes.

From the global scenario of implementing a practical work approach in physics education, several studies were carried out and came up with controversial findings. Practical work has been regarded as a crucial component of physics curricula since the 1960s. Hence, several studies suggested that physics education should emphasize practical work to achieve the required learning outcomes (Abraham & Reiss, 2012; Baloyi, 2017; Holmes et al., 2017; Otero & Meltzer, 2016; Wieman & Holmes, 2015). Indeed, a number of physics education researchers investigated the benefits of practical work and its importance in physics education. However, these researchers cannot agree on the pedagogical foundation for practical work or the learning goals of practical work. To begin with, in many school laboratories and undergraduate laboratory courses, students commonly practiced a recipe-based practical work approach (Cramman et al., 2019; Riaz et al., 2020).

Some scholars found that implementing recipe-based practical work can improve students' learning outcomes compared to traditional lecture methods (Lee & Sulaiman, 2018; Muchai, 2016; Musasia et al., 2016). It also positively impacted students’ basic skills in working with data (Volkwyn et al., 2008). In contrast, several research findings revealed that recipe-based practical work provided little impact on enhancing students' achievements (Holmes et al., 2017; Vilaythong, 2011; Wieman & Holmes, 2015), improving the physics attitudes (Sawyer et al., 2017; Wilcox & Lewandowski, 2017), and promoting epistemic beliefs (Wieman & Holmes, 2015; Wilcox & Lewandowski, 2017). In a recipe-based practical work approach, students rarely engage in reflecting on methodology and findings, but they lack meaningful discussion among themselves and with their teacher (Sani, 2014). According to Kind et al. (2011) the students took only 0.4 percent of the time to group discussion during practical investigation. The recipe-practical work approach was critiqued by Hodson (1991) as being ineffective educationally and an ill-used of time.

As a result, practical work objectives are frequently revised, fresh experimental approaches are regularly created, and pedagogical trends shift in favor of cooperative learning, student-centered activities, and inquiry (Akuma & Callaghan, 2019; di Fuccia et al., 2012; NRC, 2012; Sesen & Tarhan, 2013). These strategies enable students to acquire new scientific knowledge through the processes of formulating hypotheses, organizing and carrying out investigations, interpreting the results and reaching conclusions. In this respect, several research findings showed that implementing the inquiry-based activities improved students' epistemic views (Hong et al., 2016; Schiefer et al., 2020), physics achievement scores (Radulović et al., 2016), attitudes toward physics (Kurniawan et al., 2021; Sesen & Tarhan, 2013) and science process skills (Athuman, 2017; Chambers, 2014). However, scholars also found contradictory results regarding inquiry levels on students' learning outcomes (Jiang & McComas, 2015). Inquiry-based practical work may promote one aspect of students' learning outcomes but not the other (Akuma & Callaghan, 2019). For example, Jiang and McComas (2015) found that students engaged in open inquiry activities significantly and positively impacted students’ attitudes toward science. Similarly, open-inquiry laboratories were more effective in developing students' science process skills (Chambers, 2014).

However, frequent exposure to open inquiry negatively impacted students’ science achievement (Cairns & Areepattamannil, 2019; van Riesen et al., 2019). Others concluded that guided inquiry practices with high levels of teacher support improve students’ science achievement (Aditomo & Klieme, 2020; Jerrim et al., 2020; Jiang & McComas, 2015). In contrast, Baloyi (2017) found that implementing explicitly guided inquiry practical activities for first-year physics university students did not improve their achievements compared to recipe-based practical work. Besides such contradicting results, some scholars argue that implementing an inquiry-based approach alone does not provoke meaning construction (Taylor et al., 2018; Walker et al., 2019).

Moreover, inquiry-based strategies alone have been blamed for isolating scientific knowledge and process (NRC, 2013). This approach failed to set up multi-voiced conversations in the classroom (Mesfin, 2017). It is recommended that dialogic teaching should be combined with inquiry-based learning in science labs. Dialogic teaching encourages student-student and student-teacher interactions to facilitate physics learning (Andersson & Enghag, 2017; Gultepe & Kilic, 2015; Oramous, 2021; Walker et al., 2019). It provides a space for the students to create meaning while discussing with one another about the experiment (Alexander, 2018; Kind et al., 2011). In such a setting, small groups of students communicate with each other while performing a task intended to help them gain an understanding of the concept at hand. It offers a chance to facilitate communication about experiments.

Andersson and Enghag (2017) indicated that dialogic teaching during practical work can develop students' ability to search for answers to questions. This might inspire students to express themselves, make arguments, and offer judgments based on their physics understanding. According to Kind et al. (2011) introducing dialogic teaching in laboratories establishes a platform for students to engage in scientific practices. Researchers, for example, incorporated dialogic-based inquiry-based activities to make laboratory experiences more authentic and realistic. These researchers showed that this approach promoted students’ achievements (Demircioğlu & Ucar, 2012; Demircioglu & Ucar, 2015; Taylor et al., 2018), science process skills (Demircioglu & Ucar, 2015; Gultepe & Kilic, 2015), attitudes toward science (Walker et al. 2012), and epistemic beliefs about science (Iordanou, 2016). This approach also improves students’ scientific argumentation skills (Demircioglu & Ucar, 2015; Hosbein et al., 2021; Walker et al., 2019).

In contrast, a few studies showed that this approach did not enhance students' attitudes toward science (Gultepe & Kilic, 2015; Ural & Gençoğlan, 2019). Walker et al. (2019) also realized that the argument-driven inquiry strategy did not improve students' skills to modify their ideas or reasoning, even when given contrasting evidence. This study also revealed that students did not show a significant improvement in claims as fundamental components of argumentation. Some evidence suggested that dialogic teaching is central to learning but difficult to reflect on in classroom teaching (Henderson et al., 2018; Ping et al., 2020). Others, however, revealed that students lacked the necessary linguistic skill to understand what was happening in the lab as experiments were being carried out (Kind et al., 2011; Lemke, 1990). Instead, the students’ primary concern was completing the practical investigations.

Yet, dialogic teaching becomes an area of research interest to maximize students' engagement in physics learning. So far, little research has been undertaken to illustrate the practicability and motivating benefits of systematically integrating dialogic teaching into practical work in physics laboratories (Andersson & Enghag, 2017). Moreover, other studies indicated that students' argumentation practices, skills, and understanding takes extended times interactions to improve (Oramous, 2021). Kuhn et al. (2013), however, claimed that simply giving more time is not enough to develop students' argumentation skills, rather, they should recognize the intricate nature of argumentative practices. Therefore, the present study applied a four-stage dialogic-practical work approach to examine its effect on secondary school students' physics learning.

Concerning the implementation of a dialogic-practical work strategy in Ethiopian schools, some research findings were implicated as follows. To begin with, Ethiopia has made many efforts to advance its economy and become middle-income by 2030 (Gbre-Eyesus, 2017). The government has implemented various programs in the education system to ensure sustainable development. The education sector should ensure lifelong learning and guarantee inclusive and equitable quality education. The education sector is expected to achieve the growth and transformation strategy through educating and training individuals with strong manipulation skills, creativity, critical thinking, and attitude (Joshi & Verspoor, 2012; Teferra et al., 2018). Secondary education is meant to assist in this endeavor.

The promotion of science and technology in society is listed as one of the national priorities in the Ethiopian Education and Training Policy (MoE, 2015; Teferra et al., 2018). In this sense, science education should play a crucial role in assuring rapid, long-lasting, and widespread progress in the nation (Gbre-eyesus, 2017; Joshi & Verspoor, 2012; Teferra et al., 2018). Hence, the government has allocated a sizeable budget to science education with the aim of preparing future generations with the necessary competencies and abilities for the expanding industrial and manufacturing sectors (Gbre-eyesus, 2017; Joshi & Verspoor, 2012).

Moreover, the Ministry of Education introduced Education Sector Development and General Quality Improvement Programs and reforms to enhance the quality of science education (Hoddinott et al., 2019; MoE, 2015). The implemented reforms and programs brought about various encouraging achievements regarding access, but secondary school education faced quality problems (Asgedom et al., 2019; Hoddinott et al., 2019). Secondary education poor quality remains a critical challenge for the country (Goshu & Woldeamanuel, 2019; Hagos & Tefera, 2015; Hoddinott et al., 2019). Goshu and Woldeamanuel (2019) further added that education quality and students' learning achievement is low. The overall score of students in university entrance examinations was far below the minimum learning competency (50 percent) set by the Ministry of Education (MoE, 2014; MoE, 2017).

The reports indicated that the number of Grade 12 students who achieved 50 percent and above in physics was 16.7 percent in 2010, 10.5 percent in 2014, and 7.4 percent in 2017 (MoE, 2010; MoE, 2014; MoE, 2017). These results indicated that students' physics achievement is continuing to perform poorly. Despite students’ poor physics achievement, Ethiopian secondary schools predominantly use lecture method (Tadesse & Gillies, 2015). This method is distinguished by teachers' constant use of lecture methods of instruction, content-focused drilling and memorization, negligible student-teacher communication, and an emphasis on summative evaluation procedures (MoE, 2014; Tadesse & Gillies, 2015). It favors direct instruction by teachers and emphasizes the significance of the authoritative powers of books and teachers to gain knowledge (Rees & Roth, 2019; Tan et al., 2021). There is little interaction between students except when they are asked a question or asked to do so by the teacher. In the physics laboratories context, secondary school students do not perform practical work to the desired level (Daba & Anbesaw, 2016; Daba et al., 2016; Nigussie et al., 2018). Most students graduate from high school without basic science experiments. These students were even unfamiliar with practical work based on recipes.

Some local studies have shown that students' poor physics learning outcomes can be attributed to inadequate practical work in secondary school laboratories (Daba et al., 2016; Nigussie et al., 2018). There is, however, a trend in current research to investigate the potential impact of non-recipe-based laboratory designs on students' physics learning outcomes. Moreover, global and local empirical studies have demonstrated that applying dialogic teaching in laboratories can improve students' low achievement in physics and mechanics in particular (Andersson & Enghag, 2017; Demircioglu & Ucar, 2015; Gultepe & Kilic, 2015; Iordanou, 2016; Worku & Alemu, 2020). However, there is currently a lack of sufficient empirical research and suitable practical work designs to enhance student learning, particularly in secondary school laboratory settings. Therefore, the rationale of the current study was to examine the extent and how implementing a dialogic-practical work approach can improve students' learning outcomes at 11th Grade level in the Ethiopian secondary school context.

1.2 Statement of the problem

Numerous educational documents and research outlets showed that science education's poor quality becomes a critical challenge for formal education in Ethiopia and elsewhere. The Ethiopian Educational Roadmap revealed that the vast majority of students in secondary schools lacked the necessary scientific understanding, attitudes, and competencies (Teferra et al., 2018). The three consecutive National Learning Assessment (NLA) reports carried out in Ethiopia based on grade 10 and 12 national exams indicated that students in secondary schools have poor academic performance in physics and science in general (MoE, 2010; 2014; 2017). The third NLA report indicated that Grade 10 and Grade 12 students' physics mean scores were 29.43 % and 30.90 % respectively (MoE, 2017).

The NLA report also presented Grade 10 and 12 students’ content-wise mean scores for the 2017 academic year. For instance, Grade 10 students' mean scores were 34.22% in Electronics; 33.42 % in Waves, Motion, and Sound; 31.16 % in Electricity and Magnetism; 25.82 % in Temperature and Heat; 28.99% in Mechanics and 24.39% in Geometrical Optics (MoE, 2017). Likewise, Grade 12 students scored 27.67% in Atomic Physics, 29.54 % in Electricity and Magnetism, 33.24 % in Mechanics, 29.49 % in Temperature and Heat, and 30.36 % in Wave and Light (MoE, 2017). The findings indicated that most students performed poorly in physics and mechanics in particular. Other related studies have also shown that students have difficulty understanding mechanics topics and possess many misconceptions (Bani-Salameh, 2016; Husin et al., 2019).

In a similar vein, multiple studies revealed that secondary school students had negative attitudes toward physics (Mandado, 2017; Mbonyiryivuze et al., 2021). These studies showed that most secondary school students consider physics a difficult subject. Whether positive or negative attitudes have an impact on how well students learn physics. It is commonly established that learning and future career are hampered by a negative attitude toward physics. Similarly, studies showed that secondary school students had low science process skills (Irwanto et al., 2017; Rahardini et al., 2017). The least result was observed in students’ scores in integrated science process skills. Furthermore, science curriculums do not pay attention to integrated science process skills (Tadesse & Solomon, 2023; Yumusak, 2016). This negatively impacts students' participation and permanence in learning, creativity to solve everyday life problems, and their future lives (Gultepe & Kilic, 2015; Rahardini et al., 2017).

Likewise, very few studies conducted in Ethiopia indicated that students had naïve epistemic beliefs (Kahsay, 2019; Mekbib, 2015). Students are supposed to view science knowledge as tentative and constructed by themselves through interaction with each other. Furthermore, secondary school students get little opportunity to practice scientific argumentation skills. Students are not given the chance to develop, support, refute, or improve a scientific assertion to come to valid findings or to challenge one another's viewpoints.

Despite some observed improvements toward gender parity, empirical studies show that gender inequality persists between males and females when learning physics particularly in developing Sub-Saharan African countries (Gambari & Yusuf, 2016; Gbre-Eyesus, 2017; Musasia et al., 2016). Some studies found that male students performed better than females in physics (Ibrahim et al., 2019). As a result, less female students than males prefer physics in secondary schools and higher education institutions. This gender disparity significantly impacts the proportion of male and female students who enroll in higher education to pursue science careers. Furthermore, there exists inconsistent results in the literature regarding the strategies on minimizing gender disparities in secondary schools (Diana et al., 2020; Lee & Sulaiman, 2018).

Other empirical studies also revealed that there is a large gap in physics learning between low and high achievement levels (Hans et al., 2015). These differences presumably create differing learning opportunities and, ultimately, could lead to differences in student achievement. A dearth of literature shows that students having low achievement levels are not favored by instructional approaches applied in physics classrooms (Buchs et al., 2015; Eshetu et al., 2017). This resulted in low achievement levels developing negative attitudes toward physics, which in turn negatively impacts their physics learning outcomes.

Several factors contribute to students' low performance in physics including the implementation of inappropriate instructional strategies, a shortage of instructional resources, a lack of functional laboratories, negative attitudes among students, an overloaded physics curriculum, and a shortage of experienced physics teachers (Agube et al., 2021; Diana et al., 2020). Among them, physics teachers' teaching methods are the major factor responsible for students' physics learning difficulties (Adonu et al., 2021; Diana et al., 2020). Several studies indicated that the lecture method dominantly applied in physics classrooms resulted in secondary school students' low physics achievement (Bani-Salameh, 2016), negative attitudes toward physics (Mbonyiryivuze et al., 2021), and students’ naïve views about physics (Kahsay, 2019). This approach failed to address students' physics learning needs. This strategy discourages conversation and emphasizes the value of acquiring knowledge from authoritative sources. It disregards the significance of enabling students create meaningful knowledge themselves. In this approach, the teacher is the dominant figure in classroom talk whereas students' talk is limited to asking questions or answering teachers' questions.

In the Ethiopian secondary school setting, students are required to carry out certain practical tasks in the laboratory session, however they have few possibilities to do so (Daba et al., 2016; Nigussie et al., 2018). This indicates that applying recipe-based practical work is a new addition to physics instruction in secondary schools in this situation. Enhancing students’ physics learning cannot be achieved without adopting effective teaching and learning strategies (Diana et al., 2020; Mbonyiryivuze et al., 2021). Hence, various efforts are being made to improve education quality through reforms in curricula and pedagogical practices in science classrooms and laboratories. The idea is to use student-centered practical activities that allow extended student-student and student-teacher interactions (Baytelman et al., 2020; Schiefer et al., 2020; Shi et al., 2020). These researchers argue that a single active learning method cannot achieve all physics learning objectives.

For example, inquiry-based learning can enhance students' physics learning, however, it has been criticized for failing to encourage multi-voiced conversations in the classroom (Mesfin, 2017). It is imperative to use a combination of student-centered approaches to produce the most effective physics education pedagogy. Hence, researchers recommend applying dialogic teaching in practical work as a pedagogy to enhance students' physics learning outcomes. This approach creates an ideal platform for students to integrate the domain of observables and domain ideas into practical work (Abrahams & Reiss, 2012; Gultepe & Kilic, 2015; Walker et al., 2019). It enables small groups of students to argue with each other while performing a task, thereby engaging them in meaningful science learning processes and understanding the concept.

Despite its beneficial impact on students' learning, organizing effective dialogic teaching as a regular part of physics instruction is rare (Chen et al., 2016; Henderson et al., 2018). Secondary school physics teachers typically lack the understanding and experience to appropriately implement dialogic teaching features fully in the classroom (Sedova et al., 2014; Worku & Alemu, 2020). On the students' side, they continue to struggle with properly presenting arguments and counterarguments effectively and understanding what constitutes good evidence.

Some researchers stressed that teaching cannot automatically be considered dialogic just because communication exchanges are present (Sedova et al., 2014). Hence, researchers suggest that dialogic teaching should be appropriately designed and implemented to create authentic, inclusive, and rational classroom experiences (El Majidi et al., 2021). However, current research lacks convergence regarding what this effective implementation entails and what it takes for researchers and educators to achieve it (Kim & Wilkinson, 2019).

Moreover, empirical evidence generated on how dialogic teaching can support students' learning in physics laboratories so far is scarce (Andersson & Enghag, 2017; Walker et al., 2019). In addition, it would be difficult to summarize these studies because they were conducted on students of different ages, interventions were done in various courses, contexts, and different outcomes were measured (Seda Cetin et al., 2018; Strimaitis et al., 2017). Additionally, there is very little in-depth analysis of what students discuss and do in the laboratory and the consequences of these actions (Andersson & Enghag, 2017).

Therefore, the current study attempted to address students' physics learning difficulties in secondary schools by implementing a dialogic-practical work approach. This study used a four-stage dialogic-practical work strategy in secondary school physics labs. As far as the author's knowledge is concerned, there hasn't been enough research into how a dialogic-practical work method affects students' physics learning in Ethiopian secondary schools. Hence, the current study investigated how a dialogic-practical work approach would affect secondary school students' learning of physics.

1.3 Objectives of the Study

The main objective of this research was to investigate the potential effects of a dialogic-practical work approach on secondary school students' physics outcomes. Students’ physics learning outcomes include mechanics achievement, science process skills, attitudes toward physics, epistemic beliefs about physics, and scientific argumentation skills. This study aimed to address the following specific research objectives:

- To describe how a dialogic-practical work approach would affect students’ mechanics achievement, science process skills, attitudes toward physics, and epistemic beliefs about physics.
- To investigate the effect of a dialogic-practical work approach on students’ gender differences and ability groups in mechanics achievement, attitudes toward physics, and epistemic beliefs about physics.
- To examine the effects of a dialogic-practical work approach on students change in science process skills and scientific argumentation skills over time.
- To investigate the contribution of science process skills, attitudes toward physics, and epistemic beliefs about physics to students' mechanics achievement after learning through a dialogic-practical work approach.
- To explore how students and teachers interacted with each other during the dialogic-practical work approach.
- To explore how students perceive their exposure to the dialogic-practical work approach.

1.4 Research Questions

To address the objectives of the present study, the following research questions were designed.

1. Is there a significant mean score difference in mechanics achievement between dialogic-and recipe-based practical work groups?
    1.1 Does the mean score for mechanics achievement differ between male and female students exposed to the dialogic-practical work approach?
    1.2 Do secondary school students with different achievement levels differ in their mechanics achievement mean scores?
2. Is there a significant mean score difference in science process skills between students who conducted the dialogic- and the recipe-based practical work approaches?
    2.1 Do secondary school students who were engaged in dialogic-practical work show a difference in practical skills performance over time?
3. Is there a significant mean score difference in attitudes toward physics between students' who were exposed to a dialogic-practical work approach and a recipe-based practical work approach?
    3.1 Is there a significant difference between female and male students in their attitudes towards physics mean scores?
    3.2 Are there significant differences among the different achievement levels who were exposed to the dialogic-practical work approach in their attitudes toward physics mean scores?
4. Is there a significant mean score difference in epistemic beliefs about physics between students exposed to dialogic- and recipe-based practical work approaches?
    4.1 Is there a significant mean scores difference between female and male students in epistemic beliefs about physics?

5. Do students in the treatment group differ in scientific argumentation skills mean scores over time?
6. Do students' scores in science process skills, attitudes toward physics, and epistemic beliefs about physics have significant predictive effects on their mechanics achievement scores?
7. How do the teacher and the students engaged in dialogic-practical work approach implement dialogic talk moves?
    7.1 How do students interact with each other during dialogic-practical work sessions?
    7.2 How does the teacher interact with the students to facilitate dialogic-practical work sessions?
8. How do secondary school students perceive the implementation of a dialogic-practical work approach?

1.5 Significance of the study

This research hopes to provide two major contributions to physics teaching and learning. The first is of theoretical significance. This study could contribute to narrowing the existing research gap concerning the impact of dialogic-practical work on secondary school students' learning of physics. Additionally, this study will add to the ongoing discussion of the merits of dialogic-practical work in science education literature. This research may help the physics community realize how to implement a dialogic-practical work style in physics labs and what impact it could have on students' physics learning. In the Ethiopian context, this study may be used as a starting point for anyone interested to research on the area and may use it as the source. In addition, it provides additional information for researchers interested in conducting further research.

The second is practical significance. The study applied a pedagogical strategy that engaged secondary school students in a dialogic-practical work approach to improving their understanding of physics concepts. It implies initiating a change in the persisting teaching and learning culture in secondary school physics laboratories, thereby moving toward the desired quality of physics education. It might give secondary school physics teachers and administrators valuable insight into what the dialogic-practical work approach is and how to use it to improve student's learning outcomes in physics.

Those physics teachers who participated in the research may have the chance to see the impacts of a dialogic-practical work and compare and contrast it with the recipe-based practical work approach. The practice of a dialogic-practical work approach can motivate physics teachers to deliberately design further practical activities in school classrooms. This study might also inform curriculum designers and decision-makers of the necessity of integrating a dialogic-practical work approach into science curricula. Moreover, this research may inform teacher educators to incorporate dialogic teaching in laboratory courses to advance students' science learning.

1.6 Delimitations of the study

The current study is limited to secondary school physics laboratory setting. It did not include primary schools and higher institutions. The study is also limited to the implementation of dialogic teaching in the laboratory as opposed to physics instruction in general. Furthermore, those physics learning variables exclude some others (e.g., problem-solving, representational, etc). This study is also limited to resource-scared schools and physics laboratories as opposed to schools in resource-rich countries. There is a shortage of practical work resources in secondary schools. Due to a shortage of resources and time only two secondary schools of Bahr Dar city administration, Amhara, Ethiopia have participated in the practical work. Furthermore, this study was also limited to grade 11 secondary school natural science students.

The study only included 91 students from two classes (sections) of secondary schools. Further, the teachers who participated in this study were selected purposefully. It might affect the generalizability of the study to other secondary schools. Only two physics teachers and two lab technicians with a physics background were involved in the study. This study was conducted in a secondary school laboratory setting where students had very little practical work experience. Moreover, secondary schools did not have separate practical investigations sessions. In this study, the intervention was only carried out for one semester (four months), despite recipe-based practical work is not the status quo in these schools. Hence, the students' poor prior practical work experience for both groups might limit the generalizability of the findings. In this regard, the researcher believes that it would be appropriate to conduct the study for more than a semester. The students could be more familiar with the dialogic-practical work intervention when time extends and help to see the more pronounced effects of the intervention on physics learning. The present research focused only on practical investigations associated with mechanics topics.

1.7 Operational definitions

It is noteworthy to define the keywords used in this research. These are Attitudes towards physics, Dialogic-practical work approach, Epistemic beliefs about physics, Mechanics achievement, Science process skills, and Scientific argumentation skills.

- **Attitudes toward physics** refer to the feelings, values, and judgments held by secondary school students about the dimensions of enthusiasm toward physics, physics learning, practical work, physics teacher, and future vocation expressed in the form of like or dislike, positive or negative reaction.

- **Dialogic-practical work approach** is a pedagogical approach that engages students in well-designed argument-based practical work activities to develop physics learning outcomes.
- **Epistemic beliefs about physics** are defined as the views that students should possess about the origins of their knowledge, the certainty of their knowledge, how their knowledge has developed, why they should know physics, why they should know about it, and why they should know it.
- **Mechanics achievement** refers to students' scores on items associated with mechanics contents covered by practical investigations.
- **Physics learning outcomes refer** to students' mechanics achievement, science process skills, attitudes toward physics, epistemic beliefs about physics, and scientific argumentation skills scores.
- **Science process skills** refer to physics knowledge and skills acquired by students while engaging in dialogic and recipe-based practical work approaches. It includes skills such as making observations, classification, prediction, formulating hypotheses, identifying variables, doing experiments, interpreting data, drawing graphs and reaching conclusions.
- **Scientific argumentation skills** refer to the skills manifested in physics by students in providing sound arguments, evidence, and counterarguments, and defending arguments scientifically up to the level indicated using the Assessment of Scientific Argumentation in the Classroom (ASAC) observation protocol.

CHAPTER 2: REVIEWS OF RELATED LITERATURE

Introduction

This chapter provides significant research that informs a broad range of teaching and learning strategies in science education and particularly in practical work. This section informs us that a single pedagogy cannot achieve all the intended objectives of teaching science and practical work. It is imperative to use a combination of approaches to produce the most effective science education pedagogy. Hence, this chapter discusses the rationale for choosing a dialogic teaching approach integrated with practical work to facilitate students' physics learning outcomes. This chapter has four main sections. The first section presents the importance of science education in secondary schools and the need to apply innovative approaches to science education. This section also discusses students' physics learning outcomes including mechanics achievement, science process skills, epistemic beliefs, and attitudes toward physics.

The second section briefly discusses dialogic teaching features and their impacts on physics education. This section also discusses the theories and frameworks of dialogic teaching that have had the greatest impact on recent physics education research. It also presents the purpose of practical work and the place of practical work in the Ethiopian Physics curriculum. The third section discusses practical work models, the framework to analyze students' dialogic talk moves, and empirical research on the contribution of dialogic-practical work to students' physics learning. The last section focuses on the conceptual and theoretical underpinnings of the current study.

2.1 Science Education in Secondary schools

Science education plays a crucial role in economic growth, scientific excellence, and technological innovations (Musasia et al., 2016; Potvin & Hasni, 2014). It contributes to preparing human capital that copes with the 21st century workforce and global economy (NRC, 2012; OECD, 2013; Teo, 2019). Science education has a paramount importance in addressing the alarming rise in the need for highly educated people in science subjects (Hillman et al., 2016; Kind et al., 2007; Osborne et al., 2003). For this reason, many countries invest considerable resources in improving science teaching and learning (Tanenbaum et al., 2016; Teo, 2019). It need to cope with technological advancements and society's demands. Moreover, the education system should address rapidly evolving skill requirements.

The teaching and learning processes should focus on allowing students to acquire transferrable knowledge, skills, attitudes, and critical thinking abilities that can be used to solve problems in real life situations. Schools should also respond to students' societal and economic needs. At different times different purposes for science education are favored. Osborne (2007) says science education should focus on:

> The importance of learning deeper conceptual understanding, rather than superficial facts and procedures, the importance of learning connected and coherent knowledge, rather than knowledge compartmentalized into distinct subjects and courses, the importance of learning authentic knowledge in its context of use, rather than decontextualized classroom exercises and the importance of learning collaboratively, rather than in isolation (p. 177).

Science education should allow students to apply their knowledge and skills to address real life problems rather than focus only on mastering a set of academic subjects. However, science classrooms do not support these demands (Baloyi, 2017; Osborne & Dillon, 2008). A teacher-centered approach that predominated science classrooms puts more emphasis on content and strictly follows curriculum contents and timetables. In this approach, the teacher presents basic facts and information that support superficial learning like memorization. Students are asked to memorize algorithms to solve a problem. As a result, they cannot connect what they learn about science in classrooms to their real-life experiences. It does not encourage students to utilize their higher-order thinking skills and provides few opportunities for them to work collaboratively by engaging in argument construction.

For this reason, there has been an effort to make science instruction more inquiry-based (Akuma & Callaghan, 2019; Athuman, 2017; Cairns & Areepattamannil, 2019). Inquiry-based learning encourages students to explore new knowledge and ideas and educates them about how scientists think instead of memorizing teacher output. Inquiry-based learning is a process of involving students in making critical observations, identifying research problems, selecting research questions, formulating hypotheses, planning and conducting experiments, gathering and analyzing data, presenting the findings, and drawing conclusions with the minimal guidance of the teacher (Pedaste et al., 2015). For a long time, science educators have long held conviction that inquiry-based learning results in improved science learning outcomes.

Likewise, a large body of research revealed that inquiry-based learning generally yields encouraging results. Inquiry-based learning can take on many forms ranging from structured to open inquiry in a science classroom. Consequently, there is still much debate about whether and when inquiry-based learning can benefit student learning (Akuma & Callaghan, 2019; Cairns & Areepattamannil, 2019). In other words, there is a lack of agreement on the kinds of inquiry-based learning strategies that support students' learning outcomes. For example, Jiang and McComas (2015) found that inquiry teaching at the highest levels can significantly and positively impact students' attitudes toward science. However, medium levels of inquiry teaching are more effective at helping students understand science concepts. Conversely, students who conducted activities and derived conclusions from the data achieved the highest scientific achievement than those who planned investigations or raised questions.

Moreover, numerous studies showed that students’ knowledge acquisition and attitude towards science improved when their openness to inquiry-oriented learning increased (Cairns & Areepattamannil, 2019; Jiang & McComas, 2015). Cairns and Areepattamannil (2019), for example investigated the effects of inquiry-based learning on science achievement and attitudes toward science among 170,474 students selected from 54 different countries. The results demonstrated that inquiry-based learning had a significantly positive correlation with attitudes toward science, but had a significantly negative correlation with students' science achievement. van Riesen et al. (2019) also found that open inquiry-based learning had negative effects on students' achievement. In this respect, Aditomo and Klieme (2020) investigated the effects of teachers’ guidance in inquiry-based learning on 151,721 students’ science achievement. These students were selected from the ten highest and ten lowest science scores in PISA 2015. The results revealed that inquiry-based learning with teachers’ guidance positively improved students' science achievement, while it had a negative correlation without teachers. These scholars added that even frequently exposing students to inquiry-driven learning has a negative association with science achievements.

These results and other research studies are consistent with current theories about the need to scaffold inquiry-based learning (Aditomo & Klieme, 2020; Jerrim et al., 2020; Lazonder & Harmsen, 2016; Vorholzer et al., 2020). For example, Lazonder and Harmsen (2016) indicated that the effectiveness of inquiry-based learning depends on the adequate support provided to the students. Their results further revealed that success of inquiry-based learning is largely dependent on the availability of an appropriate guidance. Similarly, Vorholzer et al. (2020) found that inquiry-based learning with explicit and implicit guidance were equally beneficial for all upper secondary school students regardless of their prior content knowledge and procedural knowledge of formulating questions and hypotheses, carrying out investigations, and analyzing and interpreting data. In contrast, Jerrim et al. (2020) revealed no correlation between frequencies of exposure to inquiry-based learning and students' science achievement.

These empirical studies shed light on how inquiry-based learning may support students' acquisition of science knowledge. However, evaluating inquiry-based interventions has proven to be challenging due to variances in forms of inquiry, contexts, implementation, and the use of different research designs or measurements. Besides, some scholars argue that relying solely on inquiry-based approaches does not provoke meaning construction (e.g., NRC, 2013; Walker et al., 2019). Moreover, inquiry-based learning has been criticized for emphasizing learning content and inquiry in isolation. For this reason, the *Framework for K-12 Science Education* develops scientific practices that integrate scientific content and process together (NRC, 2012). This new direction allowed students to be involved in identifying research questions, prioritizing evidence, generating explanations based on the data, assessing their explanations in comparison to competing explanations, and explaining and defending their suggested explanations.

2.2 Physics Education in secondary schools

Physics is a vital branch of the natural sciences. Through it, students will develop their ability to cope with technological advancements, scientific advancements, globalization, and a dynamic workplace that determines their future (Tanenbaum et al., 2016; Teferra et al., 2018; Teo, 2019). Students must update themselves through physics education to benefit from an interconnected and competitive world. Thus, physics education should aim to produce scientifically literate students capable of using their knowledge to make informed decisions about science and technology products in everyday life, be capable of interpreting public debates, and making thoughtful judgments on controversial socio-economic issues (Rees & Roth, 2019; Seda Cetin et al., 2018). It should also enable students to contribute positively to the society's social, economic and cultural benefits (Eshetu et al., 2017; Shi et al., 2020).

Physics education at secondary school level aims to develop students' understanding of natural phenomena, providing explanations of phenomena that build on consistent and well-tested relationships between identified and carefully defined quantities (MoE, 2009; Shana & Abulibdeh, 2020). It describes and explains phenomena and helps scientists predict them. It does so through models that can take many forms, but are often abstractions that try to get at the mechanisms that link different scales of phenomena, and different phenomena. Students' physics knowledge can create many innovations that directly or indirectly contribute to their daily lives. This includes performing tasks with technologies, explaining natural phenomenon concepts, and creating mental models for information transfer.

However, in most secondary schools physics education emphasizes the development of some scientific skills and an adequate mastering of scientific concepts, in order to lay down a solid foundation on which students can rely when entering those forms of tertiary education in which physics knowledge and skills are considered essential (Agube et al., 2021; Eshetu et al., 2017; Odo et al., 2021). Accordingly, most secondary education physics courses are described as having an academic, theoretical nature because of the academic discipline structure. In the course, little or no attention is paid to technological applications and social implications of science and technology and there are few opportunities to adapt (parts of) the course to meet individual students' needs (Hoddinott et al., 2019; Odo et al., 2021). Most of these physics courses are taught through lectures.

This strategy limits teachers from disseminating information without students' active participation (Gambari & Yusuf, 2016; Odo et al., 2021). This approach favors accumulation at the expense of thinking skill development, focuses on summative assessments, and is portrayed as a passive mode of teaching. The lecture method does not necessarily result in knowledge being understood and fails to address contemporary students' requirements. Hence, only a few students will ultimately become scientists themselves. For most students, physics is a difficult and alienating subject that has scanty or no practical use after secondary school (Goshu & Woldeamanuel, 2019; Hoddinott et al., 2019). Due to this, students in several countries performed poorly in physics in secondary schools (Agube et al., 2021; Goshu & Woldeamanuel, 2019; Hoddinott et al., 2019; Odo et al., 2021).

Therefore, some nations have developed physics curriculum documents that incorporate the following aims of physics (Larrain et al., 2018; NRC, 2012; Teo, 2019). First, physics education prepares students for a (future) life-role as consumers (with the capability of coping with and making decisions concerning products of science and technology in everyday life on issues such as quality, safety, cost, health and environmental hazards, and sensible use). Second, physics education should prepare students for their future role as citizens (able to interpret public debates and make more carefully considered judgments on controversial socio-scientific issues). Finally, it should prepare students for further studies or (future) employment (of a scientific, technological, or social nature), relevant to the specific group of students (mainly senior secondary education).

To achieve these goals, student activities should be chosen carefully to give students a chance of gaining the skills necessary to apply the acquired knowledge in practical situations in everyday life and to tackle independently issues that couldn't be dealt with in the curriculum (time constraints) or issues that might come up in society in the time ahead (Adonu et al., 2021; Kim & Wilkinson, 2019). In addition, teaching methods should be less 'talk-and-chalk' by the teacher and more classroom discussion, literature research, interviewing, practicals, etc. The role of the teacher in the classroom changes into stimulating and facilitating the independent work of (groups of) students (Kim & Wilkinson, 2019; Kind et al., 2011). In the next subsections, the status of secondary school students' achievement in mechanics, science process skills, attitudes toward physics, and epistemic beliefs about physics in physics education will be discussed in detail.

2.2.1 Students' Mechanics achievement

Physics has been used to increase productivity and improve economic and industrial development by aiding technological advancement and development. As a result, physics education should focus on developing students' capacity to adapt dramatic shifts impacting industry, health, the environment, information technology, and economic growth (Adonu et al., 2021; Gbre-eyesus, 2017). For this reason, several countries have embarked on programs to support physics education development at the secondary and higher education levels. Enhancing students' conceptual understanding of physics education is also the main goal of educational transformations and policy initiatives (NRC, 2012). Physics knowledge is divided into declarative, procedural, and epistemic categories. Declarative knowledge refers to students' understanding of terms, facts, concepts, and theories of specific subject matter (Bisson et al., 2016; Ferreira & Morais, 2015).

Procedural knowledge is an understanding of how to do something, procedures, and specific techniques in a specific discipline (Ferreira & Morais, 2015). For Bisson et al. (2016) procedural knowledge refers to students’ ability to apply algorithms stepwise to solve problems. Epistemic knowledge is about understanding how to construct scientific knowledge. The present study argues that students who acquired a thorough understanding of physics concepts, theories, principles, and facts as well as the ability to apply algorithms to solve problems would perform well in mechanics achievement tests. Therefore, mechanics achievement refers to the test scores of grade 11 secondary school students on mechanics topics included in laboratory investigations.

However, there has been a general decline in students’ physics achievement in secondary schools worldwide and in Ethiopia (Agube et al., 2021; Goshu & Woldeamanuel, 2019; Odo et al., 2021; Seda Cetin et al., 2018). In national examinations, secondary school students' physics achievement was the lowest (Adonu et al., 2021; MOE, 2017; Teferra et al., 2018). Chala and Berhe (2015) found that the majority of students scored below a pass mark in the Physics model exam result in some secondary schools in Bale Zone, Ethiopia. Students' poor physics performance is a major hindrance to Vision 2030 for developing countries like Ethiopia (Gbre-Eyesus, 2017). Domain-wise, ample research findings showed that students have a poor conceptual understanding of mechanics (Bani-Salameh, 2016; Husin et al., 2019). For instance, Husin et al. (2019) revealed that Afghan students lacked an understanding of force concepts. Afghan university students had a better conceptual understanding than high school students. Still, both school and university students had difficulties conceptually understanding Newtonian mechanics.

Bani-Salameh (2016) also found that introductory mechanics instructions did not change students' misconceptions about Newtonian concepts. They found some overall improvement in students' performance. However, the pre-and post-test scores showed that the strategy did not minimize the dominant misconceptions help by the students. Bani-Salameh (2016) found that pre- and post-test results showed that students have a poor level of conceptual understanding and possess many misconceptions about mechanics both in schools and universities. Students cannot draw diagrams and identify the major principles applicable to the situation as well as recall useful analogies and identify limiting cases before deciding on a procedure by which the relevant concepts can be applied (Agube et al., 2021; Chambers, 2014; Ibrahim et al., 2019). Generally, students failed to master mechanics conceptual understanding and performed poorly in this area.

This poor student achievement has prompted educational researchers worldwide to continuously identify factors that can account for academic outcomes in the classroom. Some research suggests that factors inside and outside the classroom affect student achievement, however, experts claim that the key factor in what comes out at the end of schooling is what goes on in the classroom (Ibrahim et al., 2019). Empirical research findings confirmed that teacher quality appears to be the most important factor influencing student performance. Those teachers with sufficient academic preparation are seen to be competent in subject matter content and pedagogical skills enabling them to be effective in classrooms and produce larger student achievement gains. In this regard, the present study attempted to integrate dialogic teaching and practical work in secondary school laboratories context to examine its effect on students' mechanics achievement.

Despite progressive improvements toward gender parity, gender inequality between male and female students still prevails at all levels especially in developing Sub-Saharan African countries (Gambari & Yusuf, 2016; Gbre-eyesus, 2017; Musasia et al., 2016). Domain-wise, some studies show males outperform females in understanding mechanics (Ibrahim et al., 2019). These researchers revealed that a smaller number of females than males study physics in secondary and higher education institutions. This resulted in a gender gap in physics academic achievements. This gender disparity significantly impacts the proportion of male and female students who enroll in higher education to pursue science careers.

Several researchers indicated that the reasons for students' poor mechanics achievement were their low motivation to learn the subject, poor teaching strategies utilized by physics teachers, teachers' poor content mastery, students' perceived difficulty of the subject, and insufficient instructional resources (Bani-Salameh, 2016; Chala & Berhe, 2015; Musengimana et al., 2021). Chala and Berhe (2015) found that teachers lacked competency in their subject and method of teaching. In addition, they had a lack of interest and motivation to engage in professional tasks. For the most part, high school physics is taught using the lecture method in conjunction with laboratory experiments to verify concepts taught in lectures.

Researchers investigated the impacts of different instructional strategies on secondary school students' achievement (Adonu et al., 2021; Musengimana et al., 2021). Some studies suggested that practical work strategies can enhance physics learning in secondary schools and minimize gender disparities (Diana et al., 2020; Lee & Sulaiman, 2018). Similarly, Adonu et al. (2021) observed no significant gender differences in achievement after applying a cooperative learning approach. Chala and Berhe (2015) suggested that physics teachers should be trained on how to perform practical activities through effective utilization of available laboratory resources.

Another contesting area of research associated with mechanics achievement was on how to minimize gaps among diverse ability levels in the classroom (Buchs et al., 2015; Gambari & Yusuf, 2016). This gap in achievement among diverse ability levels impacts their overall performance in subsequent years. There is a lack of conclusive evidence on how to minimize achievement gaps at diverse ability levels. Another prevalent notion is that sophisticated skills and higher-order thinking best suitable for high achievers. Some empirical studies showed that students having low achievement levels are not favored by instructional approaches applied in physics classrooms (Buchs et al., 2015; Eshetu et al., 2017). Others contend that low-ability students perform better in mixed-ability groups where they may interact with more experienced people, seeking clarification when needed and filling in knowledge gaps (Buchs et al., 2015).

While others argue that low-ability students perform well in heterogeneous groups in which they can interact with more competent individuals, asking questions, receiving explanations, and filling in knowledge gaps (Buchs et al., 2015). Students with high achievement levels would benefit from diversified and homogeneous groups. These scholars argue that medium ability students are less favored in mixed-ability groups. Their results indicated that these students may withdraw, engage less, and hold back and be excluded from peer interaction between high- and low-ability students.

Tan et al. (2021) argue that the design of the learning environment is crucial. Empirical studies have shown that low achievers can achieve a good performance in physics if the environment is designed properly. Hence, researchers investigated the extent to which various instructions would benefit students with different achievement levels (Gambari & Yusuf, 2016; Yaduvanshi & Singh, 2019). Some of these studies indicated that medium achievement levels progress more under highly structured conditions (e.g., Buchs et al., 2015). Some researchers found that cooperative learning benefits low achievement levels more than high achievement levels (Eshetu et al., 2017). Moreover, Han et al. (2015) found that lower-performing students who were involved in STEM project-based learning activities showed statistically significantly higher mathematics growth rates than high- and middle-performing students.

In spite of this, Gambari and Yusuf (2016) demonstrated that computer-assisted Jigsaw II cooperative settings benefited students of high, medium, and low achievement levels. It also resulted in a significant difference between the three achievement levels. Conversely, Yaduvanshi and Singh (2019) revealed that students with varying levels of ability taught by the cooperative learning strategy outperformed better than the conventional comparison group. These studies differed in the effectiveness of innovative teaching strategies in fostering students' achievement. Walker et al. (2016) explored the degree to which students engaged in argument-driven inquiry would affect their practical exam scores in a general chemistry laboratory course. Regardless of their prior achievement success, they discovered that the mean score on the practical exam for the students involved in the argument-driven inquiry model was greater than the mean score for the students engaged in the recipe-based practical work approach. For students who participated in traditional practical work, there was no significant difference in practical exam mean scores between high and low previous academic achievements.

In contrast, the argument-driven inquiry approach resulted in a significant difference between students with low and high past academic achievement. Walker et al. (2016) suggested that the increased gap between the argument-driven inquiry group with high and low past academic achievement requires further research. The present study argues that the nature of current classroom as well as laboratory instruction in science is not well aligned with current recommendations for making science more meaningful, equitable, and inclusive. Moreover, instruction for lower track students tends to be less cognitively demanding and leads to social stratification in which some students have far fewer opportunities to learn (Strimaitis et al., 2017). Such unequal treatment lead to questions of what students with varying achievement levels might learn if they had access to the same high quality laboratory instruction that is usually reserved for students with high achievement levels. Furthermore, benefiting the low-achieving students to an increased extent and decreasing the achievement gap is still a challenge in most secondary physics classrooms.

2.2.2 Students' science process skills

Researchers and academics argue that science process skills help students learn science, hence, they need to acquire these skills early on from primary school onwards (Shahali et al., 2017). Consequently, in many countries, the science curriculum focuses on enhancing students' science process skills (Gultepe & Kilic, 2015; NRC, 2012; Rahmi et al., 2018). The Science Standards in the USA, for instance, include skills such as asking questions, planning and conducting investigations, analyzing and interpreting data, and engaging in arguments from evidence (NRC, 2012). Empirical research demonstrated the crucial importance of science process skills in fostering student engagement, enhancing learning persistence, maximizing students' creativity to solve challenges in daily life, and preparing students for their future selves (Rahardini et al., 2017).

The present study used the term science process skills. Science process skills are defined as “a set of broadly transferable abilities, appropriate to many science disciplines to access knowledge and reflective of scientists' behavior” (Hikmah et al., 2018; p. 132). According to this definition, science process skills refer to the abilities and competencies students possess to engage with and understand science, both conceptually and procedurally. SPSs are classified as basic and integrated. A basic science process skill consists of observation, classification, prediction, inference, measurement, estimation, and communication (Kruea-In & Thongperm, 2014). Integrated science processes include identifying variables, formulating hypotheses, defining variables operationally, performing experiments, interpreting data, and drawing conclusions.

On the other hand, Wilson et al. (2016) categorized integrated science process skills as manipulating equipment, planning and carrying out experiments, taking measurements, handling data, concluding the obtained data, and recognizing the limitations of the method used. As far as basic science process skills are concerned, the present study used the categorization chosen by Kruea-In and Thongperm (2014) with the exception of estimation and communication. There are two ways of assessing students’ science process skills. The first is direct assessment (formative assessment) of practical work, which involves assessing students’ competencies by observing them while carrying out a practical activity (Reiss & Abrahams, 2015). It is more appropriate to determine students’ competency in practical investigations.

The information is collected by directly observing how the students set up the apparatus and plan activities so that they have to utilize their skills, asking them to describe their investigation process and justifications, requesting them to interpret and analyze the data, observing them while engaging in argumentation and providing an opportunity to present their findings through drawings, graphs and written reports. While indirect assessment (summative assessment) students may be assessed using a laboratory report or complete standardized multiple-choice tests. The most commonly used written instrument to assess SPS in the literature is the Science Process Skills Test (Fugarasti et al., 2019). The science process skills test focuses on the student's conceptual understanding and practical knowledge of science process skills. However, such written items are insufficient and focus only on knowledge aspects of science process skills (Reiss & Abrahams, 2015).

In the present study, science *process skills* are defined as secondary school students’ levels of practical skills acquired and understanding of experimental procedures and techniques, data analysis and presentation, data interpretation, and making conclusions during dialogic practical work. It also refers to the skills acquired by secondary school students when assessed using both indirect and direct assessment strategies. Empirical studies indicate that the lecture method is dominantly implemented in most secondary schools (Crook et al., 2015; Yumusak, 2016). This approach emphasizes memorizing physics concepts and facts. Arslan et al. (2023) found that many secondary school science teachers have a limited understanding of science process skills. Therefore, it is unlikely that these teachers develop and support students’ science process skills.

Moreover, science curricula do not emphasize integrated science process skills (Yumusak, 2016). As a result, students scored low on science process skills tests (Irwanto et al., 2017; Rahardini et al., 2017). Rahardini et al. (2017) conducted a survey on secondary school students and concluded that the mean science process skills scores were moderate. Some studies suggested that inquiry-based activities improved students' science process skills more than traditional laboratory tasks (Irwanto et al., 2017). Similarly, Arslan et al. (2023) showed that an argument-based inquiry approach can enhance students' science process skills.

However, secondary school students scored high for planning investigations and analyzing data, formulating hypotheses at a moderate level, but scored low for determining variables and operationally defining variables (Arslan et al., 2023). Others found that students scored low in the skills of controlling variables (Erkol & Ugulu, 2014), predicting (Susanti et al., 2018), identifying the variables and testing the hypothesis (Rahmi et al., 2018), reaching conclusions, communication, and inference (Akani, 2015). These and other related studies showed that secondary school students still had low science process skills. To fill in these research gaps, this study investigated how dialogic-practical work affected secondary school students' science process skills.

2.2.3 Students’ attitudes towards physics

Science education should consider students' affective domains such as attitudes, interests, motivation, experiences, and enthusiasm. More specifically, attitudes toward science are crucial for cultivating students' motivation for engaging in scientific work professionally, improving learning standards in scientific fields, and training students who are responsible for their actions and decisions (Navarro et al., 2016). It can be considered a psychological precondition for students’ interest in studying science and pursuing scientific careers (Kind et al., 2007; Osborne et al., 2003). Moreover, students’ positive attitudes toward science are associated with their commitment and engagement in learning physics, school performance, and a deep understanding of science ideas (Kingir & Aydemir, 2012; Kousa et al., 2018; Liou, 2021). Therefore, helping students develop positive attitudes toward physics should be a vital step in physics education. Hence, researchers in science education are increasingly interested in studying students' attitudes toward science.

However, researchers faced difficulties due to the lack of an agreed-upon definition of the construct attitude in the literature. This negatively affected attitude measurement development and validation. It has resulted in measuring students’ attitudes toward science exposed to various theoretical and methodological concerns (Barmby et al., 2008; Kaur & Zhao, 2017). It hampered the consistency of attitude studies in science education and inhibited researchers from developing accurate and reliable assessments of attitudes toward science (Kennedy et al., 2016; Navarro et al., 2016). Literature uses different terminologies such as attitudes towards science, scientific attitudes, the nature of science, and scientific career interests. A variety of definitions were used for these terms.

For instance, Kind et al. (2007) defined attitude as – “the feelings a person has about an object, based on their beliefs about that object” (p.4). Individuals frequently and consistently rate the objects in their environment either positively or negatively based on their repeated exposures and these judgments influence their behavior. For Kind and his colleagues, the science teacher, the science classroom, and the science content are a few examples of the attributes that make up an object. For instance, students can judge physics teachers' teaching styles as being effective or ineffective, enjoyable or not, and fascinating or dull. Attitude requires an individual to take actions based on his/her knowledge and beliefs about various aspects of science. Kaur and Zhao (2017) also define attitudes toward physics as "the feelings, beliefs, and values held toward physics which include enthusiasm toward physics, physics learning, physics as a process, physics teacher, and physics as a future career expressed in the form of like or dislike; positive or negative reaction toward physics" (p.293). Moreover, they prefer to include feelings, beliefs, and values in defining attitudes.

Research has recently revealed that attitudes toward science and physics encompass a variety of attributes (Hillman et al., 2016; Kaur & Zhao, 2017; Kind et al., 2007; Kennedy et al., 2016; Navarro et al., 2016). Academics characterize attitudes toward science or the physics subscales differently. For example, Kind et al. (2007) identified six dimensions of attitude toward science. These are learning science in school, practical work in science, science outside of school, the importance of science, self-concept in science, and future participation in science. Kennedy et al. (2016) characterize attitudes toward science in terms of the following dimensions. These are usefulness to science career; usefulness to personal career; relevance to everyday life; relevance of science to society; enjoyableness; self-efficacy; difficulty; understanding the natural world; applicability of school science; and understanding everyday technologies.

Navarro et al., (2016) used seven subscales, such as social implications of science; normality of scientists; attitude toward scientific inquiry; adoption of scientific attitudes; enjoyment of science lessons; leisure interest in science; and career interest in science. In their *My Attitudes toward Science*, Hillman et al. (2016) identified four dimensions of attitude toward science: desire to become a scientist, value of science to society, and perceptions of scientists. Studies have revealed that attitude measurements are unreliable, invalid, and of poor psychometric quality. Because of these worries, researchers have devised and verified instruments to assess students' attitudes toward science at elementary, secondary and higher education levels (Hillman et al., 2016; Kaur and Zhao, 2017; Kennedy et al., 2016; Kind et al., 2007; Navarro et al., 2016). For example, Kennedy and colleagues (2016) developed a *School Science Attitude Survey* with 68 items to assess students' attitudes toward school science.

Similarly, Navarro et al. (2016) developed and validated the *Test of Science-Related Attitudes* with 70 items to address the lack of attitude measurement tools in Spanish-speaking schools with limited English fluency. These scholars argue that, this instrument included additional aspects of attitude toward science that need to be addressed and assessed in the classroom beyond focusing on treating attitude as simple enthusiasm in learning science in school. They further contend that this instrument has consistent psychometric properties, is easy to use, and has conceptual solidity. Likewise, Hillman et al. (2016) developed My Attitudes toward Science with 40 items to assess students’ attitudes towards science. This adequately incorporates most dimensions that have been described in the literature. This instrument contains numerous aspects of students' attitudes about science and can be used across school levels and scored easily.

On the other hand, Kaur and Zhao (2017) designed a Physics Attitude Scale to gauge students' attitudes toward physics. This tool consists of 60 items divided into enthusiasm toward physics, physics learning, physics as a process, physics teacher, and physics as a future vocation. In the current study, students' attitudes toward physics are theoretically conceptualized as the feelings and values they hold about enthusiasm for physics, physics learning, practical work, physics teacher, and future vocation expressed on a scale ranging from strongly dislike to strongly like.

These dimensions of attitudes towards physics are adapted for a variety of reasons. First, these authors explicitly defined the construct of attitudes towards physics. This instrument exhaustively included the most significant students’ attitude dimensions associated with a physics teacher, teaching methodology, and curriculum. Second, this instrument has strong psychometric qualities and evaluates the various subscales of physics attitudes. Third, it is a reliable tool with excellent psychometric qualities that may be used to test students' attitudes about physics. It may also be used to monitor changes in their attitudes toward the physics teacher, teaching approach, and curriculum.

Researchers have noted a decline in the number of students enrolling in science programs throughout the years, particularly in the most developed countries (Hillman et al., 2016; Osborne & Dillon, 2008; Potvin & Hasni, 2014). These scholars argue that in many countries across the world, the notion that student interest in STEM subjects is dwindling is now universally acknowledged. For example, Osborne and Dillon (2008) concluded that students' attitudes towards school science in 40 European countries were negatively associated with the nation’s human development index. They added that school science was less popular in all developed European countries. Additional meta-analysis results revealed that even students with high levels of scientific achievement do not pursue jobs as scientists or engineers because they lost their attitudes toward science as they progressed to secondary school (Potvin & Hasni, 2014). Furthermore, students who achieve high average science achievement have lower positive attitudes towards science.

Similar trends were observed in the US even though STEM-related occupations are rapidly rising (Hillman et al., 2016). This decline in students’ attitudes toward science in many countries affects the number of students choosing to pursue physical sciences, engineering, and mathematics in higher education. These findings contradict the need for highly educated science professionals to meet economic, environmental, and technological challenges. This problem worries governments all over the world and questions have been raised about what can be done to increase students' interest in science. In a similar vein, multiple empirical studies also showed that physics is considered the most challenging area of learning within science, and it usually attracts fewer students than other science-related subjects from secondary school to university (Ibrahim et al., 2019; Mandado, 2017; Mbonyiryivuze et al., 2021). Generally, students tend to have a negative attitude towards physics presumably because they lack interest in the subject and the syllabus itself.

A study conducted in an Ethiopian secondary school context indicated that students have a negative attitude toward learning physics lessons and doing physics experiments (Chala & Berhe, 2015; Mandado, 2017). These studies indicated that most secondary school students consider physics a difficult subject. It might be due to the learning processes involved in understanding physics, which require learners to deal with different types of representations, such as formulas, calculations, graphics representations, and also a conceptual understanding at an abstract level (Ibrahim et al., 2019). This results in many concepts and principles of physics being difficult to understand. Attitudes, whether positive or negative, affect physics learning. It is well known that a negative attitude towards physics makes learning or future learning difficult. Students with negative attitudes towards physics and limited interest in science can generally translate into low student enrolments in the science stream. This has resulted in fewer students pursuing and persevering in physics-related careers during their undergraduate degrees. Hence, the interest of students in studying physics is adversely affected.

Because of a visible decline in enrolment in physics and a fall in interest in physics around the world, many researchers have sought to estimate the attitude of students towards physics at secondary schools and universities (Hillman et al., 2016; Ibrahim et al., 2019). In this respect, physics education researchers started to communicate with the problem, understand its underlying mechanisms, and develop strategies to improve it. For example, Ibrahim et al. (2019) examined secondary school students' attitudes toward learning physics and challenges towards learning force and motion. The study participants were among Form Four 200 secondary school students who took physics as a subject at their secondary school in Malaysia. The findings of the learning attitudes test showed that most students have favorable attitudes toward physics. Their findings also revealed that the nature of the topic was the most predominant challenge in studying force and motion.

Of the several factors that can affect students' interest in science, especially in the area of Physics, the approach to teaching that is adopted by the teacher is one of fundamental importance (Mbonyiryivuze et al., 2021; Musengimana et al., 2021). In other words, teachers' inappropriate teaching methods have been suggested as a major cause of students' negative attitudes toward physics. Hence, researchers attempted to implement student-centered approaches and investigated their effect on students' attitudes toward physics. As an example, problem-based learning for mechanics improved students' attitudes toward the subject over conventional instruction (Mandado, 2017).

Despite, these efforts being made to develop students' attitudes toward physics, the outcome is still questionable (Barmby et al., 2008; Hillman et al., 2016; Navarro et al., 2016). The ubiquitous scope of these concerns, both geographically and culturally, requires an in-depth understanding of what comprises and forms positive attitudes about schools globally. Therefore, the present study aimed to examine the effects of applying a dialogic-practical work approach on students' attitudes toward physics.

2.2.4 Students' Epistemic beliefs about Physics

Epistemology is a wide term that addresses fundamental concerns such as what is knowledge and what we mean when we say we know something; what is the source of knowledge and how do we know if it is reliable; and what is the scope of knowledge and what are its limitations? It addresses students' opinions and beliefs about knowledge and knowing, definitions of knowledge, how knowledge is constructed, and how knowledge is evaluated. From the beginning to the data, science education researchers have forwarded various conceptualizations to characterize epistemic beliefs (DeBacker et al., 2008; Wang et al., 2013). It is difficult to agree with researchers about epistemic beliefs, dimensions, domain specificity, and potential relationships with other constructs.

Furthermore, there is also a lack of consensus on the use of terminologies by researchers, such as, personal epistemology (Hofer & Pintrich, 1997), epistemological beliefs (Schommer, 1994), epistemic beliefs (Muis & Franco, 2009), epistemic positions (Perry, 1970), epistemic cognition (Chinn et al., 2011), and argumentative reasoning (Kuhn, 1991). Epistemic beliefs are defined as individuals' judgments about the nature, structure, and certainty of knowledge and justification for knowing concerning knowledge acquisition and the process through which knowledge is constructed (Greene et al., 2018; Hofer & Pintrich, 1997; Muis et al., 2016).

Generally, theorists and researchers use a developmental or multi-dimensional model to conceptualize epistemic beliefs. Those authors that followed developmental models described epistemic beliefs in terms of stages (Kuhn, 1991; Kuhn et al., 2000; Perry, 1970). For instance, Perry (1970) offered nine developmental stages of epistemic beliefs grouped into four progressive categories: dualistic, multiplicity, relativistic, and commitment to relativism. It ranges from characterizing knowledge as absolute, right-and-wrong; authorities are expected to know the truth to recognize that students are active constructors of meaning, knowledge is relative, and knowledge's meaning can be context-dependent.

Kuhn (1991) identified only three stages of epistemic beliefs, such as absolutist, multiplist, and evaluativist views to characterize students' ability to defend and acknowledge alternative knowledge claims during argumentation. In contrast, the multidimensional model characterizes epistemic beliefs as a collection of discrete beliefs that emerge more or less separately from one another (Berding et al., 2017; Hofer & Pintrich, 1997; Lin & Tsai, 2017; Schommer, 1994). For example, Schommer (1994) characterizes epistemic beliefs in terms of five independent dimensions, such as the structure of knowledge, the certainty of knowledge, the source of knowledge, the nature of ability, and learning. Individuals in each dimension should progress from naïve to sophisticated beliefs (DeBacker et al., 2008; Schommer, 1994).

Hofer and Pintrich (1997) also identified the dimensions of epistemic beliefs by omitting Schommer's nature of learning factors and adding another nature of knowing factor, namely justification. Moreover, Conley et al. (2004) proposed additional dimensions of epistemic beliefs such as knowledge development. Lin and Tsai (2017) claimed that the subscales of epistemic beliefs may be inadequate to provide a reliable description of the nature of epistemic beliefs. These researchers targeted to broaden the dimensions of epistemic beliefs into six by adding new dimensions. These are the multiplicity of knowledge, the uncertainty of knowledge, the development of knowledge, the justification for knowing, the purpose of knowledge, and the purpose of knowing (Lin & Tsai, 2017, p. 8). The present study utilized Lin and Tsai's multidimensional model to conceptualize epistemic beliefs. In the current study students' Epistemic Beliefs in Physics consisted of six dimensions such as sources of physics knowledge, certainty of physics knowledge, development of physics knowledge, justification for knowing physics, purpose of physics knowledge, and purpose of knowing physics.

Science education researchers argue that students should comprehend how to gain knowledge and how knowledge develops in science disciplines (Hong et al., 2016; Schiefer et al., 2020). Researchers suggested that students should be taught implicitly to develop epistemic views (Berland et al., 2016). Researchers showed a strong interest in examining students' epistemic beliefs. This is because developing students' epistemic beliefs correlate strongly with academic achievement and science understanding (Elby et al., 2016; Greene et al., 2018). Furthermore, students' epistemic beliefs influence their choice of learning approaches, involvement in particular learning activities, and problem-solving skills (Chiu et al., 2016; Kahsay, 2019). Students with sophisticated epistemic views tend to produce sound arguments and counter-arguments and generate quality arguments (Baytelman et al., 2020).

In Ethiopia very few studies were conducted on students' epistemic beliefs (Kahsay, 2019; Mekbib, 2015) and revealed naive epistemic beliefs. However, research consistently reveals that classroom science does not help students promote epistemic beliefs. This might be because the lecture approach in science education discourages social interaction and emphasizes the necessity of gaining knowledge only from authorized sources (Rees & Roth, 2019; Tan et al., 2021). This lecture method overlooks the significance of helping students create their own knowledge through social interactions. In the laboratory context, researchers examined the effect of practical work on students' epistemic beliefs (Wilcox & Lewandoski, 2017). However, there are disagreements about the effectiveness of a given practical work strategy at enhancing students’ epistemic beliefs. In some studies, researchers found that recipe-based practical work can have limited effects on students' epistemic beliefs (Shi et al., 2020; Wilcox & Lewandowski, 2017). As a result, this study examined the impact of dialogic-based practical work on students' epistemic beliefs.

2.3 Conceptualization of Dialogic Teaching

The concept of dialogic teaching as a methodology and key competency in science education has gained the attention of many policymakers across the world (Calcagni & Lago, 2018; Henderson et al., 2018; Kim & Wilkinson, 2019). Similar to this, many studies showed a strong desire to examine how language and other forms of communication can help students develop meanings in science classrooms (Erduran et al., 2015; García-Carrión et al., 2020). Trends in the top educational research journals show a marked rise in studying dialogic teaching as a means to enhance scientific understanding. For example, a *Framework for K-12 Science Education* recognizes dialogic teaching as an essential aspect of the scientific enterprise at the K−12 level and the postsecondary level (NRC, 2012). The framework explicitly includes the need to engage students in arguments based on evidence (Practice 7). While argumentation can be implicitly applied to analyzing and interpreting data (Practice 4) and obtaining, evaluating, and sharing information (Practice 8).

In Europe, the conceptual framework created by the Organization for Economic Co-operation and Development showed the importance of involving students in the use of scientific evidence to support claims (OECD, 2013). In this document, argumentation is seen as a key competence and approach to pedagogy. Despite its growing popularity in this field of science education research, there are still many unanswered concerns and questions (Henderson et al., 2018). First, the presence of various interpretations of dialogic teaching across different disciplines resulted in a lack of commonality of key terms used. The presence of different definitions and understandings around key concepts, such as dialogue, talk, and discourse across various fields (Calcagni & Lago, 2018). It results in a lack of coherence in the field concerning what it is, how it should be implemented, and what consequences it has for students (Howe & Mercer, 2017; Kim & Wilkinson, 2019).

Argumentation is viewed as "the verbal and social activity of reason aimed at increasing (or decreasing) the acceptability of a controversial standpoint for the listener or reader, by putting forward a constellation of propositions intended to justify (or refute) the standpoint before a rational judge” (Van Eemeren et al., 2013, p. 5). While scientific argumentation is defined as “social processes where two or more individuals construct and critique arguments supported by empirical evidence, or at least capable of being verified, falsified, or weakened by such evidence to explain some phenomenon in the natural or social world” (Nussbaum et al., 2012, p. 19). In the present study, scientific argumentation is defined as a process of involving students in constructing and critiquing ideas to reach a consensus through the asking of questions, data collection, and generating claims backed by evidence (Chen et al., 2016). Sandoval et al. (2019) argue that scientific argumentation requires the integration of epistemic, cognitive, and social aspects altogether rather than distinct parts of the fabric of science.

Dialogic teaching is a term that is now frequently used, but like all concepts, it can imply a different meaning to different people. Some academics refer to dialogic teaching to any form of conversation and discussion intended to promote student involvement and learning (e.g., Alexander, 2006; Resnick et al., 2018). Some scholars limit dialogic teaching to a particular type of talk during classroom lessons (Reznitskaya & Gregory, 2013). Others use the phrase to refer to a general orientation or position toward knowledge and knowing rather than just talking (e.g., Boyd & Markarian, 2011). Despite the presence of usage variations in an evolving area of study, Kim and Wilkinson (2019) contend that there comes a point where the variations make it challenging for researchers to combine findings from several studies.

The present study employs Alexander's (2006) definition of dialogic teaching as it is concise and well-organized. His framework may be the most comprehensive in describing the types of talk and the circumstances in which talk is productive for student learning. Dialogic teaching is defined as harnessing talk to ignite interest, motivate thinking, deepen understanding, broaden ideas, construct and critique arguments, empower students for lifelong learning and democratic participation (Alexander, 2018). Alexander believes that dialogic teaching reflects a perspective that knowledge and understanding emerge through evaluating facts, debating concepts, and examining values rather than blindly accepting others' convictions. It challenges teacher epistemic hegemony. Dialogic teaching regards students’ contribution in an ongoing and continual search for meaning rather than responding to teachers' questions as a terminal point.

2.4 The effect of Dialogic teaching in physics Education

The goal of dialogic teaching is to acknowledge and counteract asymmetrical power relations by acknowledging multiple voices. It enables students to be involved in reasoning processes such as questioning claims, interrogating evidence, and analyzing reasoning. By engaging in extensive discussions with their peers, students can describe observations precisely, clarify their thinking, and justify their arguments. Some empirical studies showed that applying dialogic teaching in physics classrooms positively impacted students' academic performance, epistemological understanding, argumentation skills, communication, critical thinking, and scientific reasoning (González-Howard & McNeill, 2019; Larrain et al., 2018; Resnick et al., 2015).

Engaging students in argumentative practices helps them better structure their reasoning, consider alternative viewpoints, and develop more nuanced understandings of the topics they argue about (Iordanou et al., 2019; Kuhn et al., 2016). This method aids students in developing critical thinking abilities such as claim-evidence coordination, the creation of arguments and counterarguments, and others (Rapanta, 2021). Furthermore, a number of academics (such as Rapanta, 2021) have proven that dialogic teaching may aid students in developing their critical thinking skills, problem-solving abilities, and ability to make judgments that will affect their lives as individuals, members of society, and global citizens. Sedavo et al. (2014) found that dialogic teaching stimulates and sustains conceptual change in the science domains. Furthermore, dialogic teaching leads to metacognitive thinking.

A number of researchers have demonstrated the successful implementation of dialogic teaching and its positive outcomes for students' learning (Chen et al., 2016). However, empirical research reveals that dialogic teaching is hardly taking place in actual classroom settings (Alexander, 2006; Sedova et al., 2014). In most classrooms, the teacher is mainly focused on transmitting knowledge to students and remains firmly in control of the talk aims. The teacher undergoes a triple speech exchange structure including Initiation, Response, and Feedback (Sinclair &

Coulthard, 1975). The teacher starts the lesson by asking a closed question (initiation phase), then a student responds to the question (response phase), and finally, the teacher offers feedback on that answer (feedback phase). In such an approach, there is very little collaboration between students (Rees & Roth, 2019).

Science teachers at the primary and secondary school levels often have inadequate experience and exhibit a lack of understanding of the implementation of dialogic teaching (Sandoval et al., 2019). Additionally, putting dialogic teaching into practice calls for the creation of a learning environment that encourages students' participation and feels comfortable expressing their views. According to Henderson et al. (2018) students and teachers need to change their epistemological perspectives to consider scientific knowledge tentative and accessible to scrutiny and critique. Teachers need to change from authoritative to dialogic teaching, where uncertainty, questioning, and critique are embraced. It is difficult to find an effective strategy that supports students and teachers to critique arguments in science education instead of wasting their time searching for why right answers are right, with less emphasis placed on why wrong answers are wrong.

Furthermore, teachers who did not learn science through argumentation lack the confidence to incorporate these science practices into their classrooms. Numerous studies have revealed that students have trouble defending their positions and generating reasons to refute the opposing viewpoint. According to some researchers, pupils' weak reasoning abilities are more likely due to a lack of effective teaching methods than their inherent incapacity to acquire them (El Majidi et al., 2021; Walker & Kettler, 2020). El Majidi et al. (2021) argued that instructional techniques are urgently needed to improve students' capacity for critical reasoning and persuasive argumentation. It appears that the limited usage of dialogic teaching in classrooms is not due to teacher discontent.

The most plausible reason is that teachers cannot effectively implement dialogic teaching in the classroom (Sedova et al., 2014). According to empirical studies, teachers incorporated certain features of dialogic teaching; nonetheless, the monological approach wasted a lot of time at the expense of student engagement. Lefstein (2008) revealed that the reforms influenced teachers' lesson plans and curricular preferences, however, their interaction with students remains unchanged. His study showed that while open-ended questions are encouraged in reform-related materials, teachers tended to limit the dialogue and direct students toward the appropriate response. These empirical studies demonstrated the conflict between theory and practice.

2.5 The Role of practical work in Physics Education

Most physicists and physics educators concur that practical work is an integral component of the science curriculum (Babalola et al., 2020; Jona & Adsit, 2008; Meltzer & Otero, 2015). When implemented appropriately, practical work can serve as an essential part of physics syllabuses, teaching methods, and evaluation procedures. Experiments, practical work, and laboratory work are used interchangeably. The term practical work is commonly used in the UK, while the term laboratory experiment is usually used in the US (Sani, 2014). The literature on physics education uses practical work in many different ways. For instance, Abrahams and Reiss (2012) preferred practical *work* based on what is undertaken rather than *laboratory work* which alludes to the location.

Hodson (1991) says these concepts are subcategories of one another. The experiment is a subset of the lab work and the laboratory work is a part of practical work. He argued that practical work is a broad term that encompasses activities such as involving students in projects like collage-making, model-building, or role-playing. Hodson (1991) defined practical work as all activities and teaching strategies used to assist students actively participate. While, Millar (2004) defined practical work as any teaching and learning activity that entails examining or manipulating real objects and materials (p. 2). Practical work is defined as "all types of science teaching and learning activity in which the students, either individually or in small groups, manipulate equipment and/or real objects and materials" (Abrahams and Reiss, 2012, p. 1036). Practical work in this sense does not include virtual objects and materials such as those obtained from a DVD, a computer simulation, or even from a text-based account.

For this study, the definition of practical follows that of Ferreira and Morais (2020). Practical work is defined as "all teaching and learning activities in the sciences in which the student is actively involved and that allow the mobilization of science processes skills and scientific knowledge and that may be materialized by paper and pencil activities or observing and/or manipulating materials" (Ferreira and Morais, 2020, p.4). Based on this definition, practical work is viewed as a wide notion that encompasses more than just laboratory work and includes tasks involving active participation and interaction with objects or secondary sources of information.

While the necessity of practical work appears to be universal, there is disagreement over their pedagogical strategies or the relative relevance of the educational goals they serve (Abrahams & Millar, 2008; Abrahams & Reiss, 2012; Docktor & Mestre, 2014). Numerous researches have been done on the purposes and goals of practical work and how to execute them in science education over the years. Researchers identified different educational the aims, purposes, and goals of conducting practical work. For example, Wellington (1998) argues that practical work has cognitive, affective, and skills arguments. Cognitive arguments allow students to illustrate, envision, verify, or confirm scientific principles and hypotheses to help them grasp science and advance their conceptual understanding. *Affective arguments* are related to practical works' ability to generate motivation, excitement, interest, and enthusiasm. The skills argument presumes that practical work can foster the development of higher-order transferrable abilities like observation, measurement, prediction, inference and physical dexterity.

Jenkins (1999) also identified three aims of scientific investigations, such as cognitive, affective, and acquisition of practical and technical skills. Practical work improves students' conceptual understanding, motivates and increases their interest in science and develops skills in handling special equipment, taking measurements, analyzing data, and formulating hypotheses. These scholars mainly focused their efforts toward the cognitive, affective, and psychomotor domains. However, they gave little attention to the social aspects of practical work.

On the other hand, Bell (2005) divides practical work goals into practical, social, cognitive, and epistemological outcomes. The practical outcomes highlight the practical skills students acquire via the use of tools and materials, the creation and execution of data gathering strategies, and on-the-spot problem-solving. The student's social outcomes describe their ability to coordinate group work, communicate ideas, negotiate shared understandings, manage divisions of labor and specializations, and compare scientific results.

Cognitive outcomes show how well students comprehend fundamental disciplinary concepts, disciplinary mindsets, and scientific inquiry processes. Epistemological outcomes describe students' understanding of scientific epistemic standards and procedures. Students must know what constitutes valid evidence, what kinds of arguments are compelling, and the types of information extracted from investigations. They must also know how such knowledge can help understand social issues and other settings. Bell's classification included the social and epistemological facets of practical work missing from Wellington (1998) and Jenkins (1999).

Deacon and Hajek (2011) listed the objectives of laboratories as increasing knowledge of physics, developing practical skills, piquing and maintaining interest, attitude satisfaction, and open-mindedness in physics, developing creative thinking and problem-solving ability, and promoting scientific thinking, as well as offering practice in experimental methods. Wilson et al. (2016) argue that practical work develops conceptual understanding; manipulative skills and techniques; problem-solving skills; reporting and presenting data-analysis and discussion skills. Practical work encourages students to observe and describe accurately, and experiences facts finding by investigation. It enhances motivation and confidence, and develops health and safety, time-management skills, and team-working skills.

Babalola et al. (2020) argue that practical work enhances students' acquisition of skills, conceptual understanding, cognitive abilities, exposure to the nature of science and the scientific method, and motivation and promotion of positive attitudes to science and the learning of science. On the other hand, Leech et al. (2020) ranked four practical work priorities identified by teachers to encourage accurate observation and description, experience the process of finding facts by investigation, develop reporting, presenting, data analysis, and discussion skills, and conceptual understanding. The actual role of practical work in physics education continues to be contested (Khaparde, 2019; Otero & Meltzer, 2016).

In countries with limited resources, laboratory work needs to be critically examined. The availability of diverging goals and purposes of practical work resulted in a significant degree of fragmentation within the laboratory literature.

2.5.1 The role of practical work in Ethiopian Physics Education

In the Ethiopian context, the physics curriculum considers that practical activities provide excellent opportunities for students to get firsthand experience manipulating materials. It further added that practical work helps to provide meaningful interactions between students and their world to understand the underlying concepts, principles, and laws (MoE, 2009). Through practical work, it is possible to assess students while they are working on a task, apply their knowledge as they work on a task, select the right resources to use for the task, and report their results (MoE, 2009; p.36). Also, it aims to encourage students' curiosity and inquisitiveness about the physical world, develop critical and analytical thinking skills, maintain a balance between quantitative reasoning and conceptual understanding of concepts, support an active learning environment, and develop problem-solving skills.

Further, it develops students' skills in observing, classifying, measuring, predicting, hypothesizing, experimenting, and analyzing data (MoE, 2009; p.18). Even though the physics curriculum was prepared based on inquiry models, some studies indicated that teachers ignored practical works and taught solely using the lecture method (Gbre-Eyesus, 2017; Tadesse & Gillies, 2015). A Ministry of Education study also indicated that physics teaching is usually purely theoretical, with little practical work involved in schools (MoE, 2015). Furthermore, other studies found that in government schools practical work is not implemented very well (Daba et al., 2016; Nigussie et al., 2018). For instance, Nigussie et al. (2018) evaluated the factors that related to the complete absence or minimal execution of practical work in a few selected preparatory schools in the North Shewa Zone of Ethiopia. The results indicated that students had a strong desire to conduct practical work (in all disciplines), yet they did not conduct over 75 percent of biology and chemistry and 62.5 percent of physics practical activities.

Empirical studies identified the reasons that hinder the effective implementation of practical work in secondary laboratory rooms (Daba & Anbesaw, 2016; Nigussie et al., 2018; Sbhatu, 2021). First, in some schools' teachers had poor practical skills and lack of laboratory apparatus, chemicals, separate rooms, trained technicians and prepared laboratory materials (e.g., Daba & Anbesaw, 2016). Moreover, the existing physics curriculum is loaded with contents, full of abstract concepts, and beyond the level of understanding for the majority of students (Alemu et al., 2021). Likewise, there was a mismatch between what policy was planned and what schools and colleges taught. The training of pre-service and in-service science teachers in colleges of teacher education and universities was characterized by too much factual information, lower-order cognitive skills, few inquiry activities, and mismatches between theoretical and practical knowledge (Sbhatu, 2021).

As a result, teachers who graduated from colleges of teacher education and universities in Ethiopia did not have the necessary subject knowledge to teach effectively. In addition, they did not have the appropriate skills to implement practical work in their schools (Alemu et al., 2021). These graduates continued to use teacher-centered teaching strategies to achieve policy goals. They emphasize theoretical declarative concepts excessively and fail to consider students' cognitive development. Second, the absence of separate regular periods for practical work forced teachers to concentrate on theoretical physics concepts and theories. The researcher of the current study also faced challenges to organize practical work sessions initially. As the practical work task might not be finished in 40 minutes, the researcher, in conjunction with the teachers convinced students to come in opposite shifts.

Third, the large class size in most secondary schools' forces teachers to use demonstration methods rather than group work activities by themselves. Fourth, assessment systems do not emphasize practical skills (MoE, 2019). Standardized regional and national tests impact science teachers' and students' beliefs, practices, and attitudes regarding science and science education. In most standardized tests, items pertaining to higher cognitive skills and procedures were excluded. Hence, these tests can lead science teachers to switch to lecture methods and students might prefer rote fact memorization. This study was conducted in a secondary school context, where students' first exposure to recipe-based practical work. There is currently a lack of sufficient empirical research and suitable practical work designs to enhance student learning, particularly in secondary school lab settings.

However, a contemporary trend in this study is to look at the possible effects of lab designs that aren't recipe-based on students' learning outcomes in physics. Considering that secondary school students have little practical work experience, in this study, the researcher implemented a dialogic-practical work approach by providing appropriate guidance for the students to enhance their physics learning outcomes. The teacher's guidance focuses on presenting the problem, providing the material, offering guiding questions, and facilitating dialogic-interactive talk throughout the practical work. In this study, a dialogic-practical work approach is designed and implemented in secondary schools' physics laboratories and its effect is compared to recipe-based practical work in physics learning.

2.5.2 The goals and objectives of practical work in present study

The educational goals of the dialogic-practical work approach in the present study were adapted from the National Research Council. The National Research Council identified seven goals for practical work in high school laboratories (NRC, 2012).

Table 2.1 Comparison between NRC practical work goals and revised goals

NRC (2006)	Explanations	Revised goals
Goal 1 *Enhancing mastery of subject matter*	The laboratory should help students' master basic physics concepts, facts, theories, laws, and principles. A growing body of research in physics education indicates that a majority of students have difficulty learning basic physical concepts in a course built around traditional lectures, textbook problems, and verification experiments. Hence, laboratory experiences may enhance student understanding of specific scientific facts and concepts and of the way in which these facts and concepts are organized in the scientific disciplines.	*Goal 1* *Enhancing students' mechanics achievement*
Goal 3 *Developing practical skills and understanding the complexity and ambiguity of empirical work*	Engaging students in practical work help them to develop their skills in using scientific equipment correctly and safely, making observations, taking measurements, and carrying out well-defined scientific procedures. Students also learn how to address the challenges inherent in directly observing and manipulating the material world, including troubleshooting equipment used to make observations, understanding measurement error, and interpreting and aggregating the resulting data.	*Goal 2* *Developing science process skills*
Goal 2 *Developing scientific reasoning and developing* teamwork abilities	Laboratory practices promote student's ability to identify questions and concepts, design and conduct scientific investigations; develop and revise scientific explanations and models; recognize and analyze alternative explanations and models; and make and defend a scientific argument. Practical work is also promote a student's ability to collaborate effectively with others in carrying out complex tasks, to share the work of the task, to assume different roles at different times, and to contribute and respond to ideas.	*Goal 5* *Develop students' argumentative skills*
Goal 4 *Cultivating interest in science and interest in learning science*	As a result of laboratory experiences that make science "come alive," students may become interested in learning more about science and see it as relevant to everyday life.	*Goal 3* *Developing attitudes toward physics*
Goal 5 *Understanding of the nature of science*	Laboratory experiences may help students to understand the values and assumptions inherent in the development and interpretation of scientific knowledge. It seeks to understand the material world and that scientific theory, models, and explanations change over time on the basis of new evidence.	*Goal 4* *Improving students' epistemic beliefs about physics*

These goals were adapted since they are broad and include the most relevant aspects of practical work. Moreover, these goals were specifically set for secondary schools. In the present study, these goals were merged into five such as enhancing students' mechanics achievement (Goal 1), promoting science process skills (Goal 2), developing attitudes toward physics (Goal 3), enhancing students' epistemic beliefs (Goal 4), and promoting students' scientific argumentation skills (Goal 5) as shown in Table 2.1.

Similarly, the objectives of the dialogic-practical work approach were adapted from the Next Generation Science Standards (NRC, 2013). The Next Generation of Science Standards set performance expectations that guide what students should learn in the classroom at grade levels K-5, grade bands 6-8, and 9-12 (NRC, 2013). The present study used the Next Generation of Science Standards as a guideline to determine the science practices students should involve in through the dialogic-practical work approach. The processes involve (1) asking questions, defining problems, and planning investigations, (2) conducting investigations, analyzing and interpreting data, (3) developing explanations and evaluating results, and (4) arguing. The dialogic-practical work objectives associated with these activities were chosen from grades 9-12.

2.6 Dialogic Teaching Approaches

In the dialogic teaching literature, some scholars have focused on proposing theoretical and philosophical discussions about dialogic pedagogy and dialogic education (Matsuo, 2014; Wegerif, 2019). A number of other approaches have been developed, including accountable talk (Michaels et al., 2008; Michaels & O'Connor, 2015), communicative approach (Mortimer & Scott, 2003), dialogic inquiry (Wells, 1999), dialogic teaching (Alexander, 2006) and exploratory talk (Mercer, 1995). There are varying degrees of focus on teacher-student dialogue, small-group dialogue, and whole-class dialogue among these ranges of approaches. Each approach emphasizes a dialogic approach toward others, characterized by openness to learning and social norms that facilitate effective communication. The next section presents the essential features of dialogic teaching. It seeks to conceptually clarify the dialogic teaching construct using Alexander's model, the communicative approach, and exploratory talk. These theories have perhaps had the most impact on recent research.

2.6.1 Alexander’s Dialogic teaching approach

Alexander derived his ideas of dialogic teaching from Vygotsky's (1978) sociocultural theory of learning, Bruner's (1997) understanding of the relationship between language and thought, and Bakhtin's (1986) perspective on dialogue. Alexander contends that teachers need alternative repertoires to explore students' thinking and understanding more deeply. He characterizes dialogic interactions as those that take place when students raise questions, express opinions, and comment on concepts that come up in classes. Teachers must take into account the opinions of the students while designing the topic theme and utilize talk to give a cumulative, continuous, contextual frame to encourage their engagement with the relevant information they are discovering and generating.

Robin Alexander has developed a dialogic teaching framework and improved it over time. This is to assist teachers who want to improve classroom discourse caliber and impact - both on their own and that of their students. The framework includes justifications, principles, repertoires, and indicators. As opposed to using all-purpose formulas, this framework encourages teachers to deploy a variety of educational strategies depending on the context and demand. Justification outlines students' capacity to interact with others, form friendships, engage in their culture, and sustain a sense of group identification and cohesiveness. These guidelines outline the criteria used to evaluate dialogic conversation and the dialogic classroom. Dialogic teaching has five essential principles. These are:

> *Collective*: teachers and children address learning tasks together, whether as a group or as a class, rather than in isolation; *reciprocal*: teachers and children listen to each other, share ideas, and consider alternative viewpoints; *supportive*: children articulate their ideas freely, without fear of embarrassment over ‘wrong’ answers; and they help each other to reach common understandings; *cumulative*: teachers and children build on their own and each other’s ideas and chain them into coherent lines of thinking and inquiry; *purposeful*: teachers plan and facilitate dialogic teaching with particular educational goals in view (Alexander, 2006, p. 28).

Alexander says authentic dialogic teaching entails ongoing social interactions between students and between the teacher and the students. These interactions build on one another's ideas. This is based on exchanging open-ended questions and answers between the teacher and students that encourage posing issues and resolving issues rather than merely explaining and recalling. In a dialogic classroom, students should actively challenge other ideas. Moreover, students' discussion should be guided toward a set of goals. These characteristics show that in a dialogic class, students actively guide classroom activities. This results in a transfer of authority from the instructor to the students. The third component, repertoires, describes how groups are organized. They also describe the characteristics of everyday talk, learning talk, teaching talk, and ways of asking questions and extending discussions to facilitate classroom discourse.

Alexander considers the potential of a range of groups such as group work (teacher-led); group work (student-led); one-to-one (teacher-student); and one-to-one (student pairs) depending on the classroom context. For instance, a teacher may choose whole class teaching to conclude a daily topic. Alexander identified six broad categories of students' day-to-day talk. These are transactional, expository, interrogatory, exploratory, expressive, and evaluative. Alexander argued that in the science classroom teaching and learning process, the teacher should master these ranges of talk categories. However, in most traditional teaching, teachers tend to omit exploratory and expressive talk and stick only to the remaining talk categories. Furthermore, in everyday talk categories, there are eleven categories of student talk for learning. These are: narrate, explain, speculate, imagine, explore, analyze, evaluate, question, justify, discuss, and argue. During classroom talk, students need to listen to others attentively, think about what they hear, give others time to think and respect alternative viewpoints.

Teaching talks, on the other hand, include rote, recitation, instruction, exposition, discussion, and dialogue. Although rote, recitation, and exposition may appear traditional methods of teaching, they have an important role to impart facts, memorize information, providing explanations, and even remember formulas, equations, tables, rules, and principles. Alexander's characterization of dialogic teaching encompasses the full range of teaching talks. In contrast, it favors discussion and dialog, specifically dialogue, which has greater value in extending the spectrum of student learning. However, Nystrand (1997 as cited in Calcagni & Lago, 2018) argues that recitation creates orderly but lifeless classrooms in which there is only one authoritarian voice. In classroom discourse, tension and heteroglossia (seeking multiple interpretations and meanings) fuel students' understanding and learning and make classroom conversations dialogic. The way questions are forwarded can affect dialogic teaching. Teachers' questions may hinder or trigger students’ discussions.

Some questions may require short answers, which are common in traditional teaching and have an evaluative intent. In dialogic teaching, the questioning repertoire should include character, response cue, participation cue, wait/think time, feedback, purpose, and structure. The repertoire describes the way the teacher poses questions and invites and handles student responses. In the final repertoire, the teacher helps students share, expand, and clarify their thinking, listen carefully, deepen their reasoning, and think together. Alexander’s framework also includes a list of 61 indicators that specify how dialogic teaching looks and sounds (Alexander, 2006). Alexander's dialogic teaching framework shows that there is no one most effective technique to maximize classroom dialogue. It is the duty of teachers to choose from a repertoire that is suitable for each classroom's unique personalities and situations.

The cumulative component of dialogic teaching is typically regarded as challenging to accomplish (Alexander 2006). Teachers must possess a high degree of professional expertise as well as accurate topic knowledge, relevant instructional skills, and an awareness of each student's potential. Some academics (e.g., Sedova et al., 2014) argue that Alexander's dialogic teaching genres could be difficult to distinguish in reality. This prompts academics to suggest a list of indicators that demonstrate dialogic teaching is taking place. It includes genuine inquiries, uptake, instructor feedback of higher order, and open discussion.

2.6.2 Communicative Approaches

Other scholars established a communicative approach framework to characterize students’ speech genres in science classrooms (Ametller, 2007; Mortimer & Scott, 2003). This approach integrates two principal questions “whether the teacher interacts with students or not and whether the teacher takes into account students’ ideas as the lessons proceed or not” (Ametller, 2007, p. 1). This framework offers a viewpoint on how the teacher collaborates with the students to generate ideas in the classroom. The dynamics of the teacher-student relationship may be influenced by the way teachers interact with and communicate to their students, which can open up opportunities for teachers and students to jointly generate knowledge. Through the use of various speech patterns and forms, this method explores how teachers assist students in creating meaning in science classrooms. It is distinguished by two types of conversation between the teacher and the students, such as dialogic and authoritative and interactive and non-interactive.

The interactive-non-interactive dimension represents the extent to which students have opportunities to participate. Interactive talk allows students to participate actively in the classroom. The teacher typically engages students in a series of questions and answers. However, in non-interactive talk, students are passive listeners and the teacher only presents ideas in a lecturing style. The dialogic-authoritative discourse demonstrates how much the instructor takes into account the opinions of the pupils while the discussion is in progress (Kim & Wilkinson, 2019). As opposed to the authoritative method, where the instructor exclusively considers a single point of view, the dialogic approach encourages teachers to entertain opposing viewpoints (Mortimer & Scott, 2003). Four groups of communicative approaches—from authoritative-non-interactive to dialogic-interactive—are produced when these aspects are combined. In a non-interactive, authoritative method, the teacher lectures about scientific material without taking into account any opposing views put up by students.

When using the interactive-authoritative method, the instructor ignores opposing viewpoints and concentrates solely on the students' often-evaluated comments. This method was employed by the teacher to review a previously studied subject. An interactive-dialogic approach involves the teacher exploring and eliciting student opinions without imposing any judgment. Students have expressed a variety of opinions on the subject based on their personal experiences. Such a method involves pupils actively participating in the expression of their views while the teacher takes into account their differing points of view. In the non-interactive dialogic genre, the instructor uses a lecture teaching style to analyze the subject from many aspects. In order to promote scientific viewpoints, the instructor presents opposing points of view based on the students' everyday perspectives. Students just listen passively to the instructor's speech; only that of the teacher has a dialogic quality. The features of each dimension are listed in Table 2.2.

Table 2.2 Four kinds of talk in the communicative approach

		Dialogism	
		Dialogic Talk	Authoritative talk
Discursive	Interactive	*(A1) Dialogic-Interactive:* A range of ideas are welcome	*(A2) Non-Dialogic Interactive:* Question-and answer routine, answers are evaluated
	Non-interactive	*(B3) Dialogic-Non-interactive*: Considering the topic from different points of view	*(B4) Non-Dialogic-Non interactive:* Teacher presents a specific point of view.

*Source: Mortimer and Scott (2006).

The core idea behind the communicative method is to give teachers a variety of classroom discourse options so they may carefully set up a welcoming atmosphere where students can voice their opinions and pay close attention to what others have to say. Asking open-ended questions, exploring students' answers, and having students build on each other's ideas all contribute to dialogic discourse, which is marked by several points of view. As shown by studies (Scott et al., 2006), instructors equate dialogic teaching with dialogic-interactive classroom dialogue. However, the instructor may incorporate examples from each of the four communication styles in a particular lesson or a set of teaching sessions, and this may be seen as dialogic as a whole. It enables the instructor to alternate between authoritative communication tactics and dialogic ways (and vice versa) to make science teaching and learning meaningful (Ametller, 2007; Mortimer & Scott, 2003).

According to Mercer and Dawes (2014), strategic balance is what matters most in educational terms rather than whether one communicative strategy is superior to another. There will be moments when students must remain silent and pay attention to a knowledgeable explanation to study properly. Otherwise, students should be given the chance to voice their views, make hypotheses, listen to their peers, dispute, reason out, and receive feedback from their teachers. This will enable them to obtain a more thorough grasp of a subject. For instance, Ametller (2007) created a framework with four events to demonstrate the significance of a balanced communicative shift in classroom discourse. The first three dialogic episodes provide students with a chance to voice their current viewpoints and become involved in the issue. Multiple voice interactions can challenge students' conventional notions of knowledge (Henderson et al., 2018).

Later, in episode four, the teacher adopts a commanding style intended to rectify students' erroneous perceptions of science. According to Ametller (2007), decisions on whether to begin or end instruction in a dialogic or authoritative manner must be made in light of the subject matter being covered, particularly the degree of dissimilarity between every day and scientific viewpoints. To guide effective scientific knowledge learning, a fundamental shift between dialogic and authoritative communicative styles (and vice versa) is required. The dialogic-practical work strategy in the current study employed a communicative approach. However, the unique features of pedagogical practices may alter depending on the student's age, academic level, sociological makeup of the class, and stage of the teaching/learning process. In the current study, secondary school students had minimal exposure to dialogic teaching and practical work.

Hence, the teacher begins off with a limited amount of control over the choice and sequencing of information, skills, and practical tasks before ending them in an authoritative manner. By employing episodes of communicative approaches in a specific practical work students can participate in a dialogic discourse focused on conflicting views and building knowledge. To achieve curricular goals, a thorough summary of the daily topic should be provided. The teacher can support the class by asking students questions regarding scientific theories. Within the context of this study, Alexander's dialogic teaching is seen as an overarching ideology that embraces the educational resources that students' contributions may bring to more engaging scientific learning. On the other hand, the dialogic method of Mortimer and Scott is seen to be only one of the communicative strategies most appropriate for the situation (Mercer & Littleton 2007, p. 48). A noninteractive-dialogic approach is unmatched in its ability to explicitly accumulate ideas while connecting various points of view meaningfully.

Furthermore, even though this study emphasizes the dialogic aspect of classroom communication due to the general lack of dialogue in classrooms (Mercer et al., 2009), authoritative approaches are still seen as a crucial component of meaningful science learning (Scott 2007; Scott & Ametller 2007). The communicative approach theory provides a novel and more tangible framework for analyzing and comprehending various forms of educational communication.

Additionally, it offers a suitable framework that may be modified for communication analysis in the classroom and can be used as a theory-based planning tool (Mortimer & Scott, 2003). The communicative approach was also applied in student teachers' reflections on their videotaped classes.

2.6.3 Exploratory talk

Mercer and Littleton (2007) divided talk episodes into three categories: disputational, cumulative, and exploratory talk. These talk patterns improve students' learning performance (Mercer & Dawes, 2014). Disputational talk has little education significance to promote students learning. In this type of talk there is a lack of collaboration in decision making and no one is willing to learn from one another. This talk is characterized by disagreement and exchanges of assertions and counter-assertions and is characterized by a debate (Anderson & Enghag, 2017). The relationship is competitive, where the defense of the individuals’ ideas is prioritized over considerations of others’ explanations.

Contrarily, in a cumulative talk group members engaged in shared understanding of with minimal critical questioning of ideas. Cumulative talk is built by repetitions, confirmations, and elaborations. Like exploratory talk, it allows for construction of common knowledge by accumulation. In cumulative talk the speakers built positively but uncritically on what others have said. Information and ideas are shared in the process of constructing knowledge, but without being challenged. Mercer and Littleton (2007) claim that Alexander's dialogic teaching genres are not all dialogic. These academics propose that dialogic teaching should build on exploratory talk in which students create common knowledge and are open to modifying their beliefs. It is characterized by the co-construction of knowledge through students' constructive yet critical interaction with one another's ideas.

Academics say it is crucial for students to participate in exploratory talk to debate, accept, and expand one another's claims (Andersson & Enghag, 2017). It promotes collaborative problem-solving and social engagement to produce new knowledge. To establish consensus in groups, exploratory talk employs open idea sharing, openness to other people's views, constructive debate, and well-reasoned counterproposals (Mercer & Dawes, 2014). According to research, exploratory talk must be clearly taught and regularly performed to be successful and practiced regularly in schools (Mercer & Littleton, 2007). Overall, the principles guiding dialogic pedagogy in classroom practice encourage teachers to engage in fruitful meaning-making activities by designing assignments that spark conversation between students and teachers.

This entails providing students with the freedom to express themselves freely and be mistaken. In addition, it enables them to take turns without teacher supervision. Students should participate more actively in the classroom. For instance, exploratory discourse increases students' ability to reason and argue both alone and in groups (Lehesvuori, 2013; Mercer & Littleton, 2007). These sorts of teaching methods encourage student participation, self-assurance, independence, and responsibility while challenging power dynamics in the classroom. However, a learning-friendly environment can only be created with teachers' structured guidance (Lehesvuori, 2013). According to some academics, teachers should ask open-ended questions that call for lengthy and detailed responses while also encouraging students to deepen their ideas by comparing and restating those of others (Michaels & O'Connor, 2015; Michaels et al., 2008).

The questioning techniques emphasize reiterating other people's views (for example, Can you repeat what he just said in your own words?), adopting positions (for example, Do you agree or disagree and why?), and extending debates (for example, Would someone care to add on? Tell me more about that. Why do you feel that way? How did you come up with that answer?), and asking for confirmation (Is this usually true? Do you have any examples where it would not be effective?) (Michaels & O'Connor, 2015, p. 358). However, merely using talk moves to facilitate classroom conversations does not guarantee coherence or significant student learning (Kim & Wilkinson, 2019). These talk techniques are expected to be passed on from teacher to student so that they can practice them independently. Students must support their arguments with evidence and sound reasoning.

2.7 Models of Practical work

The present study aimed to employ dialogic-practical work in physics labs to examine its effect on students' learning. Several researchers recommended that the efficiency of a particular practical work approach depends on its capacity to establish connections between the world of observables and the domain of concepts (Abrahams & Millar, 2008; Abrahams & Reiss, 2012; Babalola et al., 2020; Millar, 2004). Educational scholars used a variety of practical work methodologies to integrate observables and ideas. According to certain academics (such as Pedaste et al., 2015), inquiry-based learning models can aid in the integration of concepts and observables.

2.7.1 Inquiry based learning Model

Science education literature produces numerous inquiry-based instructional models in laboratory settings. To ensure a successful inquiry-based learning process, Pedaste et al. (2015) designed an inquiry-driven learning model by synthesizing others' work. They claimed that there was no framework in the literature that brought all phases and sub-phases together. Consequently, an inquiry-based learning model with five unique inquiry stages was synthesized from 32 scholarly papers. The general phases are orientation, conceptualization (sub-phases: questioning and hypothesis generation), investigation (sub-phases: exploration, experimentation, and data interpretation), conclusion, and discussion (communication and reflection) (Pedaste et al., 2015). Pedaste et al. (2015) argue that inquiry-based models usually end with a conclusion. As a result, this model includes communication and reflection as sub phases of discussion, which were typically missing from inquiry-based cycles. Moreover, this cycle covers a variety of inquiry-based learning phases that were not included in others' work.

Hence, this model may be compatible with teachers' current conceptions of inquiry-based learning and help them organize their instruction. Similarly, Hasnunidah and Juli Wiono (2019) applied the following steps in the guided inquiry model: observation, formulating problems, proposing hypotheses, collecting data, analyzing data, and concluding. While others raised concerns about the effectiveness of inquiry-based models to promote students' learning (Demircioglu & Ucar, 2015; Walker et al., 2019). Science reforms recommended more inquiry-based learning in science classrooms and researchers reported the benefits of this instruction over conventional ones. However, Arslan et al. (2023) argue that inquiry-based instruction implementation at the classroom level remains in the shadowy realm of traditional instruction.

Furthermore, students must learn more open-ended discursive communication techniques since peer interactions frequently result in conventional authoritative communication. This shouldn't be the case in a genuine inquiry. Teachers in this circumstance frequently impact curriculum implementation and classroom instruction (Arslan et al., 2023). Teachers rarely use inquiry-based learning (Hasnunidah & Juli Wiono, 2019). This is due to teachers' beliefs, an inadequate amount of time for learning, a shortage of quality instructional resources, the need to teach large classes, or a lack of understanding of what inquiry is and misunderstandings about inquiry (Arslan et al., 2023). Several science teachers mistakenly believe they are using inquiry-based learning when they use cookbook investigations with extremely detailed step-by-step procedures (Hasnunidah & Juli Wiono, 2019, p.927).

However, recipe-based practical work investigations don't support desired science learning outcomes since students usually focus on the continuation of the experiment and miss the deep understanding of the experiment. It is unlikely to have a significant shift in teachers' instruction unless teachers are provided with professional development on the nature of inquiry and the implementation of inquiry in their classrooms (Arslan et al., 2023; Demircioglu & Ucar, 2015). Furthermore, extensive student work use does not necessarily equate to better learning outcomes (Abrahams & Millar, 2008). This calls for an explicit structure to vague descriptions of inquiry-based teaching methods and, specifically, the types of communication involved. However, these inquiry-based models lack explicit strategies to incorporate dialogic teaching.

2.7.2 Argument Driven Inquiry Models

In the argumentation-based method, students are taught by asking questions, making claims, providing evidence to support those assertions, and discussing their arguments with friends (Demircioglu & Ucar, 2015; Erduran et al., 2004). Since, scientific practice requires inquiry by its very nature, argumentation-based instruction has gradually moved toward laboratory settings. The argumentation-based inquiry (ADI) is defined as “the approach that allows students to establish claims or explanations about scientific questions, discuss them with their peers, gather data, and utilize evidence to support these claims or explanations" (Admoko et al., 2021, p.3). It also blends argumentation and inquiry processes.

Contrary to the argumentation-based method, ADI allows students to obtain information, make claims, and develop scientific arguments in light of the evidence (Demircioglu & Ucar, 2015; Walker et al, 2019). It is one of the laboratory-based learning models that motivate students to participate in both experimental activities and activities that require them to make scientific arguments. This approach suggests using argumentation in a scientific laboratory learning environment under structural steps to (Chen et al., 2016; Hasnunidah & Juli Wiono, 2019; Walker et al., 2019). This model has the potential to help teachers comprehend the nature of scientific inquiry and debate. Because the ADI is meant to serve as a template or guide that science teachers can use to create more educational (i.e., leads to better understanding and improved abilities) and genuine experiments for students (i.e., involve students in scientific practices such as argumentation).

Researchers examined the applicability of the ADI models with students from various grade levels and found improvements in the desired objectives, such as scientific process skills (Arslan et al., 2023; Demircioglu & Ucar, 2015; Gultepe & Kilic, 2015), physics achievements (Demircioğlu & Ucar, 2012; Taylor et al., 2018), attitudes towards science (Walker et al. 2012), epistemic beliefs about science (Iordanou, 2016); scientific argumentation skills (Demircioglu & Ucar, 2015; Hosbein et al., 2021; Walker et al., 2019). All of these findings make the ADI valuable for science teachers and secondary school students.

Unlike the guided inquiry model, this ADI model emphasizes the role of argument in the social construction of scientific knowledge in laboratories. For example, Walker et al. (2012) applied the ADI instructional model consists of seven steps as shown in Table 2.3. Walker et al. (2019) improvised the ADI model by adding two additional steps. It includes identification of the task, investigation design, data collection and analysis, production of a tentative argument, argumentation session, critique, scientific writing, and double-blind peer review as shown in Table 2.3. The ADI approach, according to Demircioglu and Ucar (2015), actively engaged students in the argumentation process so they could express and defend their opinions.

Table 2.3 The steps of the ADI instructional model and the purpose of each step

Step	Purpose
Identification of task and the research question	Attract students' attention Activate students' previous knowledge
Data generation	Give students a chance to design and conduct an investigation Provide an opportunity to students to decide what type of data they need and how they can collect the data.
Generation of a tentative argument	Give an opportunity to students to develop a tentative argument that includes a claim, evidence, and the justification of the evidence.
Argumentation session	Provide students an opportunity to discuss and share their ideas Give students a chance to get feedback about their arguments
Open and reflective discussion	Provide students an opportunity to share the knowledge and experiences that they have gained from sharing with their friends in other groups.
Write an investigation report	Provide students an opportunity to learn how to craft a written argument.
Double-blind group peer review	Give students a chance to understand a high-quality investigation report. Provide an opportunity to students to get feedback from their peers.

* Source: Walker et al. (2012, p.15).

Hasnunidah and Juli Wiono (2019) added that the ADI model encouraged students to learn how to engage students in investigations, generate arguments that articulate and argue for explanations, structure class activities as an attempt to develop, understand, or analyze scientific explanations for natural occurrences or solutions to problems. It can also give them chances to practice proposing, defending, evaluating, and revising ideas through discussion and writing, foster a classroom culture that values evidence and critical thinking, and encourage them to take responsibility for their own learning.

2.7.3 Dialogic-Practical work Approach

The present study synthesized the key features from the inquiry-based model (Pedaste et al., 2015), the argument-driven inquiry model (Walker et al., 2019), communicative approaches (Mortimer & Scott, 2003), and talk types (Mercer, 1995) to design an effective dialogic-practical work approach. The dialogic-practical work approach had four stages: conceptualization, investigation, conclusion, and scientific explanation phase as shown in Table 2.4.

Table 2.4 The phases and types of interactions in the Dialogic-practical work Approach

Phases of Practical work	Types of Interaction	Types of Talks
Conceptualization • Orientation • Hypothesis generation	*Within Groups Dialogic Interactive Talk*	Exploratory Disputational Cumulative
Investigation • Experimentation • Data Interpretation	*Within Groups Dialogic Interactive Talk*	Exploratory Cumulative
Conclusion • Conclusion • Reflection	*Within Groups Dialogic-Interactive Talk*	Exploratory Cumulative
Scientific Explanation • Summary	*Whole class Authoritative-interactive talk*	Cumulative

Before the conceptualization phase, the researcher sets the learning goals and objectives that specify what the students should learn from the task. Millar et al. (2003) suggested that goals and objectives can be set by teachers or curriculum developers. In students' textbooks, practical work objectives and goals are such as engaging students in dialogic arguments. Due to this, the present study adopted the goals of the Dialogic-Practical Work from the Nation Research Council (NRC, 2006) and the objectives from the Next Generation Science Standards (NRC, 2013). Unlike the inquiry-based learning models, in the dialogic-practical work, the researcher identified the task and research questions.

Inquiry-based models may involve students in practical work at varying levels ranging from doing with maximum guidance from the teacher to carrying out a practical task in groups or individually with minimal guidance from the teacher. However, in the Ethiopian context where secondary school students had minimal practical work experience, the teacher provided appropriate guidance for the students to perform a practical task in groups. The present study argues that argument should be embedded in science classrooms. Immersing students in dialogic practical work by scaffolding the activities can help them develop science learning outcomes and argumentation skills. Teaching students about argument structures may burden them cognitively. Furthermore, developing students' argumentation skills is time-consuming. Detailed information about the phases, types of interactions, and talks of dialogic-practical work is given below.

Phase 1: The conceptualization phase. During the conceptualization phase, the teacher informs the specific objectives of the practical work and safety precautions. The teacher sets out well-defined learning goals for the students, together with ways they can reach those goals. Furthermore, the teacher should design questions for students that are crucial to getting to know their ideas about science and can help them focus their efforts on building the desired learning. It is imperative to ask these questions to examine and determine students' prior knowledge and to trigger their misconceptions related to the topic to be investigated. Using this approach, students should brainstorm ideas about the topic with their group members. The teacher takes a *dialogic-interactive approach within the group's* communicative approach.

In this communicative approach, the teacher considers opposing viewpoints and gives each group of students’ adequate opportunity to work together and exchange viewpoints. The teacher's job at this stage is to get the students talking by presenting arbitrary data for discussion and asking for scientific responses to certain problems. The teacher walks from group to group to scaffold students' thinking, asks students to explain and support their assertions using evidence, and engages them in reasoning. Individual students share their claims and provide evidence to support their claims. However, some scholars argue that all talk is not dialogic (Sedova et al., 2014). Furthermore, Mercer (1995) argued that much of classroom student-student interaction is either disputative or cumulative, neither of which leads to productive resolution or contrast of perspectives.

Hence, in the present study even if students have the freedom to engage in disputational, cumulative, and exploratory talks, the teacher should guide them to engage in exploratory talks. Students should engage in exploratory talk to challenge, accept, and extend each other's statements (Andersson & Enghag, 2017). It encourages social interaction and critical thinking and promotes the individual and group reasoning and argumentation abilities of students to create knowledge and solve problems with each other (Lehesvuori, 2013; Mercer & Littleton 2007). However, an environment that promotes learning can only be achieved with teachers' structured guidance (Lehesvuori, 2013). In this regard, the teacher should facilitate students’ progression by asking probing questions. The teacher's main responsibility at this phase is to ensure students can articulate the connection between their model, claim, and evidence. At the end of this phase, students should craft a scientific argument that consists of claims and evidence. In other words, students were motivated to formulate a hypothesis (construct a tentative argument) in groups to be investigated during the actual phase.

Phase 2: The investigation phase. This phase is the central aspect of practical work. At this phase, students are expected to set up the equipment, determine the number of measurement trails, form tables and collect data. Throughout this stage, students are required to think and the teacher's job is to promote student-student exchanges. While the teacher takes a *dialogic-interactive approach within the group.* Teacher guidance is limited to providing cues to enhance students' deep understanding of tasks and analyzing data. Students are expected to talk cumulatively during data collection. After data collection is over, students can analyze and interpret data to make an argument involving the topic. At this step, students are expected to participate in an exploratory talk. Each group prepares provisional assertions and shares them with their colleagues.

Students must support their views with logic and facts. When confronted with contradictory information, students might modify their statements. During this stage, students are supported in sharing ideas and asked open-ended questions to justify their claims. The teacher invites each group to present its assertions to the other groups, along with any relevant details or arguments. Students are expected to demonstrate their comprehension of the subject being studied. More weight is given to student-student interaction. At this stage, students are expected to engage in cumulative and exploratory talks.

Phase 3: The conclusion phase. This phase is essential for educational goals. In this session, attention is placed on developing scientific topic knowledge through small group discussions with an emphasis on determining which is the most reliable or approved response. Students present their research and arguments to their peers, criticize other teams, and recognize arguments' advantages and disadvantages to change them. At this session students are expected to reflect on their findings among peers, comparing the results to the scientific view, creating models, reinforcing the scientific view, and revising the formulated hypothesis. Group members would be asked to share their findings with the class, and other groups would raise questions. Students would receive feedback before and after their practical work to understand their conclusions' strengths and weaknesses. Considering that different ideas are still entertained; the teacher should lead the class toward the scientific view by posing successive questions. Therefore, students will be engaged critically and constructively in a *dialogic-interactive whole-group* discussion. Students' talks, on the other hand, will be exploratory and cumulative in nature.

Phase 4: The scientific explanation phase. When making conclusions about the content and the procedure, the teacher should apply an authoritative-interactive approach. To make clear the linkages between viewpoints and potential gaps in prior thinking, the teacher compares student assumptions and misconceptions with scientific findings and hypotheses. Students compare their scientific opinions to diverse sources of knowledge to assess their validity. A teacher leads the class conversation using an authoritative-interactive style. Students also engage in exploratory and cumulative talks. In brief, the teacher elicits students' existing thinking about a topic through dialogic-interactive conversations. At the end of the phase, the teacher uses an authoritative-interactive approach to conclude the lesson.

The dialogic-practical work model has the following unique features, unlike the argument-driven inquiry model. First, Ethiopian secondary school students are new to practical work and dialogic teaching. Hence, during the conceptualization phases of the dialogic-practical work approach, the teacher selects the topics to be investigated and the objectives of practical work and provides guiding questions. Empirical research shows students do not automatically engage in detailed discourse when given a task to do jointly (Mercer & Littleton 2007). Moreover, the students' ability to provide evidence from raw data to support a claim and how to reach a consensus does not come naturally (Chen et al., 2016). In this regard, the teacher has a responsibility to scaffold activities to encourage students to communicate effectively, elicit thoughts and opinions, exhibit reasoning techniques, and promote meaning-making and knowledge generation in the process.

Second, in the dialogic-practical work approach, the students engaged in argumentation throughout the practical work phases, while, in argument-driven inquiry model, argumentation generation session was conducted after investigation design, data collection, and data analysis stages. The argument driven inquiry model ends up with peer review, while the dialogic-practical work approach, gives the teacher a freedom to summarize the main points of the topic and review students' preconceptions and misconceptions against the scientific results and theories to meet the curriculum goals through a series of question and answer strategies.

Third, the dialogic-practical work approach explicitly incorporated disputational, cumulative, and exploratory talk types. Literature suggested that the knowledge about the outcomes of the different talk types is of utmost importance for teachers when designing appropriate laboratory work sessions (Andersson & Enghag, 2017). Teachers should have a pedagogical skills on how to use disputational, cumulative, and exploratory talk types to open up dialogic spaces as well as to shape these spaces to achieve lesson goals. The teacher should apply these talk types during dialogic-practical work sessions for different teaching purposes.

Of course, the dialogic-practical work approach gave more emphasis for exploratory talk. It engages students in debates about the significance of physics ideas and various methods rather than merely instructing them on how to accomplish something. It allows students to challenge, accept and extend each other's statements and strive for consensus at a linguistic level, thus causing them to evaluate old knowledge and make links to new knowledge at a cognitive level. The dialogic-practical work approach also has certain distinctive qualities that set it apart from inquiry-based learning. First, inquiry-based learning overlooked the dialogic aspect (Lehesvuori, 2013). Second, terms commonly used (such as *teacher as a guide* or *co-inquirer*) in inquiry based learning are often uninformative when it comes to a deeper understanding of the complex interactions occurring in inquiry-based science classrooms (Oliveira 2010). Third, there is concern regarding the openness of inquiry, since it frequently follows a predetermined discovery pattern in which students follow a formula to arrive at a specific result (Andersson & Enghag, 2017).

2.8 Frameworks to analyze Dialogic-Practical work talk moves

In recent years, many models and frameworks have been created to evaluate dialogic teaching and learning (Wegerif, 2019). Analyzing the effects of dialogic education can be difficult because of the ambiguity brought on by the various views that shape the meaning that emerges from dialogism. The availability of diverse analytical frameworks poses a challenge in comparing findings across studies. It resulted in a lack of consensus on what constitutes argumentation quality, how to best define argumentation quality, and the dimensions it holds (Wachsmuth et al., 2017). Furthermore, there are diverse operational definitions of argumentation and argumentation quality dimensions. Due to the many ways scholars perceive and analyze argumentation, it might pose difficulties.

Researchers across different disciplines proposed a variety of dialogic teaching frameworks and units of analysis to assess students’ verbal and written arguments (Henderson et al., 2018; Osborne et al., 2004; Sampson et al., 2012; Toulmin, 1958; Walker et al., 2019). These frameworks are used to evaluate the effectiveness of different dialogic teaching approaches. Henderson et al. (2018) concluded that it is extremely challenging and time-consuming to evaluate argumentation across the dimensions of argument product, process, instructional context, and time.

2.8.1 Assessment of Scientific Argumentation in the Classroom

In the present study, students' scientific argumentation skills were analyzed. This section explains why Assessment of Scientific Argumentation in the Classroom (ASAC) was selected over alternative argumentation frameworks to evaluate student small group discussions. It also delved into more detail about the ASAC observation procedure. Researchers’ video or audio record while students argue, transcript the conversation, then code or score the transcription to evaluate students' arguments. According to Sampson et al. (2012), these strategies face difficulties in videotaping, transcription, coding, and counting. First, this kind of analysis is costly and time-consuming. Hence, many researchers choose a limited number of samples or narrow their attention to a single setting.

Additionally, this process presents difficulties for researchers since argumentation is frequently non-linear and different elements of argumentation, such as claim, evidence, and reasoning, are tricky to pinpoint (Sampson et al., 2012; Walker et al., 2019). Hence, to address these problems, Sampson et al. (2012) developed and verified an **A**ssessment for **S**cientific **A**rgumentation in the **C**lassroom (ASAC) observation rubric in the context of general chemistry laboratory activities.

Its goal was to assess students' arguments. Researchers can assess how well students participated in scientific reasoning by watching video recordings of actual argumentation sessions. This tool was developed to record and evaluate a series of argumentation sessions in a more comprehensive way, taking into account nonverbal social interactions (Walker et al., 2019). It will lead to a more thorough evaluation of an event's general quality.

The ASAC can be used in longitudinal research that looks at how students' skills for scientific argumentation evolves over time. It can also be used in a study that compares argumentation across various pedagogical techniques. This criterion-referenced tool can quantify the conceptual and cognitive, epistemic, and social components of a scientific argumentation session (Walker et al., 2012). It can be utilized to evaluate how students' involvement in scientific argumentation shifts over time as a result of an intervention, to compare the effects of various strategies on students' engagement in scientific argumentation, and to evaluate the type and extent of argumentation that takes place between students in the science classroom.

The ASAC observation protocol contains 18 items on a Likert-type scale. The conceptual and cognitive aspects of scientific argumentation consist of seven items. Using these criteria, the researcher can assess the study participants' focus on problem-solving abilities or knowledge advancement, evaluation of alternative claims, willingness to pay attention to anomalous data, level of doubt, capacity to offer arguments in favor of ideas, assessment of alternative claims, and, on the contrary, inappropriate reasoning techniques. The original instrument had seven items; however, Walker et al. (2019) modified it to six items. The Epistemic aspects of scientific argumentation consist of six items. It deals with the ability of the participants to differentiate between inferences and observations, the use of scientific discourse, and insufficient rhetoric for advancing a claim. It also explores the participants' evidence usage for making sense of the phenomenon. It also assesses the evidence and use of scientific theories, laws, or models during the discussion.

The social aspects of scientific argumentation have six items. It allows researchers to assess how participants engage and communicate with one another. These questions probe participants' skills for reflection, mutual respect, and openness to debating others' opinions and seeking out their own. They also probe the propensity to clarify others' ideas and level of involvement. Sampson et al. (2012) assessed the inter-rater reliability of the instrument's ability to produce similar and repeatable scores. These scholars found an acceptable fit between the two sets of total scores (.97) and for each item (.80). The items also displayed high inter-rater reliability.

These developers claimed that this tool has robust power to differentiate argumentation skills among students at various levels of education (such as between high school students and graduate students and between undergraduate and graduate students) and between the beginning and end of the intervention. All of these procedures demonstrated that ASAC is a top-notch observation tool for figuring out and monitoring the development of how students pay attention to each part of argumentation and how they affect the student's general ability to engage in effective argumentation during physics practical work. Hence, in the present study, the researcher adopted the ASAC observation protocol to assess students’ argumentation quality during dialogic practical work sessions.

2.8.2 Students’ dialogic-talk moves framework

The present study used a dialogic-practical work approach to examine its effect on students’ physics learning outcomes. Additionally, this study aimed to analyze how students engaged in dialogic talk moves in physics laboratories. Scholars used and developed various frameworks to analyze students' dialogic talk in classrooms. During laboratory work, the type of talk going on between the students can either have a conceptual and theoretical underpinning related to the topic of interest, or be related to the narrative of how students collaborate to get through laboratory and inquiry procedures. Depending on the nature of the task and the availability of tools and resources, students engaged in many levels of interaction at once while working in groups in the laboratory rooms. Therefore, it is worthwhile to explore students talk moves during practical work through the steps students took in such an interactive process.

However, there is shortage of analytical framework to analyze what students actually talk about and do during the laboratory work or inquiry (Andersson & Enghag, 2017). There were few attempts to develop analytical frameworks. For example, Barnes and Todd (1995) show how the different types of communication between students reveal the various types of activities in which they are engaging. However, on a deeper level, it also reveals their intentions and meaning-making interactions. Barnes and Todd (1995) found that students working in pairs used exploratory talk during laboratory activities to solve conceptual problems, and that they made specific discursive moves to proceed towards conclusions and agreements, like *challenge*, to question someone's scientific explanation, or *extend*, to add new information and develop each other's' ideas. They found how small group communication enhances learning by 'giving new experiences, which leads to a reshaping of a wider area of understanding, which may later affect how other similar events are interpreted' (Barnes & Todd, 1995, p. 11).

In accordance with Barnes and Todd, Mercer finds how exploratory talk: (1) combines, at the linguistic level, the speaker's challenges and requests for clarification with responses that provide explanations and justifications and (2) takes into consideration, at the cognitive level, the views of all participants, with explicit agreement preceding decisions and actions (Mercer, 1995). Similarly, Mercer (1995) used three levels to determine students' talk types. At the linguistic level, students' talk was examined in terms of how they talked to each other. Psychologically, students' talk was analyzed as thought and action. Student talk was analyzed as a kind of reasoning valued and encouraged in formal education institutions.

On the other hand, Anderson and Enghag (2017) extended the works of Barnes and Todd (1995) and Mercer (1995) to address students' discursive moves during practical work. Students' informal reasoning during practical work showed distinctive discursive moves, and student communication also showed how the content was negotiated. This analytical framework consists of exploratory, cumulative, and disputational talks. Andersson and Enghag (2017) provide a more detailed description of these talk types. These researchers constructed a four-fold matrix to perform a discourse analysis of students' talk during laboratory work to identify qualitative variations between the different talk types, both at the language and cognitive levels.

Andersson and Enghag (2017) added four major categories of moves: Action Moves, Content Moves, Purposive Moves, and Discursive Moves. Andersson and Enghag (2017) included both predefined discursive moves and undefined moves at both a linguistic and cognitive level in the dimensions of interaction and content. Interaction was defined as "the way students talk to each other at a linguistic level, and how they act towards one another at a cognitive level." Content is defined as "what students talk about at a linguistic level, and what underlying purposes they express during group discussions" (Andersson & Enghag, 2017, p.5). The distinctive characteristics of students' speech patterns for various discussion genres are displayed in Table 2.5.

Table 2.5 Coding Scheme for cumulative, exploratory, and disputational talks

Discursive moves	Definition	Cumulative talk
Request for actions	A student requests other students to contribute to the work.	Linguistic Level – Interaction
Confirmations	A student confirms by answering someone's utterance or question.	
Repetition	A student repeats someone's statement.	
Implementation	Students come with suggestions how to proceed with a measurement.	Linguistic level-Content
Use of equipment	Discussion of how equipment should be used.	
Taking notes	Measured values are forwarded to be noted.	
Declaring	A student explains how to use equipment.	Cognitive Level-Interaction
Instructing	A student tells others what to do without asking.	
Requesting	A student asks for the result of the measurement.	
Informing	Forwarding a measurements result.	
Participation	Repeating and confirming each other's utterance can be seen as a means to be part of the ongoing work process.	Cognitive Level-Content
Targeted work	All students seem to be well aware what data they are about to collect. No need of following questions.	
Completion of the task	The students are all focused on gathering necessary data and completing the task at hand.	
Handling equipment	Learning or showing how to use equipment.	

Discursive moves	Definition	Disputational talk
Assertion	Students make assertion in an ongoing dialogue.	Linguistic Level – Interaction
Counter assertion	An assertion is followed by counter assertion.	
Interpretation of a concept	Students argue for their personal view of a concept.	Linguistic level-Content
Representation of a phenomena	Students debate different representations of a phenomena.	
Defending	Stays firm in existing beliefs, without sincerely considering others' opinions.	Cognitive Level-Interaction
Condescending	Students begin to be dismissive of each other when they do not get expected response.	

Competing	Students’ contradictions lead to competition in submitting a correct answer for the task.	
Reinforcing old knowledge	Students stand firm in their beliefs, reluctant to change, their existing knowledge is reinforced.	Cognitive Level- Content
Revealing knowledge	When students’ debate back and forth, their existing knowledge is exposed.	
Discursive moves	Definition	Exploratory talk
Qualifier	A student makes a statement for others to consider.	Linguistic Level - Interaction
Challenged	The qualifier is questioned and challenged.	
Accepted	The qualifier is accepted.	
Extended	The qualifier is fully or partially accepted and then extended.	
Evaluating results	Students compare their obtained results with a tabled value.	Linguistic level- Content
Meaning of a physics concept	Students discuss how one variable is affected by others.	
Considering	Students thoroughly consider the meaning of what is being said.	Cognitive Level- Interaction
Questioning	Students’ questioning others’ explanation of a concept.	
Engaging	Students show engagement by asking following questions	
Conceptual understanding	Students try to understand the characteristics of a concept.	Cognitive Level- Content
Linking knowledge	Students value others’ reasoning based on existing ideas.	
Building on each other’s ideas	Realize that the existing way of thinking may be wrong and embrace others’ ideas.	
Creating new knowledge	Students strive to understand the implications of their results, which allow them to create new knowledge.	

The following are the reasons why the researchers in the current study adopted this analytical framework. Firstly, Andersson and Enghag (2017) extended Barnes and Todd's (1995) and Mercer's (1995) work to include both linguistic and cognitive dimensions of content. Second, they give equal emphasis to the interaction and content aspects of students’ practical work and discourse patterns. It provides insights into both students' 'doing' and 'understanding' of scientific processes. The interaction aspects at the linguistic level answer the question: How do students speak to each other? At the cognitive level, how do students act and progress? In the content part: Linguistic level: What content is in focus and what topics are discussed? At the cognitive level: What student purposes does the talk sequence express? Third, this model helps to analyze the discourse patterns of the different phases of dialogic practical work. It also provides the characteristic features of students' activities at the cumulative, exploratory, and disputational talk types.

2.8.3 Teachers' dialogic talk moves framework

The dynamics of the teacher-student relationship may be influenced by the way teachers interact with and with their students. This can open up opportunities for teachers and students to co-construct knowledge. The role of the teacher within a dialogic teaching framework has been investigated in terms of the kinds of inquiries teachers pose, the explicit emphasis on argumentation, the aims they give, and the amount of time they spend on metacognitive thinking reflection, or deep processing (Rapanta, 2021). For instance, Berland and Hammer (2012) argue that teachers should play a supporting role in promoting and establishing students' use of scientific argumentation. This gives students the ability to participate in group discussion and reasoning and provides opportunities for them to ask each other questions, demand reasons and evidence, and convince one another.

Additionally, the teacher's discursive contact with the class might affect how the students discourse and interact while they learn as well as how they perceive scientific knowledge and practices (McNeill & Pimentel, 2010; Ryu & Sandoval, 2012). Ryu and Sandoval (2012) analyzed an elementary school teacher's effort at promoting students by providing explicit justification for their claims. As the school year progressed, the students explicitly engaged in justifications as well as requesting justifications from one another and their teacher. These scholars also found that teachers' questioning techniques enabled students to actively collaborate in groups. They suggested that teachers should be trained on how to pose challenging questions to enable students to justify themselves.

McNeill and Pimentel (2010) investigated and contrasted classroom conversation when identical climate change lessons were delivered in three separate classes. They showed that student dialogic discourse was most successful when the teacher often asked open-ended questions and encouraged students to evaluate or support one another's viewpoints with reasons and examples. That is, students in these classes supported their assertions with more arguments and evidence, and they also engaged in student-student exchanges. Furthermore, students' engagement in scientific argumentation requires them to distinguish good and bad arguments based on criteria and evaluation of others' arguments and their quality (Ryu & Sandoval, 2012). Scientific argumentation practices also demand students view science as a result of the social interaction and discourse that accompany scientific knowledge building in classrooms (Reiser et al., 2012). Some authors used the term *scientific argumentation practices* (Walker et al., 2019) while others preferred *epistemic practices* (Christodoulou & Osborne, 2014; Kelly & Licona, 2018).

The term epistemic practices refer to "the specific ways members of a community propose, justify, evaluate, and legitimize knowledge claims within a disciplinary framework" (Kelly & Licona, 2018, p. 99). Christodoulou and Osborne (2014) distinguished between epistemic practices and epistemic operations. They defined epistemic operations as dialogic talk moves performed by the teacher or the students to facilitate the construction and development of knowledge and understanding. Individuals who performed these operations were considered epistemic practitioners. Several authors identified epistemic operations to address how knowledge production, evaluation, and communication are applied in science lessons.

Conversely, Jiménez-Aleixandre et al. (2008) listed the following epistemic practices: articulating knowledge, spotting patterns in data, interpreting and creating representations, creating reports and other texts, influencing peers, coordinating theories and evidence, and weighing claims against evidence. Christodoulou and Osborne's (2014) analyzed the epistemic operations of secondary science teachers' and revealed that evaluative practices were not present. These scholars recognized three descriptions of epistemic activities, such as methods of knowledge proposal, knowledge communication, and knowledge evaluation. Additionally, Kelly and Licona (2018) divided epistemic practices into four categories that correspond to cognitive processes: methods for putting out knowledge, conveying information, assessing knowledge, and legitimizing knowledge. Researchers used varying analytical models to assess students' and teachers' dialogic discursive moves (Christodoulou & Osborne, 2014; Nystrand et al., 2003; Stanford et al., 2016).

Some scholars developed frameworks to analyze the teacher's role in dialogic classrooms. For instance, Nystrand et al. (2003) found four crucial dynamic characteristics that describe good teachers' discursive maneuvers. These are uptake, high-level evaluation, and genuine queries from students. As indications of teacher constructive talk moves, Michaels et al. (2008) and Resnick et al. (2010) employed techniques including *say more*, *press for reasoning*, *revoice*, *challenge*, *restate*, *agree/disagree*, *explain others*, and *add on*. Christodoulou and Osborne (2014) examined prior research on the epistemic operation construct. They observed that the majority of these studies failed to explore how different epistemic operations bolster other epistemic practices. Christodoulou and Osborne (2014) designed a framework with a complete list of epistemic operations divided into teacher-performed and teacher-prompted categories.

The teacher-prompted action gets students talking about the event, whereas the teacher-performed discursive move allows the teacher to describe an occurrence. Epistemic operations can also be classified into groups depending on their importance in constructing knowledge, justifying knowledge claims, and evaluating scientific knowledge claims. The present study synthesized dialogic talk moves from Nystrand (2003) (authentic questions and high-level evaluation); Michaels et al. (2008) and Resnick et al. (2010) (say more, press for reasoning, revoice, challenge, restate, agree/disagree, explain others, and add on); and the two major epistemic operations performed by teachers and those prompted by teachers (Christodoulou & Osborne, 2014). In addition, Nystrand et al.'s (2003) high-level evaluation was included to analyze the teacher's dialogic talk moves as shown in Table 2.6.

Table 2.6 Teacher's epistemic operations and their description

Epistemic Operations	Description of the Epistemic Operation
Analogies and 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 counterargument	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.

*Source: Christodoulou and Osborne (2014, p.1287)

2.9 Effectiveness of Practical work for physics learning outcomes

For more than a century, it has been recognized that practical work can help students build a range of cognitive, psychomotor, procedural, attitudinal, and emotional skills relevant to comprehending and applying physics (Babalola et al., 2020; Radulovi et al., 2016). Researchers, educators, policymakers, and teachers continue to emphasize the importance of practical work in secondary school physics (Harrison, 2016; Shana & Abulibdeh, 2020). However, which practical work strategy is more effective in positively enhancing students' learning is still a debatable issue (Harrison, 2016; Lunetta et al., 2007). Whatever the case may be, it is difficult to determine whether a particular practical work strategy has been effective in achieving the objectives. Besides, investigating the effect of dialogic teaching in practical work on students' learning outcomes is an emerging area of research.

Moreover, there is a lack of reporting about what students talk about and do during practical work and the outcomes of their actions (Andersson & Enghag, 2017). Hence, this study focused on the effects of a dialogic-practical work approach on students’ science process skills, mechanics achievement, attitudes toward physics, epistemic beliefs about physics, and scientific argumentation skills. In the next subsection, the empirical evidence associated with the impact of the dialogic-practical work approach on students' physics learning outcomes was presented. Finally, a summary of the findings was presented.

2.9.1 Effectiveness of Practical work on students’ Mechanics achievement

Numerous scholars argue that implementing practical work can improve students' achievement compared to traditional lecture methods (Ateş & Eryilmaz, 2011; Lee & Sulaiman, 2018; Musasia et al., 2016; Shana & Abulibdeh, 2020). For example, Shana and Abulibdeh (2020) examined the effect of intensive practical work on students’ science achievement in comparison to conventional methods of teaching science. They participated in 94 students from grades 10th and 11th secondary schools in the United Arab Emirates. These scholars found that intensive practical activities significantly improved students’ academic achievement compared to traditional lecture methods. While other researchers argued that the recipe-based practical work approach had little impact on students' achievement on physics exams (Holmes et al., 2017; Vilaythong, 2011; Wieman & Holmes, 2015).

For instance, Wieman and Holmes (2015) examined the impact of completing introductory laboratory courses using practical work based on recipes on students’ test results. Exam results were compared between students who took laboratory courses and those who did not. Their findings revealed that, on average, students who took the lab scored much higher on the final test than those who did not. However, the ratios between students who take the lab and those who do not demonstrate that the difference in the ratios between the two groups is considerably lower than the uncertainty in both circumstances. They concluded that students who took laboratory courses performed similarly to those who did not on their final exams. One of the shortcomings of this method was having students carry out experiments, collect data, analyze, and interpret data by strictly following the instructions provided in the manual. Students get very small autonomy and control over the experiment and lack the opportunity to reflect on their methodology and findings. For these reasons, many scholars abandoned the effectiveness of this practical work approach in achieving the intended objectives.

The present study also agreed that such laboratory tasks are routine and purposeless to the students. Moreover, it has little to do with improving students’ mechanics achievement. To address these drawbacks, other authors implemented student-centered practical work strategies such as hands-on and minds-on (Ateş & Eryilmaz, 2011) and inquiry-based experiments (Radulović et al., 2016). Ateş and Eryilmaz (2011) examined the impact of hands-on and minds-on activities on 130 ninth-grade students' understanding of basic electric circuits. Their findings showed that compared with the conventional lecture method, employing hands-on and mind-on practical activities dramatically enhanced students' performance in physics.

On the other hand, Radulović et al. (2016) examined the effect of the application of laboratory inquiry-based experiments and interactive computer-based simulations on students' physics achievement. They participated in 187 high school students and found that inquiry-based experiments and interactive computer-based simulations achieved statistically significant improvements in test scores in comparison to the traditional teaching approach. These scholars added that both approaches resulted in significant progress compared to the comparison group. Additional research findings showed that guided inquiry activities positively contributed to enhancing students' achievements (Aditomo & Klieme, 2020; Jerrim et al., 2020). While other studies reported that open inquiry activities negatively affected students' achievements (Aditomo & Klieme, 2020; Cairns & Areepattamannil, 2019; van Riesen et al., 2019). Contrarily, Baloyi (2017) found that implementing explicit reflective guided inquiry practical activities for first-year physics university students did not improve their achievements compared to traditional practical work.

Recent studies suggest talk and discussion result in practical work being more educationally productive (Harrison, 2016; Taylor et al., 2018; Walker et al., 2012). For example, Harrison (2016) investigated the impacts of guided discussion at different steps of practical work on secondary school students' comprehension of physics. The results revealed that students involved in targeted discussion tasks performed better than the comparison group. According to this author, the debate that takes place during practical work has had a positive effect on students' understanding of concepts connected to practical work. However, it had no beneficial effect on students' wider understanding. Others also synergized inquiry-based activities with argumentation strategies to improve students' physics achievements (Demircioglu & Ucar, 2015; Taylor et al., 2018; Walker et al., 2012). For example, Demircioglu and Ucar (2015) examined the effects of applying argument-driven inquiry-based laboratory activities to 79 pre-service science teachers on their academic achievements. They found that pre-service teachers taught with an argument-driven inquiry approach improved their academic achievement with a big effect regarding geometrical optics compared to traditional laboratory instruction.

Taylor et al. (2018) also found that students with disabilities engaged in a structured inquiry-based argument approach scored significantly higher in science achievement with a stronger effect size than the comparison groups. Similarly, Parno et al. (2021) investigated the effects of the ADI model on grade 10 students' mechanics achievement. The results showed that the ADI model improved students' mechanics achievement in the medium category compared to the conventional learning method in the low category. After the implementation of the ADI model, students still had difficulties understanding some mechanics concepts. Arslan et al. (2023) investigated the effects of an Argument-Driven Inquiry (ADI) on 28 pre-service science teachers' achievement. The finding indicated that the post-achievement test score of the students who conducted the ADI model was significantly higher than their pre-achievement test mean score.

On the contrary, Walker et al. (2012) showed that students' achievement did not differ significantly when Argument-Driven Inquiry (ADI) was applied in introductory college chemistry labs. Despite all these efforts, not enough evidence showed the effect of the dialogic-practical work model on students’ mechanics achievement. Gender-wise, studies disagree. Some scholars found that students’ physics achievement after practical work was not gender-dependent (Kibirige et al., 2014; Walker et al., 2016). Walker et al. (2016) investigated the degree to which students' capacity to use fundamental concepts to engage in scientific practices is influenced by the argument-driven inquiry model employed during a general chemistry laboratory course. They revealed that students who took the argument-driven inquiry activities did better on the practical exam than their peers who took the recipe-based conventional sections regardless of gender differences.

Walker et al. (2016), however, found no disparity in performance between male and female students in both situations. Thus, the present study examined the effects of dialogic-practical work on students' mechanics achievements in comparison to recipe-based practical work. This is based on the assumption that a dialogical-practical approach would encourage female and male students to argue with each other. Indeed, it aims to improve students' mechanics performance regardless of gender differences. Moreover, diverse levels of achievement among students exist in a classroom. These students with varying achievement levels responded differently to different instructional strategies, which in turn has shown to impact their achievements (Hans et al., 2015). High and low achievement levels responded diversely to different instructional approaches.

Moreover, empirical research shows that not all students engage in classroom talk to the same extent (Sedova et al., 2019). The frequency with which students engage in classroom talk and how long they speak are identifiable differences among students. These findings indicate that there are different participation degrees and quality in classroom discourse. These differences presumably create differing learning opportunities and, ultimately, could lead to differences in student achievement. There were few studies that showed the more a student talked and engaged in reasoning in class, the better they performed in a reading literacy test (Sedova et al., 2019). However, studies concluded that no learning environment can be guaranteed as the best milieu for every student. The present study claim that productively organizing a dialogic-practical work approach in the laboratory setting can maximize students' interactions, which in turn minimize the achievement gaps that exist among the varying achievement levels. Therefore, the present study targeted to examine the effects of dialogic-practical work on students mechanics achievement among various achievement levels.

2.9.2 Effectiveness of Practical work on students' Science process skills

Studies show that secondary schools tend to focus on cognitive enhancement and ignore science process skills (Damopolii et al., 2020). Science education researchers recommend that engaging students in practical work provides them with more chances of acquiring science process skills (Babalola et al., 2020; Khaparde, 2019; Millar, 2004). There are disagreements, however, regarding the kind of practical work to improve students' science process skills. In contrast to conventional lecture methods, some academics contend that applying practical work might improve students' science process skills (Ates & Eryilmaz, 2011; Lee & Sulaiman, 2018; Muchai, 2016; Musasia et al., 2016; Shana & Abulibdeh, 2020). A few studies showed that recipe-based practical work had a positive impact on students' basic science process skills (Volkwyn et al., 2008).

While others argue that recipe-based practical work limits students' science process skills (Babalola et al., 2020; Holmes et al., 2017). Specifically, it had a very small impact on developing students' integrated science process skills. Hence, several researchers implemented an inquiry-based laboratory approach (Athuman, 2017; Chambers, 2014; Damopolii et al., 2020) and found that their approach developed students’ science process skills. For instance, Athuman (2017) examined the impact of an inquiry-based strategy on 263 secondary school students' science process skills in Tanzania. The researcher compared those students taught using inquiry-based learning for eight weeks on a genetics course with those students who were taught using the conventional lecture method. This study indicated that the inquiry-based method helped students develop scientific process skills compared to traditional methods.

Similarly, Damopolii et al. (2020) found that inquiry-based learning improved senior high school students’ science process skills compared to the conventional lecture method. On the other hand, Chambers (2014) showed that the open inquiry approach was more effective in developing students’ science process skills than guided inquiry. These and related research provided valuable information about how inquiry-based practical work approaches could aid students' science process skills acquisition. Studies have shown that there is no single teaching model suitable for teaching all topics at all levels to all students (Athuman, 2017). In this regard, very few researchers integrated an inquiry-based technique with an argument to increase the scientific authenticity and educational value of students' practical work experiences (Demircioglu & Ucar, 2015; Gultepe & Kilic, 2015).

For instance, Gultepe and Kilic (2015) investigated the effects of an argument-driven inquiry model on 11th-grade students' integrated scientific process skills in comparison to traditional teaching approaches. Their results indicated that participants in the argument-driven inquiry model improved students' integrated science process skills compared to the recipe-based practical work approach. These researchers found that the argument-driven inquiry approach improved students' skills to create data tables, draw graphs, analyze graphs, identify variables, formulate hypotheses, change, and control variables, except in designing experiments. These academics argued that compared to other integrated science process skills, planning experiments takes more time and effort. Even though these findings showed promising results, the study had several limitations. The study participants were only 17 highly successful students. It made the study findings difficult to replicate in high schools with diverse backgrounds (prior knowledge, large class size, and gender). Furthermore, students were given experiments and results as homework, which limits scientific argumentation implementation to the expected form. Demircioglu and Ucar (2015) looked at how the argument-driven inquiry model affected prospective teachers' science process skills. They showed that, with a moderate effect size, the argument-driven inquiry was superior to recipe-based practical work for enhancing pre-service teachers' science process skills. In addition, they noted that only 7% of the variation in students' science process skills could be attributed to argument-driven inquiry (Demircioglu & Ucar, 2015).

Susanti et al. (2018) found that scientific approach-based learning significantly improved students' science process skills before learning (pretest) and after learning using the scientific approach (posttest). Their results further revealed that the science process skills of students have increased in all aspects with the normalized average gain of the medium category. However, they increased in the predicting aspects with low categories. The highest increase in the normalized average SPS gain was observed in the skills of communication which was 0.65 and the lowest was in the skills of prediction, which was 0.17.

Ural and Gençoğlan (2020) investigated the effect of an argumentation-based science teaching approach on 69 8th-grade students' science process skills. Their results found that the argumentation-based science teaching approach was more effective in developing students' science process skills than the didactic teaching approach. Strimaitis et al. (2017) studied the impact of giving high school students the chance to engage in a variety of science practices while working in a biology lab. The findings of this study revealed that when given the chance to engage in a wide range of science practices, students enrolled in the general section of the course improved in these skills compared to those enrolled in the honors section. These students developed better skills to plan and conduct an investigation, analyze and interpret data, making an argument using evidence, and write a persuasive essay. These results show that all students might benefit from laboratory experiences that allow them to participate in a variety of science procedures.

Students in Ethiopian secondary schools receive very hardly any hands-on instruction, mostly through infrequent teacher demonstrations and recipe-based practical work. Contrarily, the government is currently undertaking educational reforms that call for teachers to place a strong emphasis on practical work, and the government has also allocated a sizable budget to equip scientific labs (Teferra et al., 2018). As part of these changes, this study develops and executes a dialogic-practical work method in the secondary school physics lab and compares it to recipe-based practical work to see how it affects students' science process skills. To the researcher's knowledge, the extent to which students' science process skills in Ethiopian secondary schools are improved through dialogic-practical work has not been researched. This study examines how dialogic-practical work affects secondary school students' science process skills.

2.9.3 Effectiveness of Practical work on students’ attitudes toward physics

A number of studies showed that practical work strategies create a learning environment for the students to actively engage in activities, thus encouraging them to develop a positive attitude towards physics. However, there are contradictory findings about the effects of practical work on students' attitudes toward physics. Some claim that even practical activities based on recipes might help students' attitudes toward physics. For instance, Muchai (2016) showed that, in contrast to conventional lecture approaches, practical work had a favorable effect on students' attitudes toward physics. Yap and Chew (2014) investigated the effect of demonstrations aided by ICT tools on upper secondary school students' attitudes toward physics in Singapore. The study participants were 94 students selected from four express stream and five normal stream physics students from four secondary schools. The results elucidated that students’ attitudes towards physics learning improved significantly for both groups who used demonstrations supported by ICT tools.

Contrarily others claimed that recipe-based practical work failed to improve students' attitudes toward physics (Sawyer et al., 2017; Wilcox & Lewandowski, 2017). In this regard, some researchers attempted to apply inquiry-based activities (Akuma & Callaghan, 2019; NRC, 2012; Sesen & Tarhan, 2013). Inquiry-based learning provides an opportunity to set up an experiment, explore, analyze the results, and make conclusions with varying degrees of autonomy. Some researchers demonstrated that this approach helped students develop positive attitudes toward physics (Kurniawan et al., 2021; Sesen & Tarhan, 2013; Walker et al., 2012).

Kurniawan et al. (2021) evaluated how inquiry learning and Jigsaw learning models affected secondary school students' attitudes toward physics in Indonesia. The results showed that inquiry learning and Jigsaw learning models developed students' attitudes toward physics positively compared to the traditional method. Their findings also showed that in comparison to the lecture method, inquiry learning, and Jigsaw learning models fostered attitudes toward practical investigation, enthusiasm to learn physics, adoption of scientific attitudes, and boosted their study time.

Similarly, Sesan and Tehran (2013) looked at how high school students' attitudes toward chemistry were affected by inquiry-based laboratory activities. They demonstrated that compared to practical work based on recipes, inquiry-based laboratory activities dramatically increased students' favorable attitudes toward chemistry. Academics recommended inquiry-based laboratory activities to boost students' positive attitudes. Additionally, Walker et al. (2012), the argument-driven inquiry model increased students' attitudes toward chemistry. While others (Ateş & Eryilmaz, 2011; Demirciolu & Ucar, 2012; Ural & Gençolan, 2019) noticed that even innovative practical work strategies did not enhance students' attitudes toward science and or physics. For instance, Ateş and Eryilmaz (2011) looked at how ninth-grade pupils felt about physics after engaging in hands-on and mental activities. These researchers revealed that, compared to the comparison group, students who engaged in hands-on and mind-on activities did not have a positive impact on their attitudes toward physics.

Similarly, other scholars indicated that argument-driven inquiry did not improve students' attitudes (Demircioğlu & Ucar, 2012; Ural & Gençoğlan, 2019). For instance, Ural and Gençolan (2019) looked into how 69 eighth-grade students' attitudes toward science were affected by an argumentation-based scientific teaching style. This study found that students' attitudes toward science were unaffected by argumentation-based scientific instruction. The previously mentioned research revealed mixed or contradictory findings about the possible advantages of various practical work approaches to students' attitudes toward physics.

The second controversial issue was the effects of gender differences on students’ attitudes toward physics. Some researchers indicated that females are more likely than males to adopt a positive attitude toward physics (Anwer et al., 2012; Heng & Karpudewan, 2015; Walker et al., 2012). Others concluded that males had more positive attitudes toward physics than females (Kousa et al., 2018). Other research revealed that attitudes toward physics between females and males are not significantly different (Zeidan & Jayosi, 2015). According to Ibrahim et al. (2019), attitudes toward physics between males and females did not differ statistically significantly. They also indicated a positive attitude toward learning physics irrespective of gender differences.

There is a dearth of research on how a dialogic-practical work approach affects both male and female students' attitudes toward physics. Hence, this study aimed to examine the effects of gender differences on students’ attitudes toward physics in comparison with a dialogic-practical approach. This study was conducted based on the assumption that dialogic-practical work allowed students to interact equally regardless of gender disparity. This might develop students’ attitudes toward physics irrespective of gender differences.

The third contentious research topic was the impact of students' varying academic attainment levels on their attitudes toward physics. The majority of research concludes that there is a link between students' attitudes and achievement levels (Kingir & Aydemir, 2012). Research has demonstrated that academic success favorably impacts students' attitudes (Kousa et al., 2018). There are, however, a few studies (Fulmer et al., 2019; Osborne & Dillon, 2008; Potvin & Hasni, 2014) that challenge these findings. For instance, Fulmer et al. (2019) found that, compared to students from lower-performing schools, students from the highest-performing schools had a negative attitude toward science. Students chosen from high-performing schools did not exhibit favorable views about physics (Osborne & Dillon, 2008; Potvin & Hasni, 2014).

As a consequence, there is a vacuum in the body of work that specifically demonstrates how students' achievement levels affect their attitudes toward physics. This study looks at how students' attitudes toward physics are affected through a dialogic-practical work approach. It also explores potential attitudinal differences between males and females and variations in achievement levels as a result of dialogic-practical work interventions. The current dissertation aims to close the knowledge gap about the impact of dialogic-practical work on high school students' attitudes toward physics in Ethiopia.

2.9.4 Effectiveness of Practical work on students’ Epistemic Beliefs

Epistemic beliefs have been and continue to be a central topic of several studies in educational research (Conley et al., 2004; Schiefer et al., 2020; Wilcox & Lewandowski, 2017). It is crucial to science study and a crucial objective in and of itself. Due to its significance, there have been multiple efforts to encourage students' epistemic beliefs at various educational levels (Muis et al., 2016; Schiefer et al., 2020). Academics have developed and used instructional strategies to support students' epistemic views (Walker et al., 2019). Researchers in education have looked at how students' practical work shapes their epistemic beliefs. It is predicated on the idea that hands-on learning can help students learn science more effectively, inspire and foster positive attitudes toward science and science learning, develop laboratory skills, and comprehend how scientists work in science (Babalola et al., 2020; Torres et al., 2013).

Physics education researchers showed that traditional practical work limits students' epistemic beliefs (Wieman & Holmes, 2015; Wilcox & Lewandowski, 2017). In this approach, students struggle with the formulation of research questions, the development of an investigation plan to obtain scientific evidence, the analysis and interpretation of data, and the establishment of conclusions supported by empirical data (Baloyi, 2017; Sani, 2014; Vilaythong, 2011). This approach focused on operating equipment rather than encouraging them to implement ideas to advance their knowledge (Hofstein & Lunetta, 2004). This recipe-based practical work had a limited impact on enhancing students’ epistemic beliefs (Wieman & Holmes, 2015; Wilcox & Lewandowski, 2017). Several studies across various disciplines have demonstrated the dire need to transform this approach into a student-centered discourse (Rees & Roth, 2019). In fact, combining dialogic instruction with hands-on learning can provide students with more chances to engage in science practices.

Only a few researches have demonstrated how these speech patterns might improve learning outcomes and enable students to construct meaningful, evidence-based explanations of scientific events (Walker et al., 2012; Walker et al., 2019). Such meaning-making strategies also promote theoretical understanding in science learning and encourage students to shift their epistemic views (Tan et al., 2021). Many policy documents advocate inquiry-based laboratory activities (NRC, 2012). Some authors revealed that involving students in inquiry-based activities can promote epistemic beliefs about physics (Cotabish et al., 2013; Hong et al., 2016; Schiefer et al., 2020; Shi et al., 2020). Hong et al. (2016) used a case study design to evaluate how students participating in online collaborative meaning-making activities can enhance their epistemic beliefs. After the intervention was carried out for eighteen weeks on 41 undergraduate students, the pre-posttest results revealed a beneficial relationship between the formation of epistemic beliefs and involving students in more fruitful and successful collaborative meaning-making-oriented inquiry activities. These researchers recommended that collaborative inquiry activities fostered a more sophisticated epistemic understanding of knowledge formation.

Furthermore, Shi et al. (2020) argue that first-year engineering students who engaged in inquiry-based physics laboratory activities showed more expert-like epistemic beliefs relative to those students using recipe-based laboratory activities. However, the recipe-based practical work groups showed negative shifts in epistemic beliefs between pre-and post-test scores. Ozgelen (2012) examined the effects of inquiry-based activities on 45 aspiring science teachers' epistemic views. Their findings showed that between pre- and post-inquiry activities, prospective science teachers had improved their epistemic beliefs. Similarly, Ozgelen's findings revealed that pre-service science teachers held more sophisticated views of certainty and sources of knowledge. However, there was no significant improvement in truth attainability and justification for knowing between pre- and post-interventions.

Iordanou (2016) examined the effects of argumentation in the scientific and social domains on 44 sixth graders' epistemological understanding. The results indicated that undertaking dialogic-based activities developed a more sophisticated domain-specific epistemological understanding. In the qualitative analysis, it emerged that students' views of evidence importance vary depending on whether they study physical science or social science. Physical science students believed evidence was the primary source of knowledge. Students in the social science field, however, believed that subjective perception and their own experiences were fundamental sources of knowledge. Students who participated in a science-centered argumentation intervention, on the other hand, showed respect for scientific evidence and thought it was essential to belief formation. Students who took part in the same intervention but focused on a social issue thought that personal experiences met the requirements for substantial evidence.

This bolsters the idea that various domains have distinct problems when developing epistemic understanding. Iordanou suggested that epistemological understanding can be achieved through argumentative activities. These studies provided promising insights into the effects of inquiry-based practical work and dialogic teaching strategies on fostering students’ epistemic beliefs. Due to context differences, implementation inconsistencies, and the use of various research methodologies or measurements, it has been challenging to evaluate the effectiveness of these various treatments. Moreover, numerous studies have focused on showing the effects of epistemic beliefs on students' argumentation skills and quality. However, less research has been done to investigate the potential impact of dialogic practical work on students’ epistemic beliefs.

However, there is a dearth of research on the impact of dialogic practical work on students' epistemic beliefs. Hence, the current study examined the effects of involving students in dialogic practical work on strengthening students' epistemic beliefs in physics. Studies revealed that epistemic beliefs are closely related to gender (Ali et al., 2021; Chiu et al., 2015; De Juanas et al., 2014; De Juanas & Beltrán, 2012). However, the findings on student gender's effect on epistemic beliefs development lack consistency. Some authors found that female and male students did not differ in developing sophisticated EBs in science (Ali et al., 2021; De-Juanas et al., 2014). Ali et al. (2021) showed that gender had no significant effect on students' epistemic beliefs. Others explicitly described gender contributions in terms of epistemic beliefs subscales. Ongowo (2020) and Ozkan and Tekkaya (2011) found that neither the source of knowledge nor the certainty of knowledge differed significantly between males and fameless.

Furthermore, Ongowo (2020) found that students had no significant differences in the justification dimension. On the other hand, Ozkan and Tekkaya (2011) discovered that females exhibited more sophisticated beliefs about knowledge justification. For the dimension of knowledge development, females showed a statistically significant difference from males (Ongowo, 2020). On the contrary, Chiu et al. (2015) found that students showed substantial gender differences in dimensions of uncertainty, complexity, and sources of knowledge; however, no gender difference was observed in justification. De Juanas and Beltrán (2012) revealed that among the subscales of fixed ability and quick knowledge, females possess significantly more elaborate epistemic beliefs than males. Males feature more elaborate beliefs than females in the dimensions of simple and certain knowledge. Regarding simple and certain knowledge, females showed more naïve beliefs than males. These show inconclusive gender discrepancies and require further investigation. The present study attempted to address the effect of gender differences on students' epistemic beliefs after conducting a dialogic-practical work approach.

2.9.5 Effectiveness of Practical Work on students' scientific Argumentation skills

Students should be motivated to understand science on their own through active participation in developing their ideas (Hasnunidah & Juli Wiono, 2019). One way to develop students' thinking skills is to engage them in argumentation. Scientific argumentation skills are needed for students to have logical thinking, distinct opinions, and reasonable explanations of their knowledge

(Demircioglu & Ucar, 2015). In this way, science education shifts to argumentative skills. Hence, science students who learn science know scientific explanations of natural occurrences, use them to solve problems, and comprehend the other information they acquire. In this respect, students should comprehend science jargon and actively engage in scientific activities like observation and reasoning (Walker et al., 2019). Many students have difficulty actively practicing argumentation skills (Kuhn et al., 2013; Walker et al., 2019). Some studies revealed that implementing the argument-driven inquiry (ADI) model can empower students in enhancing argumentation skills in learning science (Demircioglu & Ucar, 2015). This model is intended to make laboratory instruction more informative.

For example, Hasnunidah and Juli Wiono (2019) revealed that applying the ADI learning model increased grade eight students’ argumentation skills, both in writing and orally compared to the guided inquiry model. They claimed that the ADI model produced a notable improvement in science reasoning abilities. According to these studies, supporting students to participate in argument-driven inquiry can improve their argumentation skills in terms of the complexity of the argument and its structure. They stated that ADI activities helped both male and female students improve their argumentation skills. Admoko et al. (2021) investigated the impact of using the ADI approach to enhance high school students’ scientific argumentation skills. The results showed that the ADI learning model considerably improved students' science arguments between pre- and-post-test. These findings support the claim that the ADI learning approach enhances students' scientific argumentation skills. Similarly, others have also investigated the effects of Argument-Driven Inquiry on students' argumentation quality.

For instance, Hanifah and Admoko (2019) revealed that tenth-grade students improved their argumentation skills after implementing the ADI approach. Demircioglu and Ucar (2015) used an argument-driven inquiry model to change students' argumentation skills at the beginning, middle, and end of practical work. According to the findings, there was no discernible change between the treatment and comparison groups' argumentation level scores at the beginning and middle of the intervention. The argumentation level score of the ADI group, however, was significantly better than the comparison group scores at the end of the intervention. Contrarily, Walker et al. (2019) found that students could not improve their argumentation quality by employing an argument-driven inquiry instruction model within a two-semester general chemistry laboratory. The results indicated that students did not modify their claims or arguments even when challenged with conflicting evidence. Students were reluctant to amend the assertion as a legitimate part of the argument.

Seda Cetin et al. (2018) investigated the impact of ADI activities on Turkish high-school students' argumentation skills in contrast to a more conventional structured inquiry method. The results revealed that students who received this innovative approach for seven weeks outperformed those who received structured inquiry instruction on argumentation skills. In addition, female students grouped under the ADI approach performed better on argumentation tests than their male counterparts. The findings suggest that Turkish students' argumentation skills may be significantly improved when they participate in a wide range of scientific practices.

On the other hand, Andersson & Enghag (2017) investigated how the laboratory work's actual design may affect upper secondary school students' disputational, cumulative, and exploratory talks. These scholars investigated students' talk types while involved in planning, preparing equipment, collecting data, processing data, and analyzing results. In most cases, students engaged in cumulative and exploratory talks. The results also revealed that students generated the most exploratory talk during problem-based styles and the least in expository laboratory styles. These scholars concluded that the number of exploratory talks students engaged in was influenced by laboratory work styles and the characteristics of the activity.

These studies have provided valuable insights into the effect of dialogic talk for students' scientific argumentation skills. Yet, it is quite difficult to summarize the findings from these studies as they varied considerably – students were of different ages, interventions were done in different courses, and different outcomes were measured (Sedova et al., 2019). Hence, more research is needed to explore how a dialogic-practical work strategy would affect students' scientific argumentation skills in secondary schools in particular.

2.10 Theoretical Framework of the study

In the current study, we looked at how students learned physics using a dialogic-practical work strategy in secondary school physics labs. As a result, Bakhtin's dialogism theory and Vygotsky's constructivist theory of learning served as the foundation for this research. In the following subsections, we will discuss briefly each theory and how it will inform the current study. These subsections present a theoretical and conceptual framework associated with a dialogic-practical work approach.

2.10.1 Constructivist theory of learning

Constructivist theories of learning emerged from the cognitive sciences. It explains how people interpret their experiences and information to form meaning and construct knowledge (Baloyi, 2017). It directly contradicts behavioral theories of learning, which hold that pupils get knowledge from their teachers directly. Science knowledge should be viewed by constructivist learners as an active process of knowledge production (Lin & Tsai, 2017). To validate scientific information found in textbooks, practical activity should extend beyond carrying out experiments, utilizing instruments, capturing data, and reproducing graphs. In other words, when performing practical work in physics labs, students should have the chance to actively contribute to knowledge construction.

Cognitive constructivism and social constructivism are the two primary subcategories of constructivist theories of learning. Cognitive or personal constructivism aims to understand how people make sense of the world (Piaget, 1970; von Glasersfeld, 1995). Piaget, who pioneered the individual constructivist theory, said that students' cognitive processes are where learning takes place. He also believed that until a student reaches a specific developmental stage, they cannot learn anything. Therefore, practical work should be carefully planned to change students' prior learning or experiences to meet their unique requirements and capacities. This can be done before adding new knowledge to their cognitive framework, or schema.

On the other hand, social constructivist theory (Vygotsky, 1978) recognizes the significance of social interaction in knowledge development. The fundamental tenet of social constructivist theory is that information is actively produced by the student based on social interaction with others rather than being directly communicated from the teacher to students (Andersson &

Enghag, 2017; Calcagni & Lago, 2018). The learning of the disciplinary core ideas and the practices of science therefore involve both personal and social processes. The social process of learning involves exposure to the language, representations, concepts, and the practices that make science different from other ways of knowing. This process requires input and guidance about “what counts” from people that are familiar with the goals, norms, and epistemological commitments that define science as a community of practice (Strimaitis et al., 2017, p.93). Thus, learning is dependent on supportive interactions with others.

The individual process of learning, in contrast, involves the construction of new knowledge and new ways to explore the unknown through the appropriation of important ideas, modes of communication, modes of thinking, and practices for generating new knowledge by making sense of an experience and integrating new views with the old. Jean Piaget argues that learning at individual level takes place in three stages: assimilation, accommodation, and disequilibration. Assimilation is the incorporation of newly acquired information into previous understanding. Accommodation is the process of adapting previous understanding to unfamiliar experiences. Disequilibration is the process by which thinking reconciles cognitive contradictions between newly acquired and old experiences.

Vygotsky argues that learning happens twice, first on the social level (through of the interpersonal interaction between students and teachers and between students and other students), while the second takes place on the individual level (on the level of internalized psychological processes) (Sedova et al., 2014). Learning, according to Vygotsky, takes place in a social, cultural, and historical environment. More importantly, his theories on how language and the mind interact have influenced social science studies in general and educational research in particular. Vygotsky believed that classroom discussion builds on students' prior knowledge and experiences. Effective teaching techniques should include students' contributions in the classroom and provide them with the chance to discuss their views with others (Calcagni & Lago, 2018).

Vygotsky says language and the sociocultural environment have a crucial role in mediating and influencing behavior and helping us understand how students interpret their surroundings (Lyle, 2008). Vygotsky’s work laid the foundation for language use in shaping students' thoughts. Researchers have been motivated to study how talk impacts learning and argumentation. By incorporating this theory into classroom practice, researchers enable rich discourse to be created, largely in order to eliminate direct instruction dominance. The present study argues that learning is not a mere function of maturation. Instead, it can happen at any stage as long as knowledgeable others can provide scaffolding strategies to guide students to the level they can achieve. Vygotsky operationally defined this supported learning environment as a zone of proximal development (ZPD) in which the learner (novice) and an expert (teacher) negotiate meaning. The ZPD represents the distance between the child’s actual developmental level and the child’s ability to perform with the help of an adult or more capable peer (Zady et al., 2003). Here the expert supports the learning by holding parts of the task in store until the learner is capable of completing the task alone. This cognitive support is generally described in terms of scaffolding.

According to Lazonder and Harmsen (2016), scaffolding involves guiding students through difficult tasks by outlining what to do and how to execute them. Additionally, it gives the student specific tools with which to organize, or streamline their tasks It bridges the gap between what students can accomplish on their own without assistance and what they can accomplish with the right amount of guidance, mentoring, and reinforcement from competent peers or teachers in the classroom (Lehesvuori, 2013). The teacher assists students in implementing dialogic practical work in a physics laboratory setting. This is accomplished by drawing on their existing knowledge and disassembling challenging jobs into simpler, more doable stages. In this respect, the use of dialogic teaching in physics laboratories and how it promotes and encourages student learning should be well-known to the teacher. Moreover, the intent of support or scaffolding should focus on enabling the students to attain the higher levels of conceptual hierarchies on their own.

According to studies (Sadler, 2004; Sampson & Clark, 2009), students who engaged in scientific debate found it difficult to come up with a logical explanation, utilize enough relevant facts to form evidence, and comprehend what constitutes credible evidence. Sadler (2004) says students frequently make illogical assertions, lack the ability to analyze and evaluate arguments, and seldom employ scientific evidence to back their decisions. Teachers have a duty to provide scaffolding resources to improve students' abilities to offer arguments, evidence, justifications, and counterarguments. As developing these skills takes time (Kuhn et al., 2016), teachers will support students until they can analyze and evaluate arguments, make justified claims, and recognize opposing arguments. At the beginning of practical work sessions, the teacher should explicitly guide students to argue with each other, generate arguments and counterarguments, formulate hypotheses, plan investigations, collect data, and analyze and interpret data. As students develop these skills, guidance will be minimized. More opportunities will be offered for the students to take charge of dialogic-practical work tasks.

The present study extracts the following fundamental implications for teaching physics in the laboratory setting from these theoretical perspectives. First, students must have opportunities to use disciplinary core ideas and participate in science practices to learn about them. Laboratory settings are ideal for social construction of knowledge and investigation of natural phenomena using the tools, models, theories, and modes of communication valued within a specific discipline (Strimaitis et al., 2017).

Second, students must understand why certain aspects of a practice are more productive or useful than others in a particular field. They must also understand why. For example, scientists often plan to control variables and conduct multiple trials when designing a scientific investigation. Consequently, students should not only be engaged in science practices, such as designing an investigation, but also be taught why certain strategies or techniques related to each practice are more useful and productive in certain situations than others, such as controlling variables or including multiple trials.

Third, students must develop an understanding of how to engage in dialogic conversations by providing sound evidence, arguments and counter-arguments while interacting with each other to reach consensus. For cognitive development and learning to occur, there must be actively competing and original ideas. Students must also be active in criticizing, questioning, and even debunking others' assertions to enlarge and develop students' perspectives and result in an honest reevaluation of their own ideas or viewpoints relative to those of others. This results in the co-construction of knowledge, the recalibration of understandings, and the deepening of understandings. Finally, it is vital to play the right role in guiding students through a dialogic-practical work approach to facilitate their physics learning.

2.10.2 Dialogic theory

Bakhtin (1986) introduced the concept of dialogism. Bakhtin (1986) contends that everyone can resist, confront, and make personal meaning of social exchange. According to Bakhtin (1986), language is a living process made up of various voices that are in conflict with one another, voices that are transient, real, and fictitious, and that emerge through social contact. The utterance (written and oral), which is defined as a distinct and one-time occurrence that marks a link in the chain of discourse, is the basic building block of speech and communication. It always reacts to previous utterances and waits for a response. In this case, the utterance is dialogical as long as the response defines the unit. Bakhtin (1986) contends that the potential for being answered is the first and most significant test of whether an utterance is decisive. The utterance then symbolizes the unity of a social relationship that evolves inside and via language. This relationship transmits, materializes, and recreates human history.

Meaning is extracted from an endless and constant exchange of ideas between the speaker and the listener, otherwise, utterances would be worthless (Calcagni & Lago, 2018; Teo, 2019). Language (the spoken or written word) and its associated tone, sound, and body language all play a vital role in interpreting an utterance's meaning. Bakhtin's idea of 'dialogical meaning-making allows students to participate in the development of socially constructed knowledge through dialogic exchange (Lyle, 2008, p.225). Bakhtin argues that meaning involves conflicting and interacting with several voices. As a result, rather than information being passed down from speaker to speaker, knowledge is generated between them. In this view, language is not just an act performed by a person, but also a social phenomenon that is shaped by otherness (the perspectives of others).

In this Bakhtinian perspective, every statement is dialogical in the sense that it is constantly addressed and expects a response. In a classroom setting, students should engage in social interactions with each other or with the teacher to acquire knowledge (Reznitskaya & Gregory, 2013, p. 110). Therefore, the current study is underpinned by Bakhtin's concepts of meaning-making processes in dialogic-practical work. The researchers agreed that each utterance was dialogic. To extract meanings from students' utterances, they should be involved in student-student interaction or student-teacher interaction during practical work. The present study converges Bakhtin's and Vygotsky's works to engage students in practical investigations with one another. It also engages students to solve scientific problems, debate social issues, and evaluate evidence provided by others. Bakhtin and Vygotsky value social interaction, active engagement, and negotiation instead of passively accepting, assimilating, and acquainting knowledge from a higher authority, such as a teacher or a textbook.

2.11 Conceptual Framework of the study

The principles obtained from the sociocultural viewpoint of teaching and learning are briefly introduced in the above section. It additionally provided a general review of dialogic teaching features discussed in the literature. Sociocultural perspectives emphasize spoken language. In science classes, dialogic theories govern the consideration of many voices, viewpoints, and ideas. This part provides a critical overview of successful practical work models to formulate a conceptual framework for dialogic-practical work. The current study used a dialogic-practical work strategy in physics labs while relying on the aforementioned theoretical lenses to investigate its influence on students' learning outcomes in physics. The dialogic conceptual framework featured a sequence of lessons. Using dialogic-interactive communication, we invited students to debate how to carry out tasks and interpret results. Additionally, students had to define problems plan experiments, describe data, and communicate findings to one another. We anticipated that these activities would result in interactions among students, which would lead to physics learning.

The present study hypothesized that every possible type of interaction would not produce the desired outcomes. This study hypothesized that dialogic-interactive talks paired with exploratory talks would lead to data-supported explanations and demands for justification, thus improving students' scientific argumentation skills. All intended physics learning outcomes are produced by the hypothesized mediating mechanisms together. Very few studies investigated the correlations between epistemic beliefs about physics, science process skills, mechanics achievement, and attitudes towards physics. For example, Abungu et al. (2014) investigated the effect of the science process skills teaching approach on students' achievement. The results revealed that this approach significantly affected students' achievement. Several studies found that students with a positive attitude toward science are more inclined to excel in the science subjects being taught than those with a negative attitude (Cheng & Wan, 2016; Kousa et al., 2018; Musengimana et al., 2021).

According to these studies, there was a positive correlation between students' achievement and their attitude toward science subjects. For instance, Shana and Abulibdeh (2020) found a positive relationship between attitudes toward practical work and students' science achievement. Cheng and Wan (2016) revealed that attitudes toward science in general and science self-efficacy, interest in learning science, utilitarianism, performance, and success motives, in particular, showed favorable correlations with students' science achievement. A study by

Taslidere (2020) found that previous achievements and previous physics course grades contributed 60.6% to students' current accomplishments. However, physics interest, motivation, gender, and perceptions of teacher-directed activities collectively accounted for a small variance in students' achievements.

Ibrahim et al. (2019) discovered a negative and substantial link between students' physics achievement and attitudes toward the subject. They explained that students who have positive attitudes toward physics have lower grades in the subject. In contrast, students with a poor attitude to physics tend to do well in the subject. It suggests that physics achievement and physics attitudes are unrelated. Without a positive outlook toward physics, students may receive high scores in the subject, and vice versa. Some studies have focused on the relationship between students’ attitudes toward physics and science process skills. Zeidan and Jayosi (2015) discovered a favorable correlation between Palestinian secondary school students' attitudes toward science and their development of science process skills. The association between students' attitudes toward science and their science process skills was 0.69. This study also revealed a substantial variation in science process skills in favor of females, while attitudes toward science did not differ by gender. Cheng and Wan (2016) also looked at the connection between students' test results and epistemic views. They discovered that students from Taiwan, Singapore, and the Mainland of China have highly developed scientific epistemological beliefs. The Taiwanese students scored just a little higher than the Singaporean and Mainland Chinese students.

Liang et al. (2023) examined the influence of epistemic beliefs on Academic Achievement in an Online Collaborative Learning Context for College Students. The results of a survey of 503 college students participating in online group collaborative learning showed that college students' Internet-specific epistemic beliefs in online collaborative learning contexts significantly and positively predicted academic achievement. Sadi and Dağyar (2015) investigated the relationship between students' epistemic views and learning conceptions. These scholars stated that sophisticated beliefs tend to have higher learning conceptions, whereas those with naive beliefs tend to have lower learning conceptions (such as memorizing, preparing for exams, and calculating and practicing). This indicates that students' epistemic view determines their inclination to learning approaches.

In addition, Sadi and Dayar (2015) found that students' epistemic beliefs about justification and development as well as their higher-level conceptions of applying, understanding, and seeing things in new ways were significantly and positively correlated with students' self-efficacy in learning biology. However, there was a strong but unfavorable relationship between source and certainty and students' self-efficacy. Additionally, calculations and practice were strongly and adversely linked to students' epistemic beliefs regarding knowledge sources and certainty. On the other hand, there was a strong and positive correlation between exam preparation and epistemic beliefs such as justification and development. This finding focused only on the role of epistemic beliefs in students' preference and engagement in a given instructional strategy. However, they hardly mentioned the effects of a given instructional strategy on students' development of sophisticated beliefs.

According to Cheng and Wan (2016), the drive for learning science has a complex relationship with science performance, science learning approaches, scientific epistemic views and achievement, and scientific epistemic views and interest in learning science. Cheng and Wan

(2016) suggested that further research is needed to differentiate the relationship between attitudes toward physics and students' achievement. There is no conclusive evidence that attitudes, particularly self-efficacy, affect students' achievement. The present study indicated the hypothetical diagrammatic correlation between epistemic beliefs about physics, science process skills and attitudes toward physics and mechanics achievement as shown in Figure 2.1.

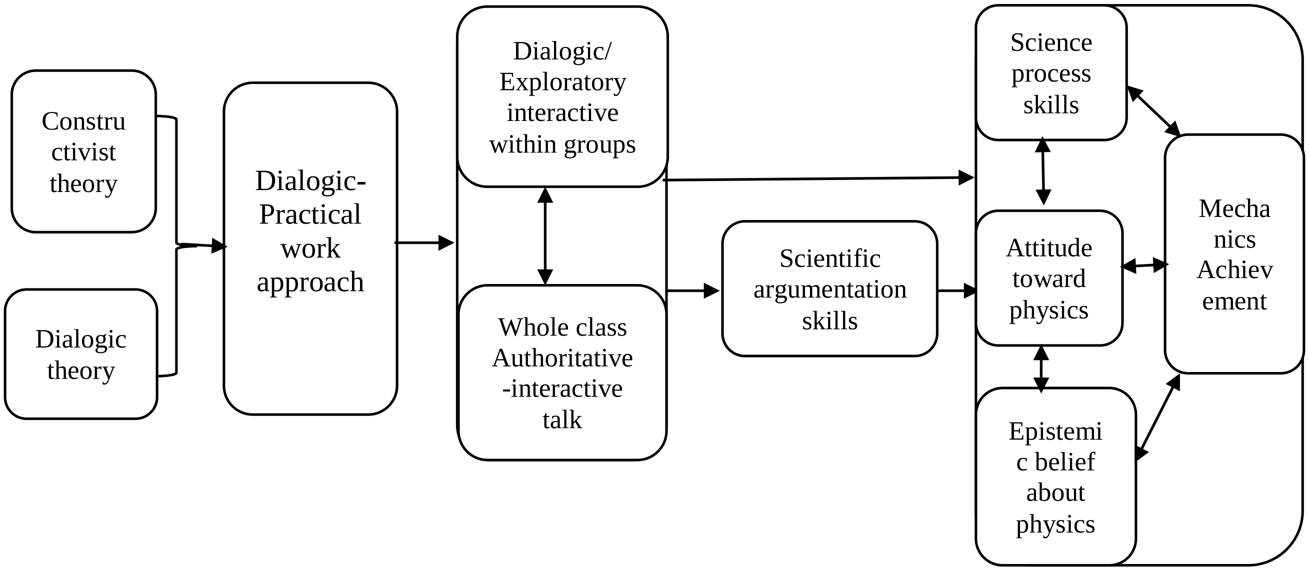


Figure 2.1 Conceptual Framework of the study

CHAPTER 3: RESEARCH METHODOLOGY

Introduction

This chapter establishes the research methodology for the present study. The research methodology describes how a dialogic-practical work style affects secondary school students' physics learning outcomes. The chapter opens with a general review of the philosophical and theoretical viewpoints that guide the present study methodology. It justifies choosing a mixed methods design. In this chapter, research methods, data-gathering strategies, and sampling methods are thoroughly covered. Furthermore, various triangulation techniques, trustworthiness standards, ethical issues, and the researcher's role will also be discussed. Finally, a thorough discussion of the methods employed to ensure the reliability and validity of the instrument, and the pilot test processes was discussed in detail.

3.1 Philosophical Paradigms

Creswell (2014) defines paradigms as “a general philosophical orientation about the world and the nature of research that a researcher brings to a study” (p. 35). At every stage of the research process, researchers' philosophical worldviews or paradigms serve as a guide to help them make cogent, moral, and theoretically sound decisions. Positivism, post positivism, constructivism, and pragmatism are the four main paradigm types used in educational research (Creswell, 2014). Positivism holds that social reality is organized and that there is an "out there" reality just waiting to be discovered. Regardless of the research process, there is a known, recognizable, and demonstrable causal link between variables (Hesse-Biber & Leavy, 2010, p. 8).

Post-positivists contend that there is an objective reality (similar to positivists), however, only imperfectly and probabilistically apprehensible (Creswell, 2014). Post-positivists believe science is theory-laden. Science relies on wide, well-researched scientific theories, rules, or models to question ideas or make sense of events. By applying deductive logic and hypothesis testing, post-positivists can justify data and prove or disprove the theory, but not in absolute terms (Hesse-Biber & Leavy, 2010). A researcher with a post positivist paradigm begins with a theory and engages in hypothesis testing and measurements. In this paradigm, the researcher collects data that either supports or refutes the existing theory and then makes necessary revisions. The researcher also believes that measurement is always uncertain and that taking more measurements can minimize errors.

Interpretative paradigms assert that meaning cannot exist without human interpretation. In this viewpoint, the only way to comprehend social reality is to extrapolate the meaning individuals attach to interactions, behaviors, and things (Creswell, 2014; Hesse-Biber & Leavy, 2010). Researchers who operate within interpretative traditions value experience and perspective as significant sources of information. For interpretive researchers, the world exists, but various people interpret it in vastly different ways.

The pragmatic paradigm supports the use of a variety of methodologies to address research questions. Pragmatism's focus on *what works* makes it suitable for use in mixed-methods studies that combine qualitative and quantitative assumptions into a single investigation (Tashakkori & Teddlie, 2010). Additionally, it gives researchers the chance to select from a variety of available study approaches, tactics, and processes to analyze the problem at hand. It opens the door to a variety of approaches, paradigm pluralism (including both objective and subjective knowledge), various presumptions, and various approaches to data gathering and analysis.

Therefore, the current study is informed by the pragmatic paradigm and thus flexibly use the strengths of both post positivist and interpretivist worldviews. The researcher in the current study favor the pragmatist position based on the belief that there is a single reality that may be perceived by different observers in a variety of ways. Therefore, a pragmatic paradigm is best suited to mixed methods research (Tashakkori & Teddlie, 2010). The pragmatic worldview offers the mixed methods researcher an opportunity to choose multiple research methods, techniques, and procedures to understand the problem. In the present study, there are quantitative and qualitative research questions.

The quantitative research questions aim to investigate the possible causal relationships between the dialogic-practical work approach and students' physics learning outcomes. The qualitative research question explores students' and teachers' dialogic talk moves during dialogic-practical work sessions. It requires getting an in-depth understanding of students' views about dialogic-practical work approaches and providing different quotes as evidence of multiple perspectives on the same event. In answering these two broad categories of research questions, both quantitative and qualitative research methods are needed. Therefore, the current research employs a mixed research methods.

3.2 Research Methods

The current study determined how the dialogic-practical work method affected secondary school students' learning outcomes in physics. It was necessary to use both quantitative and qualitative methods to address the two major research problems in this study. Researchers might blend quantitative and qualitative research perspectives, techniques, data types, and analyses to develop a nuanced and thorough understanding of the research problem (Creswell & Plano Clark, 2018; Plano Clark & Ivankova, 2016). In this respect, employing mixed methods research is important. It also permits the use of methodological eclecticism, paradigm pluralism, emphasis on a continuum rather than a collection of dichotomies, iterative and cyclical research techniques, and focus on diversity at all levels of the research enterprise (Tashakkori & Teddlie, 2010). Researchers can gather both quantitative and qualitative data through mixed-methods research. These data incorporate several sorts of information to enhance our comprehension of the research questions.

It also helped the researcher investigate the consistency of findings generated from quantitative data collection instruments (written tests and questionnaires) and qualitative data collection instruments (laboratory video recordings and interviews) about the problem. Findings from qualitative and quantitative data complement one another to address various aspects of the phenomena under study. The researcher understood the impact of dialogic-practical work on secondary school students' learning outcomes in physics by integrating results from both modalities. In the current study, the researcher evaluated the impact of dialogic-practical work and recipe-based practical work on students' learning outcomes in physics. As a result, the researcher adopted a non-equivalent pretest and posttest quasi-experimental design.

Quasi-experimental research is undertaken to assess the efficacy of an educational intervention in field situations where random assignment is impossible or not present (Price et al., 2015; Creswell, 2014). In this design, the treatment group and the comparison group were selected without random assignment. In this study, the treatment and comparison groups were selected and assigned using a lottery system. In this study, the treatment group was exposed to a dialogic-practical work approach and the comparison group used a recipe-based practical work approach to perform the same mechanics experiments. The present research was to determine whether there were any differences in the pre-and post-test mean scores between the dialogic and recipe-based practical work groups.

Table 3.1 shows the intervention design. The researcher assigned the intact classes to dialogic- and recipe-based practical work groups. Before the interventions, both groups took pretests (O_1 and O_1). After eight weeks of involvement in practical work, both groups took post-tests (O_2 and O_2).

Table 3.1 Two quasi-experimental Non-Equivalent group design

Groups	Pre-test	Teaching approach	Post test
Treatment Group	O_1	Dialogic-Practical work	O_2
Comparison Group	O_1	Recipe-based practical work	O_2

The current study employed many case studies to address qualitative research questions. In a multiple case study, "each unit of analysis implies a different kind of data collection, a different focus of data analysis, and a different level at which statements about findings and conclusions would be made" (Patton, 2014, p. 228). In the present study considered dialogic-practical work sessions as composed of different segments (e.g., student-student dialogic talk moves, student-teacher dialogic talk moves, and students’ perceptions). A multiple case study approach was used to understand student-student interaction moves and student-teacher interaction moves based on preset dialogic talk moves frameworks. Through this design, we explored how students involve in dialogic talk while doing dialogic practical work. It is used to collect and analyze qualitative data to develop a more in-depth understanding of students' dialogic-talk moves.

Three units of analysis are used: (1) student-student dialogic talk moves, (2) teachers' dialogic discursive moves, and (3) students' perceptions of dialogic-practical work. The qualitative data for the two units of analysis were collected from small group dialogic-practical work video recordings. For the third unit of analysis, semi-structured interview data were collected from four secondary school students. These students were selected systematically from different achievement levels to understand their views about dialogic-practical work.

3.3 Research Designs

The present study gathered both quantitative and qualitative data simultaneously. Both data were given similar weights and viewed as equivalent sources of information for the study. The current investigation is best suited to a convergent parallel mixed-methods design. It also enables the researcher to use the best aspects of both quantitative and qualitative data collection (Creswell, 2014). The study's mixed research methods design made it possible to look at how the dialogic-practical work approach affected students' learning outcomes in physics. Qualitative and quantitative data are collected in parallel and analyzed separately. The researcher merges the findings obtained by confirming or disconfirming the results during interpretation sections as shown in Figure 3.1.

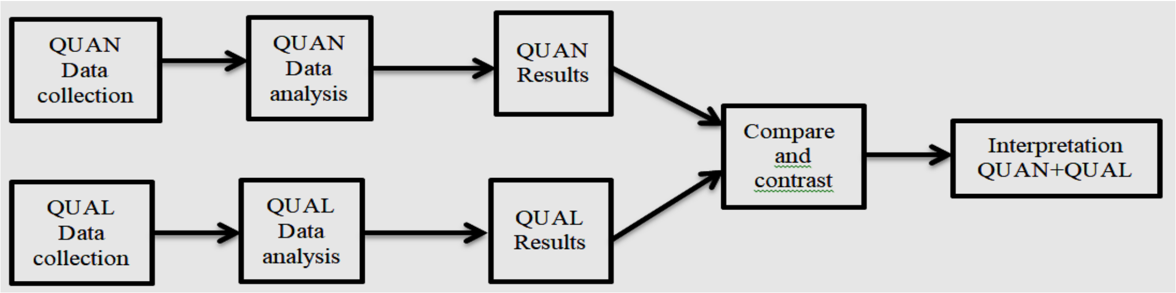


Figure 3.1 Concurrent triangulation design of data interpretation

3.4 Research site, Target Population and the participants of the Study

The research site for this study was Bahir Dar city administration, Ethiopia. Bahir Dar is the capital city of Amhara Regional state. This research site was selected purposively due to its proximity and easy access to get enough data. Bahir Dar City administration has five governmental secondary schools. All these secondary schools have equivalent facilities such as laboratory rooms, equipment, apparatus, ICT rooms, and libraries. Students have the same socioeconomic status. The target population of the present study was governmental secondary school grade 11 natural science students in Bahir Dar, Ethiopia. First, two secondary schools were selected using the lottery method. Two different secondary schools were selected to minimize data contamination due to the communication between the groups which in turn influence how both groups score on the outcomes.

Second, from these two different secondary schools, one intact class from each secondary school was once more selected using lottery technique from the available grade 11 natural science classes. Finally, one intact class was randomly chosen to be in the treatment group and the other to be in the comparison group using a lottery system. A total of 91 secondary school natural science students with females 41 and males 50 with an overall mean age of 18 participated in the study. Among them, 45 students were assigned as a comparison group and 46 students were grouped as a treatment group as indicated in Table 3.2.

Moreover, one physics teacher from each school was purposively chosen with the help of inclusion criteria of qualification and experience regarding teaching physics at the grade 11 level. All teachers had a bachelor's degree and had been working in secondary schools for more than 20 years. Students in the treatment and comparison groups were divided into two practical work sessions with the guidance of the classroom physics teacher to make it easily manageable as illustrated in Table 3.2. The students were further categorized into small working groups of mixed ability and gender to make the implementation of practical work more effective.

Table 3.2 Number of students classified by gender and practical work approaches

Practical work approaches	Sex		
	Male	Female	Total
Treatment Group	26	20	46 (50.6%)
Comparison Group	24	21	45 (49.4%)
Total	50 (55%)	41 (45%)	91 (100%)

3.5 Variables of the study

This study looked at how the dialogic-practical work approach affects secondary school students' physics learning outcomes. In this study, physics learning outcomes represent students' epistemic beliefs about physics, achievement in mechanics, science process skills, and attitudes toward physics scores. The implementation of a dialogic-practical work method can serve as a pedagogical strategy in physics labs to improve students' learning outcomes in physics. The development of students' scientific argumentation skills over time was also examined.

Independent variable

This study employed a quasi-experimental design. The study had one independent variable with two levels: Dialogic-practical work approach and Recipe-based practical work approach. A dialogic-practical work approach and a recipe-based practical work approach were applied to the treatment group and comparison group respectively. The present study compares the mean scores obtained from these two approaches.

Dependent variables

In this study, there were five dependent variables. These are mechanics achievement (DV1), science process skills (DV2), attitude towards physics (DV3), epistemic beliefs about physics (DV4), and scientific argumentation skills (DV5).

3.6 Data collection Instruments

This study examined the effects of a dialogic-practical work approach on secondary school students' physics learning outcomes. To determine the impact of the intervention on the dependent variables: the mechanics achievement test, science process skills test, physics attitudes scale, and physics epistemic beliefs scale were administered before and after the intervention. These instruments were adapted slightly from standardized instruments. The quantitative data were collected from secondary school students using the Mechanics Achievement test (MAT), Physics Process skills test (PPST), Physics Attitudes Scale (PAS), and Physics Epistemic Beliefs Scale (PEBS). Furthermore, Laboratory Assessment Rubrics (LAR) and ASAC observation protocols were used to collect data about students' practical skills and scientific argumentation skills respectively.

3.6.1 Validity and Reliability of instruments

The current study was informed by a mixed research method that incorporates both quantitative and qualitative data. When adapting and revising instruments, the researcher considered the relevance of each instrument to particular research questions. The researcher should also assure the quality of the instruments to bring the intended results. To ensure the quality, the validity and reliability of the instruments were checked. Instrument reliability refers to its ability to repeat measurements with the same outcome (Taber, 2018). Validity represents the extent to which an instrument measures what it claims to measure and how well it measures something.

The researcher attempted to build validity starting with data collection through data analysis and interpretation. In this study, quantitative data collection instruments, such as the Mechanics achievement test (MAT), Physics process skill test (PPST), Physics attitudes Scale (PAS), Physics Epistemic Beliefs Scale (PEBS), and qualitative data collection instruments such as semi-structured interviews, group work discussion video recordings, and laboratory report documents were prepared. The data collection instruments were adapted from other studies. In the current study, the researcher followed certain steps to ensure the validity and reliability of these instruments. Firstly, the theoretical constructs were properly operationalized, thereby showing clearly what they mean, how they can be measured, and what outcomes they can produce. Thus, constructs such as mechanics achievement, science process skills, attitudes toward physics, and epistemic beliefs about physics were defined.

Second, the researcher prepared a test blueprint to ensure that the course objectives are adequately sampled from the test items. The researcher collected an initial pool of items from standardized instruments. The researcher checked whether the tests adequately covered different content areas, skills, and behaviors. The researcher also decided the number of items to be incorporated depending on the importance of each practical work topic and the level of the cognitive domain. A review of the appropriateness and levels of cognitive domains was conducted by experienced physics lecturers and high school physics teachers. Additional care was taken to minimize the two major threats to construct validity, such as construct underrepresentation and construct irrelevant variance. Fair numbers of items were allocated to each practical work topic to minimize construct underrepresentation.

3.6.1.1 Mechanics Achievement test (MAT)

This test investigated the effect of dialogic teaching intervention in physics practical work on students' mechanics achievement. To assess secondary school students' mechanics understanding and rigorously quantify their mechanics content knowledge, the researchers used a Mechanics Achievement Test (MAT). A majority of the items focused on topics such as measurement, kinematics, dynamics, work and energy, conservation of momentum, torque, liquids at rest, and simple pendulums. The Mechanics Achievement test was slightly adapted from standardized instruments such as the Force Concept Inventory (Hestenes et al., 1992), Force & Motion Conceptual Evaluation (Thornton & Sokoloff, 1998), Mechanic Baseline Test (Hestenes & Wells, 1992), Energy and Momentum Conceptual Survey (Singh & Rosengrant, 2003), and Test of Understanding Graphs in Kinematics (Zavala et al., 2017).

The researcher prepared additional items on topics not covered by the standardized instruments. A total of 25 multiple-choice questions were prepared. Most of these standardized instruments were developed to analyze freshman university students' introductory physics understanding in English-speaking nations. Hence, these items were modified to make them easily understandable by secondary school students. Two physics college lecturers reviewed the mechanics achievement test for appropriateness and representativeness. Based on the recommendations and comments provided by these lecturers' certain items were revised and paraphrased and some items irrelevant to the construct being measured were removed. As much as possible, items were fairly distributed (such as easy, medium, and difficult) to counteract construct-relevant variance issues. Before the instruments were duplicated for a pilot study two physics lecturers evaluated the appropriateness, clarity, readability, attractiveness, and difficulty level of each item for the participants.

Finally, the researcher considered these comments and suggestions. These items were piloted with 65 grade 12 natural science students from non-participating schools. The pilot data were analyzed using Statistical Package for Social Sciences (SPSS) computer software version 26. Students' answers were split into two halves, "1" representing correct answers and "0" for wrong answers, to analyze test reliability coefficients. For such types of items, the researcher used the Kuder-Richardson (KR-20) method to calculate reliability coefficients (Leech et al., 2005). The overall alpha coefficient for these items was 0.74. Since the questions were organized from various standardized instruments and additional items were prepared by the researcher, the 25 items were named the Mechanics *Achievement Test (MAT) (See Appendix A)*. MAT was administered to the recipe-based and dialogic-practical work groups both before and after the interventions.

3.6.1.2 Physics Process skills test (PPST)

The present study aimed to investigate the effect of dialogic-practical work on secondary school students' science process skills. For this purpose, 20 multiple-choice items were adapted with only small modifications from various standardized instruments (e.g., Dillashaw & Okey, 1980; Shahali et al., 2017; Zeidan & Jayosi, 2015). The instrument consisted of items focused on observation, classification, inferences, predictions, controlling variables, operational definition, formulating a hypothesis, setting up experiments, drawing conclusions, interpreting data and graphs, and drawing graphs. The items were piloted with 63 grade 12 natural science students from non-participating secondary schools. The test's Kuder-Richardson reliability coefficient was 0.79. This instrument was named the *Physics Process Skills Test (PPST) (See*

Appendix B). The treatment and comparison groups both took this test before and after the intervention.

3.6.1.3 Physics Attitudes Scale (PAS)

This instrument is used to examine how students' attitudes toward physics were affected via dialogic-practical work approach. For this purpose, a 30-item Likert-type questionnaire was adapted from the standardized instrument developed by Kind et al. (2007) and Kaur and Zhao (2017). The responses were graded on a 5-point Likert scale, where 5= strongly agree was the highest possible score and 1=strongly disagree was the lowest. Two Ph.D. physics candidates and a physics educator edited the English version of the attitudes toward physics questionnaire. All feedback and suggestions were considered during the instrument's preparation. The researcher translated the English version of the questionnaire into Amharic to make them easily understandable by secondary school students.

Afterward, the Amharic version was reviewed by two physics lecturers. Two other physics lecturers evaluated whether the statements' purpose was suitable for the measuring instrument if the statements were understood by the participants, whether all statements in the measuring instrument were readable, whether the questionnaire was attractive, and whether each item was appropriate for the participants' level of difficulty. Finally, the researcher incorporated the comments and suggestions into the overall layout of the test paper. These included the size of the font, the sufficiency of the workspace for learners, correct language usage, and clarity of instructions. This questionnaire was administered to 65 grade 12 natural science students for piloting purposes from a non-participating school. The Cronbach alpha coefficient of a questionnaire with 30 items was calculated and the overall reliability coefficient was 0.81. This questionnaire is named as *Physics Attitudes Scale (PAS) (See Appendix C).*

Moreover, this instrument had five dimensions: enthusiasm for physics (6 items), physics learning (6 items), practical work (6 items), physics teacher (6 items), and future vocation (6 items). Some authors argue that instruments having subscales (or dimensions) with a high overall alpha do not necessarily imply that all items are strongly related (Taber, 2018). The alpha values for enthusiasm for physics, physics learning, practical work, physics teacher, and future vocation were 0.70, 0.57, 0.66, 0.54, and 0.64 respectively. Among the dimensions, four had Cronbach alpha values below the rule of thumb value (0.70). The researcher kept using these dimensions, because, for a multi-scale instrument with a few items, alpha values lower than 0.70 should be taken as a satisfactory instrument (Taber, 2018).

Among Taber's (2018) studies, for instance, there are five items of interest in school science with Cronbach alpha values of 0.50, while the interest in domestic activities had three items with 0.45. Hillman et al. (2016) added that the dip in Cronbach’s alpha coefficient was slightly below the benchmark of 0.70 dependent on the number of items. Indeed, adding more items leads to higher Alpha values. The Physics Attitude Scale was administered to the treatment and comparison groups before (pretest) and after (posttest). For the purpose of examining the change in attitudes toward physics, the mean post-test scores of the two groups were compared.

3.6.1.4 Physics Epistemic Beliefs Scale (PEBS)

The fourth quantitative instrument was the Physics epistemic beliefs scale. This instrument assessed secondary school students' change in epistemic beliefs about physics before and after the dialogic-practical work intervention. For the current study, 30 items with a 5-point Likert scale were adapted from a standardized instrument designed by Lin and Tsai (2017) and Kaur and Zhao (2017). This scale was translated into Amharic to make it easily understandable by students. It was piloted by administering it to 63 grade 12 natural science students from non-participating secondary schools. As a result, the overall reliability coefficient of the questionnaire became 0.82. These 30 items were further paraphrased, modified, and kept ready for use during the intervention. This instrument is named as *Physics Epistemic Beliefs Scale (PEBS) (See Appendix D).*

The instrument had six subscales: sources of knowledge, certainty of knowledge, justification for knowing, development of knowledge, and purposes of knowing. The alpha values of the sources of knowledge (5 items), certainty of knowledge (5 items), development of knowledge (5 items), justification for knowing (5 items), purpose of knowledge (5 items), and purposes of knowing (5 items) were 0.64, 0.57, 0.58, 0.74, 0.70, and 0.66 respectively. Among the six subscales, the sources of knowledge, certainty of knowledge, and development of knowledge had an alpha value of less than 0.70. Scholars argued that most often the subscales of epistemic beliefs in various instruments have low internal consistency coefficients (DeBacker et al., 2008; Leal-Soto & Ferrer-Urbina, 2017; Paechter et al., 2013).

For example, Paechter et al. (2013) developed an epistemic beliefs questionnaire, called the Oldenburg Epistemic Beliefs Inventory. This instrument was administered to 471 university students in Germany and the Cronbach alpha values of the source of knowledge were 0.50, the structure of knowledge was 0.56, the control of learning was 0.57, and the speed of learning was 0.76. The Physics Epistemic Beliefs Scale (PEBS), a 30-item questionnaire, was maintained for interventional reasons. Each of the groups received this questionnaire both before and after the intervention.

3.6.1.5 Students’ scientific argumentation skills

To evaluate the students' scientific argumentation skills, four small group discussion videos were recorded in the lab rooms. Only the dialogic-practical workgroup discussions were recorded. This study utilized the ASAC observation protocol revised by Walker et al. (2019) to assess students' scientific argumentation skills (*see Appendix E*). This rubric contains eighteen items with six items each examining the conceptual, epistemic, and social components of scientific argumentation skills. Each item must be rated on a scale from 0 (Not at all) to 3 (Often). Zero was the lowest possible score and 54 was the highest possible score.

The details of the ASAC observation protocol was presented in section 2.6.1. This observation protocol was used to assess students' scientific argumentation skills throughout the intervention. Videos were scored by the researcher and a research assistant following training on the ASAC observation protocol. The training was conducted on simultaneous video scoring followed by discussion and resolution of score differences. Once the complete set of videos was scored, inter-rater reliability was established. Cohen Kappa's inter-rater reliability was .85.

3.6.1.6 Laboratory Assessment Rubrics (LAR)

Laboratory Assessment Rubrics (LAR) were prepared to evaluate students' practical skills performance for each experiment. The rubrics were adapted from Gultepe and Kilic (2015) and Liew et al. (2019). The rubrics were used to assess students' practical skills throughout the dialogic-practical work interventions (*See Appendix F*). Twenty skills were organized into four domains, such as the domain of data design, execution, analysis, and evaluation. The items were scored as (0) very low, (1) satisfactory, (2) good, and (3) excellent. The minimum LAR score was zero while the maximum score was 60. Two physics educators and two physics teachers reviewed it to ensure its validity. While students conducted practical investigations at secondary schools, the researcher and a trained secondary school physics teacher observed and evaluated the work. The LAR's inter-rater reliability was 0.89, indicating high internal consistency and reliability. Creswell (2014) recommend that the consistency of the coding be in agreement at least 80 % of the time for good qualitative reliability. The LAR was used as an observation checklist to assess students' practical performance during dialogic-practical work.

3.7 Procedure of Data Collection

The data were collected from secondary school students in 2021. First, the researcher thoroughly analyzed practical activities available in students' physics textbooks and syllabi. Second, the researcher visited secondary schools in Bahir Dar town to assess the availability of equipment and apparatus. The researcher also assessed the opportunities and challenges of conducting practical activities in secondary school laboratories. The researcher talked with the physics instructors about the status of the research and how to move forward without altering the content of the courses. Before the interventions were implemented, the researcher administered a pretest of a mechanics achievement test, physics process skill test, attitudes scale, and epistemic beliefs scale on grade 11 secondary school students.

In both secondary schools, practical work utilization was low, mostly owing to infrequent teacher demonstrations and recipe-based practical work. In this study, the treatment group engaged in a dialogic practical work approach and the comparison group conducted a recipe-based practical work approach. Eight tasks from mechanics topics were chosen for each group. It included measuring objects' length, area, and volume; determining the density of objects, the Archimedes principle, the coefficients of friction, Newton's second law using Atwood's machine, conservation of linear momentum, the period of a simple pendulum, and equilibrium. These practical work topics were chosen for the following reasons. First, it was relatively easy to get practical work apparatus and equipment in secondary school laboratories. Second, students had extensive background knowledge of mechanics topics starting in the lower grades. Indeed, students might readily participate in dialogic teaching.

Therefore, both dialogic-and recipe-practical work approaches were new experiences for the participants. Indeed, three sample data were prepared for the two groups before the interventions (*see Appendix H*). The objective of the first sample data was to help students understand scientific data. It was intended to provide hints about how to handle measurement errors, treat anomalous data and the need to take the average of more than three measurements rather than a single measurement. Students were expected to understand that measurements are never the same because of uncertainty. The second data set focused on controlling variables in practical work. Students should know that controlling one variable at a time is essential to investigating the relationships between dependent and independent variables. The third activity helped students learn how to plot data on a graph. They were expected to understand the relationship between variables.

The researcher prepared separate laboratory manuals for the dialogic- and recipe-based practical work groups. With the exception of the pedagogical approach, significant care was taken to synchronize the laboratory manuals and practical activities as closely as possible to reduce validity threats. In both groups, the interventions were carried out by physics teachers and lab assistants with similar years of secondary school teaching experience. A dialogic practical work manual has been prepared based on dialogic teaching methods to enhance secondary school students' physics learning outcomes (*see Appendix I*). Students were divided into small groups for laboratory activities. This required them to articulate and defend ideas, inquire about and provide explanations, and question one another's perspectives on physics practical work.

The laboratory handbook for dialogic-practical work lists the specific objectives, the tools employed, and the leading questions. Many lab assistants and teachers in Ethiopian secondary schools adhere exclusively to lecture techniques. The teacher and the lab assistant who took part in the dialogic-practical work received five days (25 hours) of training sessions. This training's main emphasis was on the qualities of productive dialogic-practical work, how to put it into practice effectively, and how to guide student debate in lab sessions. In order to gain personal experience with its application, they participated in dialogic-practical work investigations. The students were divided into four-person mixed-ability and mixed-gender working groups. Students in the treatment group work on dialogic practical tasks with the support of the physics teacher and the lab technician.

Each student in a group engaged in dialogic-practical work should know what to do, understand why they are doing it, and positively contribute to the group's work. Everyone participates in debates and decision-making, has a meaningful role to play, is skilled at playing that role, and adds to them. While the students’ debate, record, and analyze data, the teacher should assess how effectively each group functions and provide tips and suggestions. Dialogic-practical work includes conceptualization, practical investigation, conclusion, and scientific explanation phases.

Conceptualization phase: The task was introduced at this phase, and leading questions were provided (*see Appendix I*). For directing students towards scientific practice, thoughtful guiding questions and suitable scaffolding activities were offered. Students determined their present comprehension level of the subject under study at this phase. For instance, sample open-ended and closed-ended questions were given to the groups to help them identify the variables that affect an object's ability to float or sink in a liquid. Each group debated whether or not an object's buoyancy is affected by its volume, size, weight, geometric shape, density, and the amount of liquid it contains. It was the teacher's duty to scaffold activities that allowed students to enhance their science learning objectives and argumentation skills through dialogic-practical work as they had not previously been explicitly taught how to debate (Cavagnetto & Hand, 2012).

All groups were urged to actively engage in discussion with one another and provide arguments based on the suggested questions. Students were not allowed to conduct activities in groups at this phase. Each group was required to devise a preliminary scientific argument (formulate a hypothesis). For example, group three students wrote the following hypothesis:

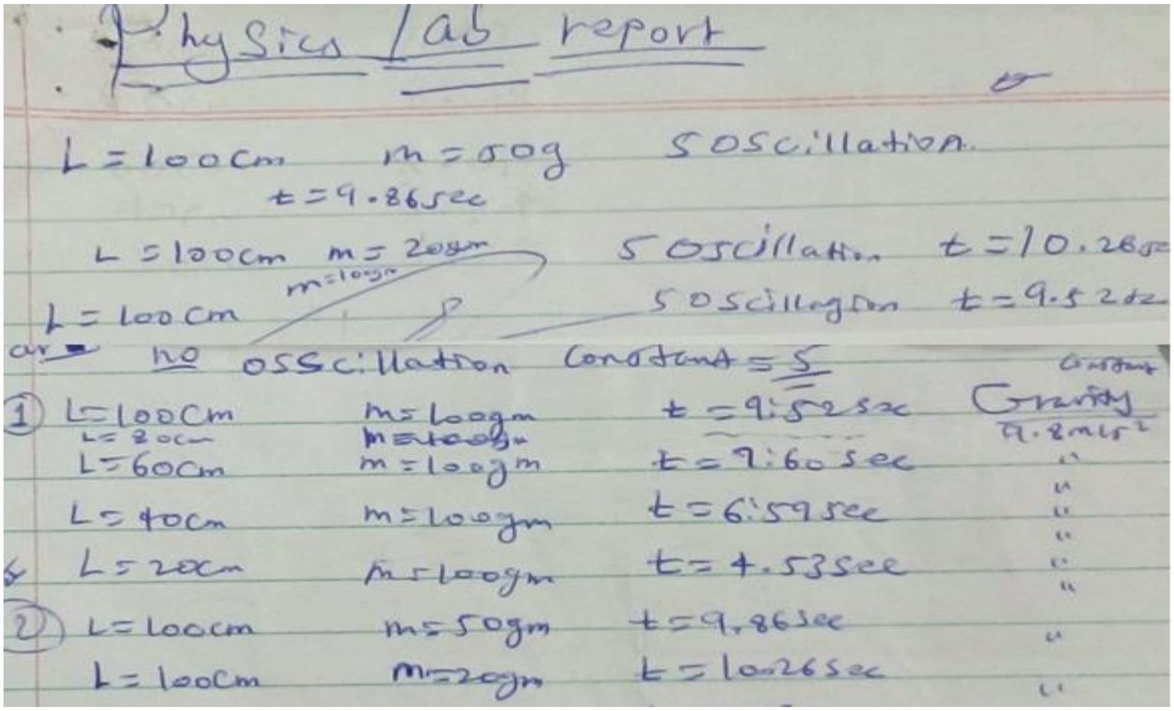
> *An object's density and liquid volume in the container determine whether it floats or sinks. Objects with a density greater than liquid will sink, while objects with a density less than liquid will float*.

Further, they added that:

> *When additional liquid is added to a container, an object that initially sinks in the liquid will float.*

The teacher purposely avoided giving students the right answers when there was a fundamental dispute among them. Students are invited to develop their own hypotheses instead, which will be verified later.

Investigation Phase: With just a little assistance from the teacher and the lab technician, students managed the data collection trials, the data processing, the interpretation, and the investigation's conclusions throughout this phase. Every group member was urged to contribute positively to the arguments and decision-making. Students were actively involved in debating with one another, making assertions and offering evidence to back them, erecting apparatus and equipment, gathering data, and analyzing data. While the students collected, analyzed, and interpreted data, the teacher and laboratory assistant regularly assessed how well each group was progressing and provided tips and reminders. Figure 3.2 displayed some of the data that a group of students had gathered by keeping the length constant (100 cm) while altering the mass of the object.



Physics lab report

L = 100cm m = 50g 5 oscillation.
t = 9.86sec
L = 100cm m = 20gm 5 oscillation t = 10.28
m = 100gm
L = 100 cm 5 oscillation t = 9.52
or no ossCillation Constant = 5
Constant
① L = 100Cm m = 100gm t = 9:52sec Gravity
~~L = 80cm~~ ~~m = 100gm~~ 9.8m/s²
L = 60Cm m = 100gm t = 9:60 sec "
L = 40cm m = 100gm t = 6:59sec "
L = 20cm m = 100gm t = 4.53sec "
② L = 100cm m = 50gm t = 9.86sec "
L = 100cm m = 20gm t = 10.26sec "

Figure 3.2 Sample data collected by a group of students

Conclusion phase. During this stage, students engage in discussion and debate within their groups. Each group thoroughly discussed the evidence before drawing its own findings and defended its claims against peer critiques. They evaluated whether the practical work findings supported or refuted their hypothesis. The students were requested to reflect on their findings and other groups challenged the presenters by posing questions. Students should make models, reinforce scientific viewpoints, compare outcomes, and amend their original hypotheses. *Scientific explanation phase*. At this stage, the teacher summarizes the key ideas of the topic. He contrasts students' prejudices and misunderstandings with scientific findings and hypotheses and draws clear parallels between everyday views and scientific views. By posing multiple questions, the teacher utilized interactive talk to lead the class toward the desired result. Students should have cumulative discussions. Each group was asked to write a laboratory report to be submitted in the next session.

A recipe-based practical work approach consists of five steps as shown in Figure 3.3. In the first stage, the teacher provides an overview of how the laboratory activity will be conducted. The manual provides the specific objectives, the theoretical background of the topic, data collection and analysis techniques, and interpretation techniques in detail to verify a pre-defined result. Students read the manual theory (see *Appendix J*). Then, the teacher thoroughly described the expected outcomes of the investigation to the students. Students were given instructions to follow step-by-step procedures throughout the practical work to arrive at the expected outcomes. Students were given detailed instructions by the teacher and the lab assistant while doing the experiment, gathering data, analyzing and interpreting data, and drawing conclusions.

Next, the students work in groups to collect data and record their observations or measurements in data tables supplied to them. The next step is data analysis. Students are guided by the teacher through the process of developing a conclusion based on data. This conclusion is then compared to the expected or known value. At the final stage of this approach, students communicate their findings and make connections to significant scientific concepts or principles. Following data collection and analysis, the teacher outlined the practical work results for the entire class. In this method, students are also not given the opportunity to share, critique, or revise arguments as part of an investigation. Each group wrote a report. The teacher evaluated the reports from each group and provided feedback to the students in the subsequent class.

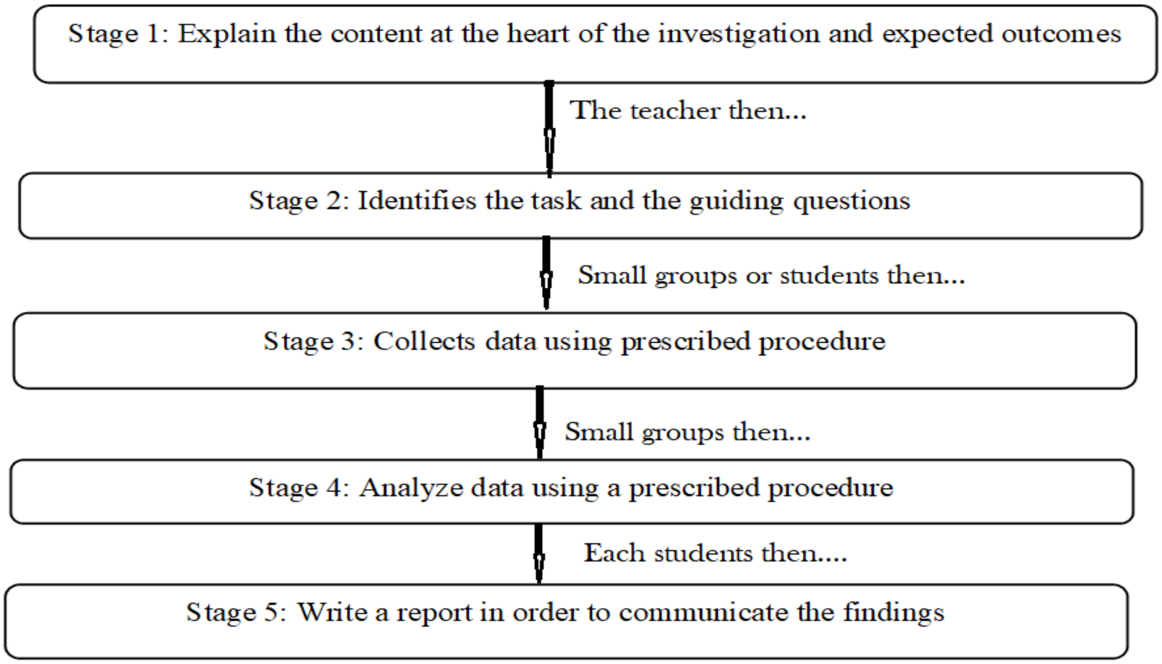


Figure 3.3 Steps for recipe-based practical work approach (Source: Walker et al., 2016, p. 1102)

At the end of the interventions, the mechanics achievement test, physics process skill test, physics attitudes scale, and physics epistemic beliefs scale were administered to the dialogic- and recipe-based practical work groups. These quantitative data were post-test scores. Likewise, the researcher used laboratory assessment rubrics to gather data about students’ functional skills performance improvement at the beginning, middle, and end of the intervention. There are four categories in the rubrics: experiment design, data analysis, graphing, and determining variables and hypotheses. Students' scientific argumentation skills data were collected using video recordings of dialogic-practical work sessions. Qualitative data were collected through video recordings and semi-structured interviews. Four episodes of video recordings were taken to explore students' and teachers' dialogic talk moves.

3.8 Data analysis Techniques

The research questions were addressed based on the quantitative and qualitative data analysis findings. The quantitative data were gathered at the start and end of the intervention, while the qualitative data were collected throughout the actual work sessions. In this section, quantitative and qualitative data analysis methods are presented.

3.8.1 Quantitative Data Analysis Methods

3.8.1.1 Students’ mechanics achievement (DV1)

To determine the effect of the dialogic-practical work approach on students’ mechanics achievement, data were collected using the mechanics achievement test. After cleaning the data and checking all the required assumptions for test statistics, an independent sample t-test and paired sample t-test were employed to analyze the mean difference in students’ pre-and post-test scores between and within the groups respectively. The normalized achievement gains for each group were calculated. Data were analyzed using Statistical Package for Social Sciences (SPSS) version 26.

3.8.1.2 Students’ science process skills (DV2)

To determine the effect of dialogic-practical work on students' science process skills, the pre- and post-tests were collected using a physics process skills test. After checking all the necessary assumptions, independent sample t-test and paired sample t-test were used to analyze the significant differences between pre-test and post-test mean scores in comparison to and within groups respectively. However, the pre-and post-test mean scores of the subscales of the science process skills for the treatment and comparison groups did not satisfy the assumption of normality and equality of variances. Hence, the Mann-Whitney U test was conducted to compare students' pre-test and post-test mean scores between groups. In addition, laboratory assessment rubrics were used to collect data about the effect of dialogic-practical work on students' change in science practical skills over time (beginning, middle, and end of the intervention). The groups' mean scores did not satisfy normality and variance equality assumptions. In this regard, the Friedman Test was used to compare the mean scores (repeated measures within the group) at three intervals of time.

3.8.1.3 Students' attitudes toward physics (DV3)

After considering all the presumptions, the independent sample t-test and paired sample t-test were employed to analyze the differences in the pretest and posttest scores for students' attitudes towards physics across groups as well as within the treatment and comparison groups. One-way ANOVA was used to analyze the differences in pretest and posttest scores between the treatment and comparison groups for the attitudes of students at different ability levels towards physics. The mean pre- and post-test scores of each subscale were also compared between the treatment and comparison groups using a one-way MANOVA analysis.

3.8.1.4 Students' epistemic beliefs about physics (DV4)

After considering all the assumptions, the pretest and posttest epistemic beliefs about physics mean scores were compared and contrasted between and within the treatment and comparison groups using independent sample t-tests and paired sample t-tests. A one-way MANOVA was used to analyze the differences in mean scores on the physics epistemic beliefs subscales between the treatment and comparison groups. Additionally, the students with varying achievement levels' mean difference between their epistemic beliefs about physics for the treatment and comparison groups were analyzed using one-way ANOVA.

3.8.1.5 Students’ scientific argumentation skills (DV5)

To assess the students’ progress in scientific argumentation skills, data was analyzed using the ASAC observation protocol. The treatment group’s progress in scientific argumentation skills through time was analyzed. The preliminary assumption checking indicated that the students’ mean scientific argumentation scores marked deviations from normality. Hence, a repeated measures Friedman test was used to analyze students’ improvement in scientific argumentation skills over time. While a Wilcoxon signed-rank test was used to see the possible differences between the different intervals of time.

3.8.1.6 Contribution of some dependent variables to mechanics achievement

After assessing the assumptions needed, the contribution of science process skills, attitudes toward physics, and epistemic beliefs about physics to the dialogic-practical work group’s students’ mechanics achievement score was analyzed using multiple linear regression.

3.8.2 Qualitative Data Analysis Methods

Qualitative data analysis answered two qualitative research questions (RQ7 and RQ8). The researcher wanted to understand in depth how the teacher and the students engaged in dialogic discourse during dialogic-practical work sessions. Additionally, the study looked into how the dialogue between the teacher and the students contributed to secondary school students' physics learning. Finally, it also explored secondary school students’ perceptions of dialogic-practical work.

3.8.2.1 Analyzing students' dialogic talk moves

First, the four small group dialogic practical work sessions were analyzed using a deductive analytical approach. This was in line with the guiding questions that framed the investigation from the start: interaction at linguistic and cognitive levels and content at linguistic and cognitive levels. The video recordings of thematic discourse analysis has already been divided into shorter episodes based on the phases of the activities students were engaged in. These episodes include the conceptualization phase, implementation phase, conclusion phase, and scientific explanation phase. The researcher has participated in collaboratively coding lesson transcription to create and construct a shared understanding and working definition of the essential discourse kinds applied to the data.

The analysis was conducted by iteratively identifying sequences where specific forms of dialogue were performed by the teacher or students. It was flexible enough to let additional categories emerge when needed. Twenty percent of the lessons were selected for the inter-rater reliability assessment. Each researcher separately coded each lesson in this subset, based on the predefined framework, and correlations were established. Inter-rater reliability reached a reasonable level with Cohen's Kappa of 0.80, with all disagreements detected, discussed, and settled. Students' dialogic moves were examined using Anderson and Enghag's (2017) analytical framework, which included three talk types: exploratory, disputational, and cumulative.

During the dialogic-practical work, students interacted with each other at several levels simultaneously. The analysis investigated how students engaged in such an interactive process and how the actual content was explained. Each talk type can be analyzed in terms of interaction and content aspects of students' practical work discourse patterns. Furthermore, this model helps to analyze discourse patterns of dialogic practical work process. It aimed to investigate how students speak to each other, how students act and make progress on the task. It also investigates what content is in focus and what topics are discussed, and what students' purpose does the talk sequence express. Small group discussions were studied in terms of disputation, cumulative, and exploratory talks.

3.8.2.2 Analyzing Teachers' dialogic talk moves

The second qualitative analysis aims to explore how the way teachers talk to, and with, their students can influence the dynamics of the teacher-student relationship. This study focused on a qualitative case study of an experienced teacher's attempts to implement dialogic-practical work in a secondary school physics laboratory. It was targeted to identify elements of dialogic talk moves implemented by a secondary school physics teacher during dialogic-practical work. This qualitative analysis explored how the teacher effectively guided the dialogic-practical work intervention. It aimed to extract the opportunities and challenges encountered by the teacher while employing dialogic-practical work approach. Furthermore, the themes that emerged from this analysis might agree or contradict the students' change in scientific argumentation skills over time. The present study used Christodoulou and Osborne's (2014) comprehensive model of epistemic operations to analyze teacher dialogic talk during dialogic-practical work. This framework identified teacher’s talk moves that characterize the construction of knowledge, evaluation, and justification.

Here the coding was conducted by categorizing epistemic operations as teacher-performed and teacher-prompted. Teachers would be required to introduce and engage students in a variety of discursive and reasoning practices. Dialogic talk moves initiated by the teacher can help students engage in epistemic practices. This subsection attempted to answer the question of what features of teachers’ dialogic talk moves or epistemic actions were present during dialogic-practical work sessions. Furthermore, it focused on how these dialogic talk moves promote epistemic practices of knowledge construction, justification, and evaluation of knowledge claims in secondary school dialogic practical work.

From the conceptualization stage to the whole-class conclusion, a step-by-step discourse analysis was conducted. The types of dialogic talk moves used by teachers to promote dialogic-practical work were identified and discussed. This qualitative analysis focused on teachers' dialogic talk moves and the way these talk moves helped students engage in the construction, justification, and evaluation of knowledge claims.

3.8.2.3 Analyzing students semi-structured interviews

The third qualitative analysis explored students’ perceptions about the dialogic-practical work approach. The present study conducted a semi-structured interview with four students who participated in the dialogic-practical work approach for eight weeks. Individual interviews lasted approximately 25 minutes. The researcher recorded all interviews with a digital voice recorder to facilitate smooth discussions. Creswell (2014) suggested that all words in recoding data must be transcribed to capture the interviewee's details. Hence, the researcher and a research assistant conducted verbatim transcription of the audio-taped data. To avoid bias and find accurate data, recorded data was re-listened to for each interview.

Second, a thematic analysis was conducted. This often involved *coding* words, patterns, or recurring responses, and separating them into labels or categories. In the third step, the researcher and the research assistant organized these codes into themes. Categorizing and coding entailed identification of words and segments in the transcripts that related to students' experience and perceptions about the implementation of the dialogic-practical work approach. Care was taken to ensure rigorous, systematic and methodical data analysis. Field notes were used to interpret meanings and fill in missing links in interview data.

Refinement of identified themes continued by holding consensus discussions with the research assistant during the data analysis phase (Creswell, 2012). A list of themes was made for each transcript. These themes were then clustered according to similarity. The list of themes was compared to the data and codes were assigned. The most descriptive wording for each theme was found, and it became the data theme. The data were then divided and organized into the relevant themes, categories and sub-themes using QDA Lite software.

3.9 Trustworthiness, Triangulation and Ethical considerations

In the previous section, we discussed the procedures to ensure the validity and reliability of quantitative instruments. This section discusses the trustworthiness criteria for qualitative studies. The next subsection will also describe techniques for establishing these criteria. The various types of triangulation and ethical considerations of the researcher were also considered to ensure the quality of the current study.

3.9.1 Trustworthiness Criteria

According to Lincoln and Guba (1985), trustworthiness is the degree to which an investigator can convince audiences that the results are worthwhile. There are four criteria to validate qualitative studies' trustworthiness. These are *credibility* (in preference for internal validity), *transferability* (in preference for external validity/generalizability), *dependability* (in preference for reliability), and *confirmability* (in preference for objectivity). *Credibility* is a criterion for establishing confidence in the truth of qualitative study findings (Creswell, 2014). The credibility of the current study was ascertained through prolonged engagement.

The researcher achieved this by co-teaching the course, conducting interviews, participating in all laboratory room observations (episodes of dialogic-practical work sessions), and assessing responses in tests, questionnaires, and interviews. The researcher was substantially engaged with the secondary school teachers throughout the research time. He established a positive rapport with them not only as participants in the study, but also as prospective professional colleagues. As a result, the researcher was able to build trust and friendship within the research environment. As a result of this prolonged involvement, the researcher was able to gain insight into students' understanding of the research topics, their science process skills levels, and their beliefs and views about the physics subject. This minimized student views distortions. Also, persistent observation resulted in a good deal of data from which relevant elements of the study could be identified and examined in detail. This increased the credibility of the study.

Transferability provides the ability to extrapolate conclusions from one specific transmitting context (the research setting) to another specific receiving context (other contexts with a comparable setting). Transferability was attained in the current study using a thick description of contextual factors such as the study site, participants, and the research setting. This detailed description allows readers to decide how confidently they can transfer the current study results to other situations. This description may help readers picture the scene and add a sense of shared experience to the conversation. When qualitative researchers, for instance, offer multiple viewpoints on a theme or describe the context the results become more plausible and deeper.

Dependability relates to the consistency of the findings if the study is replicated in the same (or similar) context (Lincoln & Guba, 1985). This has been described as the stability of data over time. Dependability relies on external auditing to evaluate the accuracy of results and whether interpretations and conclusions are supported by the data. The current study did not incorporate outside dependability audits. This is because the researcher holds that external auditors are not as immersed as the researcher in the study to provide interpretations consistent with the data. Lack of dependability criteria may be a limitation, though.

Confirmability is a way of ensuring that the findings of a study "are a function solely of the subjects (respondents) and conditions of the inquiry and not the biases, motivations, interests, and perspectives of the inquirer" (Lincoln & Guba, 1985, p. 81). In the current study, confirmability was addressed by relying on original sources of data such as video-recordings of dialogic-practical work sessions and semi-structured interviews with full transcripts of the latter. Transcripts were used to quote participants verbatim to support the researcher's interpretation of their views in physics laboratory room discourses. Hence, gathering a variety of data from various sources can increase the accuracy of the information and the outcomes. This makes it possible to fairly and simply replicate the study.

3.9.2 Triangulation

Creswell (2014) defines triangulation as the process of gathering data from several sources and assessing evidence from those sources to give the study more credibility. Various data sources were used to ensure triangulation, including test instruments, ASAC observation protocols, audio-recorded interviews, and video-recorded dialogic-practical work sessions. Furthermore, the current study applied multiple methods of data gathering and analysis as well as combined multiple research designs and paradigms. The current study, guided by pragmatic principles, utilized a combination of quantitative and qualitative research designs to enhance the quality of the study.

3.9.3 Ethical Considerations

Every stage of the research process—from choosing the research topic to performing research aims and interpretation and reporting study results—must be guided by ethical standards (Hesse-Biber & Leavy, 2010). It entails safeguarding study participants, building confidence with them, fostering research integrity, protecting institutions from misbehavior and improper behavior, and dealing with fresh, difficult issues (Creswell, 2014). The researcher should also address issues such as personal disclosure, authenticity, and credibility of the research report; the role of researchers in cross-cultural contexts and personal privacy. The researcher followed the recommendations provided by Creswell (2014).

First, the researcher received clearance from Addis Ababa University, Department of Science and Mathematics Education to access secondary schools and participants. The researcher discussed with Bahir Dar town administration education heads and secondary school principals about guarding against misconduct and impropriety. The secondary school principals provided the letter to the physics department head. A face–to–face discussion was held with the department head, grade 11 physics teachers, and laboratory technicians about what is planned to be done and the reasons behind practical work. The researcher provided sufficient information about the measures to prevent research participants from the pandemic and finally, a consensus was reached.

In the second step, the participants were contacted directly and told what the study's main goal was. The participants and researchers had open talks about the objectives, methods, potential benefits, and potential drawbacks of this study. The participants' confidence was strengthened and research integrity was promoted throughout the discussion. Before respondents provided any data, they had to sign an informed consent form agreeing to the terms of the study. The study's objectives and the advantages of participation were described in the informed consent form. Additionally, it featured guarantees for the participants' anonymity and their right to withdraw at any time. The researcher did not compel participants to complete the informed consent form when obtaining their participation for the study. The study only included willing participants, and they had the option to decline before, during, or after their initial participation.

The researcher discussed with the study participants in advance the purpose of the data and how audio and video data would be collected. During data analysis, the researcher used code names for participants and school settings to protect their privacy and anonymity. The researcher did not disclose any personal identities of the participants and avoided information that would harm the school and participants during reporting the research findings.

To ensure the credibility of the research report, the researcher avoided siding with participants and disclosed only positive results. During reporting, Creswell (2014) argued that the researcher may suppress, falsify, or invent findings to meet his/her or an audience's needs. In order to avoid these fraudulent practices, we conducted rigorous statistical analysis, and reported all the findings and perspectives. The procedures used in quasi-experiments may be a potential ethical issue. A comparison group might be adversely affected by not receiving the beneficial treatment. To counter this issue, the researcher devised two strategies. First, the discussion questions prepared for the treatment group were given as supplementary exercises. Second, at the end of the interventions, dialogic-practical work sessions were organized for the comparison group.

CHAPTER 4: RESULTS

Introduction

This chapter reports the analysis and results of the quantitative and qualitative data collected to address the research questions. Quantitative and qualitative data were collected through test instruments, questionnaires, rubrics, and semi-structured interviews for analysis and interpretation. Multiple assumptions about test statistics were evaluated to choose appropriate data analysis techniques. The first section of this chapter analyzes and reports findings regarding differences between groups in attitudes toward physics, mechanics achievement, science process skills, and epistemic beliefs about physics. Based on quantitative data, groups showed mean differences in mechanics achievement, science process skills, attitudes toward physics, and epistemic beliefs about physics. In the second section of the paper, qualitative data were transcribed, categorized, and themes identified. Moreover, the final themes were analyzed and reported.

4.1 Analyses and Results of Quantitative Data

The pretests about students' mechanics, science process skills, attitudes toward physics, and epistemic beliefs about physics were collected before the intervention started. Students were administered pretests to assess their baseline achievement, science process skills, attitudes toward physics, and epistemic beliefs about physics. After the intervention, the same tests and questionnaires were administered. These test scores were used to analyze the mean difference between the dialogic-and recipe-based practical work groups. Descriptive statistics of pre-and post-test scores of the treatment and comparison groups were displayed in Table 4.1.

Table 4.1 Descriptive statistics of pre-and post-test scores of the groups

			Pre-test scores		Post-test scores	
Learning Groups	N	Variables	Mean	SD	Mean	SD
Treatment	46	Mechanics Achievement	8.87	2.75	13.22	2.31
	46	Science process skills	7.41	2.43	10.83	3.01
	46	Attitude towards physics	3.22	0.32	3.90	0.41
	46	Epistemic beliefs about physics	3.16	0.27	3.76	0.22
Comparison	45	Mechanics Achievement	8.51	1.86	9.98	2.33
	45	Science process skills	7.60	2.07	8.87	2.61
	45	Attitude towards physics	3.24	0.26	3.44	0.48
	45	Epistemic beliefs about physics	3.15	0.26	3.31	0.27

Note: M= Mean, SD= Standard Difference.

4.1.1 Assumptions for Pre-and Post-test statistics

To choose which statistics to use most often two assumptions: the normality and homogeneity of variances must be checked beforehand. The test of normality was used to check whether the data was normally distributed or not. The normality of test score data was checked by employing visual inspection of graphs like histograms, Q-Q, and box plots. It can also be checked by evaluating the skewness and kurtosis values. Statisticians argue that skewness and kurtosis values less than ±1.0 are normally distributed (Field, 2013). Z-values can also be used to measure data normality. The z-scores are manually calculated using the formula Z= Statistics/Std. error. By the rule of thumb, if the absolute value of Z is less than 1.96 the test is normally distributed. On the other hand, if the Shapiro-Wilk output is significantly greater than .05, the test is normally distributed. Both the Z-scores and the Shapiro-Wilk output values were used to assess the normality test of the quantitative data.

The second assumption is the homogeneity of variance between groups. Levene's Test of Equality of Variances can be used to test the hypothesis of variance homogeneity. It determines if the variances of the two groups are substantially different. The homogeneity of variance assumption was met if the significance value was more than 0.05 (p >.05), which indicates that the variances were not statistically different from one another. In these situations, the t value and degrees of freedom in the row representing the expected equality of variances were taken into account. If *p* < .05, equality of variances was not assumed, then data disproved the supposition that variances were homogeneous.

In this subsection, the normality and homogeneity of variances for the pre and post-Mechanics achievement (MA), science process skills (SPS), attitudes toward physics (ATP), and Epistemic beliefs about physics (EBPs) mean scores were analyzed. Table 4.2 presents the skewness, kurtosis and z-values of the MA, SPS, ATP, and EBPs pre-and post-test scores.

Table 4.2 Test of normality for the MA, SPS, ATP, and EBP pre-and post-test scores

Variables	Skewness			Kurtosis			Shapiro-Wilk	
	Statistic	Std. Error	Z-Value	Statistic	Std. Error	Z-value	df	Sig.
Pre-MA score	0.05	0.26	0.29	-0.54	0.51	-1.04	86	.16
Post-MA score	0.03	0.27	0.11	-0.39	0.54	-0.72	78	.44
Pre-SPS score	0.14	0.26	0.54	-0.34	0.51	-0.67	86	.09
Post-SPS score	0.16	0.27	0.59	-0.39	0.54	-0.72	78	.43
Pre-ATP score	0.18	0.26	0.68	-0.42	0.51	-0.82	86	.46
Post ATP score	-0.32	0.27	-1.19	-0.55	0.54	-1.02	78	.13
Pre-EBPs score	0.12	0.26	0.45	-0.46	0.51	-0.90	86	.24
Post-EBPs score	-0.16	0.27	-0.59	-0.56	0.54	-1.04	78	.36

As indicated in Table 4.2, the absolute values of the skewness and kurtosis of the pre-mechanics achievement test scores (skewness = .05 and kurtosis = -.54) were less than one and the z-score (Z skewness= .19, and Z kurtosis= -1.04) were less than 1.96. Similarly, the absolute values of the skewness and kurtosis of the post-mechanics achievement, pre-science process skills, post-science process skills, pre-attitude towards physics, post- attitude towards physics, pre-epistemic beliefs about physics, and post- epistemic beliefs about physics mean scores were less than one.

Furthermore, the absolute value of the z-scores of the post-mechanics achievement, pre-science process skills, post-science process skills, pre-attitude towards physics, post- attitude towards physics, pre- epistemic beliefs about physics, and post-epistemic beliefs about physics mean scores was less than 1.96. Moreover, the Shapiro-Wilk outputs were used to check the assumption of normality of variances. The Shapiro-Wilk outputs of the mean scores for pre-mechanics achievement, $p = .16$; post-mechanics achievement, $p = .44$; pre-science process skills, $p = .09$; post-science process skills, $p = .43$; pre-attitude towards physics, $p = .46$; post-attitude towards physics, $p = .13$; pre-epistemic beliefs about physics, $p = .24$; and post-epistemic beliefs about physics, $p = .13$ were greater than .05.

These results revealed that the pre-and post- mechanics' achievement, science process skills, attitude towards physics, and epistemic beliefs about physics mean scores were normally distributed. Hence, the pre-and post-test scores of mechanics achievement, science process skills, attitude towards physics, and epistemic beliefs about physics satisfied normality conditions. The second assumption was checking variance equality. The Levene test checks variance equality. Table 4.3 shows Levene’s test for pre- and post-mean scores of mechanics achievement, science process skills, attitude towards physics, and epistemic beliefs about physics. Table 4.3 demonstrated that Levene's test results for the pre-mechanics achievement mean score, $F(89) = 2.90$, $p =.09$; the post-mechanics achievement mean score, $F(89) =.06$, $p =.81$; the pre-science process skills mean score, $F(89) = 2.08$, $p =.15$; and the post-science process skills, $F(89) =.06$, $p =.81$ were greater than .05. Additionally, the results of Levene's test for pre-attitude towards physics mean score, *F* (89) = 1.77, *p* = .19; post-attitude towards physics mean score, *F* (89) = 3.52, *p* =.07; pre-epistemic beliefs about physics, *F* (89) =.01, *p* =.96 and post-epistemic beliefs about physics, *F* (89) = 1.68, *p* =.20, of which were greater than .05.

Table 4.3 The Levene's Test for the pre-and post- MA, SPS, ATP, and EBPs scores

MA test scores	*F*	*Df*	*Sig.*
Pre-MA mean score	2.90	89	.09
Post- MA mean score	0.06	89	.81
Pre-SPS mean score	2.08	89	.15
Post-SPS mean score	.06	89	.81
Pre-ATP mean score	1.77	89	.19
Post-ATP mean score	3.52	89	.07
Pre-EBPs mean score	0.01	89	.96
Post-EBPs mean score	1.68	89	.20

The results of the Shapiro-Wilk, skewness, kurtosis, and Q-Q analyses revealed that the students' pre-test and post-test scores of the treatment and comparison groups were normally distributed. Variance homogeneity was examined using Levene's Test for Variance Equality. The pretest and posttest mean scores' variances were homogeneous. These preliminary analyses demonstrated that parametric testing assumptions were satisfied. In both pretest and posttest scores, normality and homogeneity of variance were maintained. Hence, parametric statistics can be employed to compare groups' pretest and posttest mean scores.

4.1.2 Analyses and Results of students' pre-and post-test scores

In this subsection, the impacts of dialogic-practical work and recipe-based practical work on secondary school students' learning outcomes in physics were compared. The pre-assumptions showed that the results of the pre-test and post-test meet the criteria for normality and equality of variances. To assess mean score changes within and between the comparison and treatment groups, t-tests were the appropriate statistics.

4.1.2.1 Analyses and Results of students' pre-and post-Mechanics Achievement test scores

In the current study, students engaged in recipe-based and dialogic-practical work strategies on a few chosen mechanics topics. The topics were chosen in accordance with the availability of laboratory materials and resources in secondary schools. Topics that are familiar to the students were selected to promote their engagement in dialogic practical work in physics labs. The treatment group conducted a dialogic-practical work approach, whereas the comparison group employed practical work based on recipes for eight weeks. Before and after the intervention, 25 items were administered to both groups. At the end of the intervention, a post-mechanics achievement test was administered. A mechanics achievement test was used for this purpose (*see Appendix A*).

The first research question was: *Is there a significant mean score difference in students' mechanics achievement exposed to dialogic-practical work and recipe-based practical work approaches?*

It contrasted the effects of the dialogic-practical work method with the recipe-based practical work approach on secondary school students' achievement in mechanics. The study's hypothesis was that, because the treatment and comparison groups were of the same grade level and were taking the same physics course, their mean scores on mechanics achievement did not substantially differ prior to intervention. An independent sample t-test was conducted to analyze the mean score difference between the treatment and comparison groups' mechanics achievements before intervention.

As illustrated in Table 4.4, the pre-mechanics achievement mean score for the comparison group was 8.51 out of 25 (one mark for each of the 25 items) and the treatment group was 8.87. The pre-mechanics achievement mean score differences between the treatment and comparison groups revealed no statistical significance, *t* (89) = -.29, *p* =.46. It showed that the mechanics understanding of the students in treatment and comparison groups was nearly identical. This underlined the fact that prior to the intervention, both the treatment and comparison groups had similar mechanics comprehension. The types of practical work approaches used could be the cause of discrepancies in post-mechanics achievement scores.

Similarly, an independent sample t-test was used to the post-mechanics achievement scores difference between the comparison and treatment groups as shown in Table 4.4.

Table 4.4 Independent sample t-test for pre-and post-Mechanics Achievement scores

Variable	Groups	*N*	*M*	*SD*	*t*	*df*	*Sig.*
Pre-MA mean score	Treatment	46	8.87	2.80	-0.29	89	.46
	Comparison	45	8.51	2.26			
Post-MA mean score	Treatment	46	13.22	2.31	7.80	89	.000
	Comparison	45	9.98	2.33			

As shown in Table 4.4, there were significant differences in the treatment and comparison groups' mechanics post mean scores, *t* (89) = 7.80, *p* < .001, 95% CI [3.05, 5.14], d=1.76. The mechanics achievement mean score difference between groups was significantly higher than the average value. The outcomes showed that the treatment group's mean score on the mechanics achievement post-test, M=13.22, SD=2.31 was greater than the comparison group's, M=9.98, SD=2.33.

To examine the effects of the interventions on the group's post-test results on mechanics, additional paired sample t-test analysis was carried out. Table 4.5 displays descriptive statistics and paired sample t-test findings for treatment and control groups.

Table 4.5 The paired sample t-test results of the treatment and comparison groups

Groups	MA scores	*N*	*M*	*SD*	*T*	*df*	*sig.*
Treatment	Pre-mean score	46	8.87	2.75	-12.82	45	.000
	Post-mean score	46	13.22	2.31			
Comparison	Pre- mean score	45	8.51	1.86	-1.82	44	.000
	Post mean score	45	9.98	2.31			

The results showed a statistically significant difference between the treatment group's pre- and post-intervention mean scores, *t* (45) = -12.82, *p* < .001, 95% [3.77, 5.18], d = 1.76. According to the findings, there was a 95% confidence interval between 3.77 and 5.18 for the difference in the mean score for mechanics achievement between pre- and after-treatment. The treatment group's pre- and post-test mean score differences for mechanics achievement were significantly bigger than the average value (Cohen, 1988). The posttest mean score for the dialogic-practical work group, M= 13.22, SD=2.31 was greater than the pretest score, M = 8.87, SD = 2.75.

Similar to this, there was a significant difference in mechanics achievement test scores of the comparison group between the prior and after the intervention, *t* (45) = -1.82, *p* < .001, 95% CI [0.05, 0.89], *d* =.75. The impact was of a medium size. The comparison group's posttest mean score, M = 9.98, SD = 2.31 was marginally higher than the pre-intervention mean score, M = 8.51, SD =1.86. The treatment group's mean mechanics achievement test score increased from 8.87 ± 2.75 to 13.22 ± 2.31 after participating in dialogic-practical work for eight weeks. Students who conducted dialogic-practical work showed a paired difference of 4.35 in their overall mechanics achievement mean scores with a standard deviation of 3.14.

The comparison group’s mechanics achievement means scores also increased from 8.51 ± 1.86 to 9.98 ± 2.31 after performing recipe-based practical work. The comparison group who conducted recipe-based practical work showed a paired difference of 1.47 in their posttest mechanics achievement mean scores with a standard deviation of 1.56. The result revealed that the treatment group demonstrated more improvements in post-test mean scores for mechanics achievement than the comparison groups.

4.1.2.1.1 Analysis of students' gender difference on mechanics test scores

This sub-research investigated: *Do female and male secondary school students experiencing dialogic- and recipe-based practical work methods differ in mechanics achievement mean scores?*

This sub-research question investigated the differences in mechanics achievement mean scores between male and female secondary school students, within and across groups. An independent sample t-test was used to examine the disparity in mean mechanics achievement scores between male and female students of the dialogic-practical work group. Prior to intervention, results showed that no significant difference was observed between female and male students of the treatment group's mechanics achievement scores, t (45) = -1.68, p =.10. Likewise, female and male students of the comparison group showed no significant difference in mechanics achievement mean score before intervention, t (44) = -1.31, p = .51 as shown in Table 4.6. Therefore, secondary school students assigned to each learning group had the same mechanics understanding irrespective of gender.

Table 4.6 Female and Male students post Mechanics achievement mean scores

Groups	Gender	*N*	*M*	*SD*	*t*	*df*	*sig.*
Pre treatment	Female	20	8.10	2.57	-1.68	44	.10
	Male	26	9.46	2.83			
Pre comparison	Female	19	8.32	1.73	-1.31	43	.51
	Male	26	8.65	1.67			
Post treatment	Female	20	12.40	2.52	-1.37	44	.06
	Male	26	13.85	2.57			
Post comparison	Female	19	9.53	1.93	-.72	43	.19
	Male	26	10.31	1.98			

Next an independent sample-test analysis was conducted to examine whether there was a significant difference between female and male students' mechanics achievement post-mean scores within the group. Table 4.6 showed that there was no statistically significant difference between female and male dialogic-practical work group's mechanics achievement scores, *t* (44) = -1.37, *p* = .06, 95% CI [-2.99, .58], d = 0.44. The effect size was medium. Of course, the male students in the treatment group had a slightly higher post-mechanics achievement mean score, *M* = 13.85, *SD* = 2.57 than their female counterparts, *M* = 12.40, *SD* = 2.52.

Similarly, the comparison group's post-mean scores for male and female students did not vary significantly, *t* (43) = -.72, *p* =.47, 95% CI [-2.22, 1.05], d = 0.24. The impact was minimal. The post-mean achievement score for male students in the comparison group was M = 10.31, SD = 1.98 slightly higher than female students in the same group, M = 9.53, SD = 1.93.

Additionally, an independent sample t-test analysis was performed to determine if mechanics achievement scores for male and female students participating in the dialogic-practical work approach differed from those participating in the recipe-based practical work approach, as shown in Table 4.7.

Table 4.7 Female and Male students Mechanics achievement scores

Students	Learning groups	*N*	*M*	*SD*	*t*	*df*	*Sig.*
Female	Treatment	20	12.40	2.52	3.98	37	.000
	Comparison	19	9.53	1.93			
Male	Treatment	26	13.85	2.57	5.56	50	.000
	Comparison	25	10.31	1.97			

As shown in Table 4.7, there was a statistically significant difference in mechanics achievement post scores between female students who were exposed to the dialogic-practical work approach and the group who used recipe-based practical work, *t* (37) = 3.98, *p* < .001, d =

1.27. Female students in the dialogic-practical work group had a post-mean score of M=12.40, SD=2.52, which was higher than the post-mean score of the comparison group of M=9.53, SD=1.93. Similar to this, the results revealed a statistically significant difference in the mean post-mechanics score between male students in the treatment and comparison groups, *t* (50) = 5.56, *p* < .001, d = 1.39. It revealed that male students of the treatment group scored *M* = 13.85, *SD* = 2.57 higher than the comparison group, *M= 10.31*, *SD = 1.97*.

4.1.2.1.2 Analysis of students with varying achievement levels test-scores

The second sub-research question was: *Do secondary students having different achievement levels differ in mechanics achievement scores after conducting dialogic-and recipe-based practical work approaches?*

This sub-research question examined the effects of the intervening variable students' ability groups on mechanics achievement test scores. The treatment and comparison groups were categorized based on 2020/21 two semester classroom physics average scores obtained from secondary schools' record offices. The students were categorized into three achievement levels (ability levels) based on their mean physics scores using Zady et al. (2003) criteria. These scholars employed some specific scores to divide groups. Students who scored:

- $x < 50$ ………. low achievement levels,
- $50 \leq x \leq 69$ ……….. medium achievement level, and
- $x \geq 70$ ……….. high achievement level (Zady et al., 2003, p.45).

The mechanics achievement scores of the three ability levels (high, medium, and low achievement levels) were analyzed to examine the presence of significant differences among themselves as a result of dialogic- and recipe-based practical work interventions. First, an independent sample t-test was conducted to analyze the differences in mechanics achievement mean scores between the treatment and comparison groups of high, medium, and low achievement levels.

As illustrated in Table 4.8, before the interventions, the low achievement levels in the treatment group showed no significant mechanics achievement mean score difference compared to the comparison group, *t* (30) = -.78, *p* =.44. The medium achievement levels of the treatment group also had no significant mechanics achievement mean score difference as compared to the comparison group, *t* (27) = -.36, *p* =.72. Moreover, the high achievement levels who were assigned to the treatment group showed no significant mechanics achievement mean score difference as compared to the comparison group, *t* (23) = .61, *p* =.55. The analysis of the results revealed that students with the same ability levels had the same levels of understanding of mechanics before the intervention.

Table 4.8 Independent sample t-test output of of different Achievement levels

Mean scores	Learning groups	*N*	*M*	*SD*	*df*		*Sig.*
Pre-low	Treatment	18	8.11	2.73	30	-.78	.44
	Comparison	14	8.79	2.49			
Pre-medium	Treatment	15	8.73	2.84	27	-.36	.72
	Comparison	14	9.07	2.16			
Pre-high	Treatment	13	10.08	3.01	23	.61	.55
	Comparison	12	9.42	3.35			
Post-low	Treatment	18	11.64	1.43	30	8.07	.000
	Comparison	14	7.54	1.05			
Post-medium	Treatment	15	13.64	1.74	27	4.34	.000
	Comparison	14	10.69	1.80			
Post-high	Treatment	13	15.61	2.14	23	5.02	.000
	Comparison	12	11.91	1.44			

After the intervention, the low achievement level who conducted the dialogic-practical work approach showed a significant mechanics achievement mean score difference as compared to the recipe-based practical work approach, *t* (30) = 8.07, *p* < .001, 95% CI [3.05, 5.15], d = 3.27. The estimated Cohen's d value claimed that the magnitude of mean score difference on mechanics achievement between the low achievement levels of the treatment and comparison groups was much larger than typical (Cohen, 1988).

Therefore, it can be explained that low achievement levels who conducted the dialogic-practical work approach scored higher mean, M=11.64, SD = 1.43 than those who applied recipe-based practical work approach, M= 7.54, SD = 1.05 in their posttest mechanics achievement. Similarly, the medium achievement levels who conducted the dialogic-practical work approach showed a significant mechanics achievement mean score difference as compared to the recipe-based practical work group, *t* (27) = 4.34, *p* < .001, 95% CI [1.55, 4.35], d = 1.67. The estimated Cohen's d value claimed that the magnitude of mean score difference on mechanics achievement between the high achievement levels of the treatment and comparison groups was much larger than typical (Cohen, 1988).

After the intervention, the high achievement levels who conducted the dialogic-practical work approach showed a significant mechanics achievement mean score difference as compared to the recipe-based practical work group, *t* (23) = 5.02, *p* < .001, 95% CI [2.17, 5.22], d = 0.93. Accordingly, high achievement levels who conducted dialogic-practical work approach scored higher mean M= 13.64, SD= 1.74 than those who conducted recipe-based practical work approach, M= 10.69, SD= 1.80. The estimated Cohen's d value claimed that the magnitude of mean score difference on mechanics achievement between the high achievement levels of the treatment and comparison groups was much greater than typical value (Cohen, 1988).

Therefore, it can be explained that high achievement levels who conducted the dialogic-practical work approach scored significantly higher mean score, *M*= 15.61, *SD* = 2.14 than those who employed recipe-based practical work approach, *M* = 11.91, *SD* = 1.44. The effect sizes of the three achievement levels had typical large value. Relatively speaking, the effect size value for the low achievement level was extremely large compared to the medium and high achievement levels. The mechanics achievement normalized learning gains of the ability groups between pre- and post-test scores within the group were also calculated.

Table 4.9 indicated that the low, medium, and high achievement levels of the treatment group showed a medium category of learning gains between pre- and post-test mechanics mean scores.

Table 4.9 Normalized Mean gain of students' mechanics achievement of ability groups

Learning Groups	Achv't Levels	*N*	*M*	Achv't Levels	*M*	<*g*>	Decision made
Treatment	Pre-low	18	8.11	Post low	11.64	0.30	Medium
	Pre-medium	15	8.73	Post-medium	13.64	0.44	Medium
	Pre-high	13	10.08	Post-high	15.61	0.56	Medium
	Total	46	8.87		13.22		
Comparison	Pre-low	16	8.79	Post-low	7.54	-0.11	Very low
	Pre-medium	16	9.07	Post-medium	10.69	0.15	Low
	Pre-high	13	9.42	Post-high	11.91	0.24	Low
	Total	45	8.51		8.98		

The normalized learning gain of the high achievement levels (.56) was higher than the medium (.44) and low achievement levels (.30). For the comparison group, the mechanics achievement learning gain of the low achievement level between pre- and post-mean scores was -.08 (very low) and showed a decline in mean scores; medium achievement level was .10 (low category); and high achievement level was .16 (low category).

The next analysis was conducted to show the frequency score of students transformed to the next level after dialogic- and recipe-based practical work approaches were applied to each group. First, the students' pre- and post-mean scores out of 25 percent were converted into 100 percent. Second, based on these mean scores, students were further categorized into four achievement levels (ability groups) using the Polonia and Ravi (2020) criteria. They categorized students who scored below 41.00 as a low category, between 41.0 and 60.0 were grouped into a medium category, and between 61.0 and 80.00 were grouped into a high category, and above 81 were categorized as very high category (Polonia & Ravi, 2020; p.138). Table 4.10 shows the numbers and percentage of students in each category.

Table 4.10 The percentage of students' who categorized at different ability levels (N=89).

Groups	Low	Medium	High	Very high	Percentage
Pre-treatment	26 (56.5%)	15 (32.5 %)	5 (11%)	-	46 (100%)
Post-treatment	4 (9%)	24 (52%)	15 (32.5%)	3 (6.5%)	46 (100%)
Pre-comparison	33 (73%)	11 (25 %)	1 (2%)	-	45 (100%)
Post-comparison	18 (40%)	21 (47%)	6 (13 %)	-	45 (100%)

As shown in Table 4.10, 56.5% of students in the treatment group and 73 % of students in the comparison group were categorized as low on their pre-mean scores. Only 32.5% of the treatment group and 25% of the comparison group were considered medium. Only 11% of the treatment group and 2% of the comparison group were categorized as high category.

After implementing a dialogic-practical work method, the proportion of students in a low category fell from 56.5% to 9%. As a consequence of the dialogic-practical work intervention, students from the medium category increased from 32.5% to 52.5%.

Moreover, following the implementation of the dialogic-practical work method, the proportion of students in the high category rose from 11% to 32.5%. After the dialogic-practical work intervention, 6.5% of students were categorized as extremely high, while none were in the category before it. After the implementation of the recipe-based practical work approach, the proportion of students in the low category fell from 73 to 40%. The frequency of students in the medium category grew from 25% to 47%. In a similar fashion, the percentage of students migrating from the low and medium categories to the high category rose from 2% to 13%.

The next analysis was conducted to see if there was a significant difference in mechanics achievement mean scores among the varying achievement levels. The preliminary analysis showed that the assumptions of normality of tests and homogeneity of variances were not violated. Hence, a one-way ANOVA was employed to determine whether there was a statistically significant difference among the mean achievement scores among the three achievement levels. The descriptive statistics revealed that there were mean disparities in pre-test scores for mechanics across the three achievement levels (high: M = 10.08; medium: M = 8.73; low: M = 8.11; SD = 2.37).

The results of the one-way ANOVA showed that there were no significant mean score differences on the students' pre-mechanics achievement exam among achievement levels in the treatment group, F (2, 43) = 2.00, p =.15. Moreover, there were pre-test mean scores differences in the comparison group's mechanics achievement among the achievement levels (M = 9.42, SD = 1.80 for high, M= 9.07, SD = 1.72 for medium, and M= 8.79, SD = 1.59 for low achievement levels, respectively). The one-way ANOVA analysis indicated that there were no significant mean score differences on the pre-mechanics achievement test of the comparison group among achievement levels, *F* (2, 43) = 3.96, *p* =.52. These results demonstrated that the three achievement levels were assumed to be at the same level in their mechanics achievement before the intervention. After the treatment and comparison groups had conducted practical work for eight weeks, a similar mechanics achievement posttest was administered. Similarly, one-way ANOVA tests were carried out to find out if there was a significant difference in mechanics achievement scores across ability levels as shown in Table 4.11.

Table 4.11 The one-way ANOVA statistics for post-MAT scores of achievement levels

Groups	Variable		Sum of squares	*df*	Mean square	*F*	*Sig.*
Treatment Group	Pre-Ach.	Between groups	29.58	2	14.79	2.00	.15
		Within groups	317.63	43	7.39		
		Total	347.21	45			
	Post-Ach.	Between groups	48.16	2	24.08	3.96	.026
		Within groups	261.67	43	6.09		
		Total	309.83	45			
Comparison Group	Pre-Ach.	Between groups	3.88	2	1.94	.67	.52
		Within groups	121.36	42	2.89		
		Total	125.24	44			
	Post-Ach.	Between groups	3.53	2	1.76	.44	.65
		Within groups	167.45	42	3.99		
		Total	170.98	44			

The treatment group's post-mechanics achievement scores showed a significant difference between at least two achievement levels, *F* (2, 43) = 3.96, *p* =.026. The findings showed that there was a substantial mean difference between two achievement levels in posttest scores. For the comparison group, however, there was no discernible difference in post-mean scores across at least two levels of mechanics achievement performance, *F* (2, 42) =.44, *p* =.65.

A Bonferroni post-hoc multiple comparison test was conducted to determine which levels of achievement significantly impacted the mean scores as shown in Table 4.12. The results revealed that there was a statistically significant post mean score difference between the treatment group's high achievement level, M = 15.61, SD = 2.14, and low achievement level, M = 11.64, SD = 2.33, *p* =.022, 95% CI [2.28, 6.06], d = 1.86, with a generally large effect size.

Table 4.12 The post hoc test of post Mechanics achievement test by achievement levels

MAT mean scores	Achievement level (I)	Achievement level (J)	Mean Difference (I-J)	Std. Error	Sig.
Post treatment	High	Medium	1.97	.73	.35
		Low	3.97	.75	.022
	Medium	High	-1.97	.73	.35
		Low	- 3.97	.72	.71

However, the treatment group's post-mechanics achievement scores did not show a statistically significant difference between the high achievement level, M = 13.64, SD = 1.74 and medium achievement level, M = 13.64, SD = 1.74, *p* =.35, 95% CI [-.54, 3.14], d =1.01, with a big effect size. Likewise, the treatment group's post-mechanics achievement scores did not differ statistically significantly between the medium achievement level, M = 13.64, SD = 1.74 and low achievement level, M = 11.64, SD = 2.33, *p* =.71, 95% CI [-.54, 3.14], d =.97, with a typical large effect size.

4.1.2.2 Analysis of students’ science process skills post-test score

The second research question was: *Is there a significant mean score difference in students’ science process skills exposed to dialogic-practical work and recipe-based practical work approaches?*

This research question determined how the dialogic-practical work method affected science process skills of secondary school students. A physics process skills test was utilized to gather information about students' science process skills (*see Appendix B*). This exam was designed to evaluate students' comprehension of science process skills ranging from the most fundamental to the most sophisticated skills. Before and after the intervention, the test was administered to both the comparison and treatment groups. The maximum score on the science process skills test was 20. Before the interventions, the comparison group scored 7.60 and the treatment group scored 7.41 out of 20 points.

Table 4.13 Independent sample t-test output for pre-and post-SPS mean scores

Variable	Groups	*N*	*Mean*	*SD*	*t*	*df*	*Sig.*
Pre-SPS score	Treatment	46	7.41	2.43	-0.38	84	.70
	Comparison	45	7.60	2.07			
Post-SPS score	Treatment	46	10.83	3.01	3.28	88	.001
	Comparison	45	8.87	2.61			

An independent sample t-test was run to examine the pre-mean scores difference between the treatment and comparison groups for students' science process skills as indicated in Table 4.13. The results showed no statistically significant differences between the comparison group's pre-mean score, M = 7.60, SD = 2.07 and the treatment group's pre-mean score, M = 7.41, SD = 2.43 of science process skills, *t* (89) = -.38, *p* = .70. Hence, the two groups had the same science process skills understanding levels before the intervention.

As shown in Table 4.13, an independent sample t-test was used to determine if there was a significant difference in post-mean scores between the treatment and comparison groups. The results showed that a statistically significant difference was observed in the posttest mean scores for science process skills between the treatment and comparison groups, *t* (89) = 3.28, *p* < .001, 95% CI [0.88, 3.60], d = 0.75. The post mean score of the treatment group who carried out a dialogic-practical work approach, M=10.83, SD= 3.01 was higher than the comparison group who conducted recipe-practical work, M= 8.87, SD= 2.61. It had a medium effect size.

To determine the variation in students' mean scores for science process skills between pre- and post-tests, a paired sample t-test analysis was carried out. As shown in Table 4.14, the science process skills post-mean score for the treatment group, M = 10.83, SD= 3.01 was higher than the pre-mean score, M = 7.41, SD = 2.43 for the same skill set. The results of the paired sample t-test indicated that it was statistically significant with the following values: *t* (46) = -8.64, *p* < .001, 95% CI [1.68, 3.82], d =.99. The effect size was enormous.

Table 4.14 Paired sample t-test comparison between pre and post SPS mean scores

Groups	SPS scores	*N*	*M*	*SD*	*t*	*df*	*Sig.*
Treatment	Pre-mean score	46	7.41	2.43	-8.64	45	.000
	Post-mean score	46	10.83	3.01			
Comparison	Pre- mean score	45	7.60	2.07	-3.27	44	.002
	Post mean scores	45	8.87	2.61			

For the comparison group, the results demonstrated that a statistically significant difference was observed between the pre- and post-mean scores of science process skills, *t* (45) = -3.27, *p* < .002, 95% CI [0.01, 1.22], d= 0.45. The descriptive statistics showed that the post-mean score, M = 8.87, SD=2.61 was marginally higher than the pre-mean score, M = 7.60, SD = 2.07 for science process skills. The effect size was small. The treatment group who conducted dialogic-practical work showed a paired difference of +3.42 in their overall science process skills mean score with a standard deviation of 2.30.

4.1.2.2.1 Analysis of students' basic and integrated process skills

The sub-research question was: *Do secondary school students engaged in dialogic and recipe-based practical work approaches differ in components of science process skills mean scores?*

To examine the effect of dialogic-practical work on students' science process skills, 20 items were prepared and administered as pre-and post-tests. The items consisted of basic and integrated science process skills. The distributions of the items on each component were: observation (2 items), classification (2 items), prediction (1 item), inference (2 items), control variables (2 items), operational definition (1 item), formulating hypotheses (2 items), experimenting (3 items), interpreting data (2 items), reaching conclusions (2 items), and drawing graphs (1 item). Before and after the intervention, 46 students from the treatment group and 45 students from the comparison group took the physics process skills test.

The percentage of students that properly responded to the science process skill question on average throughout the dialogic and recipe-based practical work groups is presented in Table 4.15. The percentage of students that successfully answered each of the eleven science process skill components is displayed in Table 4.15. The percentage of students that correctly answered each of the eleven science process skill components were converted to 100 percent. The results showed that on both basic and integrated science process skills tests, a greater percentage of students in the treatment group had correct responses than the comparison group.

Students performed better on the basic science process skills than on the integrated science process skills. Relatively, few students in the treatment group correctly answered questions about operationalization, drawing conclusions, and drawing graphs. For the treatment group, the highest and lowest percentages of science process skills are inference (64.0%) and operational definition (32.5 %) respectively. Students are rarely trained to use operational definition skills in physics labs. For the comparison group, students scored high on inference (43.5 %) and lowest on formulating hypotheses (27.5 %). Using Irwanto et al. (2017) classification, the percentage of students results in science process skills were categorized into three groups.

- Above 66.7 % (high category),

- 33.3% to 66.7 % (medium category), and
- Less than 33.3 % (low category).

Except for the operational definition, the percentage of science process skills scores for the treatment group fell into the medium category. The comparison group had medium categories on observation, classification, prediction, inference, and control variable. While they scored low on operational definition, experimenting, formulating hypotheses, interpreting data, reaching conclusions, and drawing graphs. Additional analysis was performed to examine the difference in mean scores on each science process skills subscale between the treatment and comparison groups. The preliminary analysis results indicated that basic and integrated science process skills mean scores did not meet normality and variance equality conditions.

In order to run a Mann-Whitney U test, the following four assumptions must be met. First, there should be one dependent variable that is measured at the continuous or ordinal level. Since, the students mean scores on the components of science process skills were at continuous level, it satisfied the first assumption. The second assumption stated that there must be one independent variable that consists of two categorical groups. In this case, the independent variable had two groups: treatment and comparison.

The third assumption was about the presence on independent observations. In this study, there was no relationship between the observations in each group of the independent variable or between the groups themselves. The last assumption was determining the distribution of scores for both groups of the independent variable have the same shape or different shape. In practice, the Mann-Whitney U test is more broadly used to interpret whether there are differences in the distributions of two groups or differences in the medians of two groups. If the two distributions have a different shape, the Mann-Whitney U test is used to determine whether there are differences in the distributions of your two groups. However, if the two distributions are the same shape, the Mann-Whitney U test is used to determine whether there are differences in the medians of your two groups. Indeed, to use the Mann-Whitney U test, the medians distribution of process skill scores for treatment and comparison groups must have the same shape (including dispersion). Hence, the Mann-Whitney U-test was utilized to examine the difference in mean scores on components of science process skills between the treatment and comparison groups.

Table 4.15 The Mann-Whitney U-test statistics for the two groups' post scores.

SPSs	Treatment Group score	Comparison Group score	Mann-Whitney	*Z*	*Sig.*
Observation	25 (62.5 %)	14 (36.8 %)	462.50	-3.40	.001
Classification	24 (60 %)	16 (42 %)	572.50	-2.03	.04
Prediction	22 (55 %)	15 (39.5 %)	622.00	-1.60	.11
Inference	25.5 (64 %)	16.5 (43.5 %)	299.00	-4.76	.000
Control variable	22 (55 %)	13 (34 %)	522.00	-2.61	.009
Operational definition	13 (32.5 %)	11 (29 %)	733.00	-.34	.74
Experimenting	22.7 (57 %)	11 (29 %)	562.50	-2.99	.003
Formulating hypothesis	21 (52.5 %)	10.5 (27.5 %)	487.00	-2.94	.003
Interpreting Data	22 (55 %)	12 (31.5 %)	545.00	-2.69	.007
Reaching conclusion	17 (42.5 %)	12.5 (33 %)	706.50	-.97	.34
Drawing Graphs	17 (42.5 %)	12 (31.5 %)	697.00	-.75	.46

The results indicated that a significant mean score difference was observed between the treatment and the comparison groups among the basic science process skills on observation, $U = 462.50, Z= -3.40, p = .001$; classification, $U= 572.50, Z= -2.03, p = .04$; and inferences, $U= 299.00, Z= -4.76, p < .001$. However, no significant difference was observed between the treatment and comparison groups on prediction, $U= 622.00, Z= -1.60, p = .11$.

Regarding the integrated science process skills, the results revealed a significant mean score difference between the treatment and comparison groups on controlling variables, $U= 522.00,$

Z= -2.61, *p* = .009; experimenting, *U= 562.50*, *Z = -2.99*, *p* = .003; formulating hypotheses, *U= 487.00*, *Z= -2.94*, *p* = .003; and interpreting data, *U= 545.00*, *Z= -2.69*, *p* = .007. Contrarily, the mean scores of the treatment and comparison groups did not show significant differences in the skills of operational definition, U= 733.00, Z= -.34, p =.74; reaching conclusions, U= 565.00, Z= -1.34, p =.08; and drawing graphs, U = 697.00, Z= -.75, p =.46.

4.1.2.2.2 Analysis of students' practical work skills change over time

The sub-research question was: *Do secondary school students who engaged in dialogic-practical work show a difference in science process skills over eight weeks?*

Practical skills observation rubrics were used to assess students' science process skills development through time (*See Appendix F*). The rubrics had twenty skills organized into four domains: data design, execution, analysis, and evaluation. The items were scored as (0) very low, (1) satisfactory, (2) good, and (3) excellent. The minimum rubric score was 0 and the maximum score was 60. The data were collected to assess the treatment group's level of improvement in science process skills at three intervals of time (beginning, middle, and end) of the intervention. The mean scores at the beginning of the intervention were M= 11, SD = 0.51; at the middle, M = 42, SD = 0.53; and at the end, M = 53, SD =0.67.

The preliminary analysis revealed that the data did not satisfy normality and variance equality. Therefore, a repeated measures Friedman Test was used to determine whether or not there is a statistically significant difference between the means of a group of students' practical skill scores at three intervals of time in a treatment group. To apply a Friedman Test with repeated measurements, the following conditions must be met. First, the data must be continuous.

Therefore, the first assumption was satisfied since students' practical skills scores were continuous data.

Second, this test can be used to compare three or more related groups. In this case, the data was collected from the treatment group at three time points, then we had three groups of related data. In this analysis, we had three related groups (the three points in time) of students' practical skill scores. The pre-analysis confirmed that the data met the necessary assumptions. Hence, we conducted the repeated measures Friedman test analysis whether or not the dialogic-practical work approach brought a significant effect on students practical scores at three time points, as shown in Table 4.16.

Table 4.16 Students SPS mean scores at three phases

Practical work sessions	*N*	*Sum*	*Mean*	*SD*	X^2	*df*	*Sig.*
SPS Rubrics 01	20	11.00	0.50	0.51	40.84	2	.000
SPS Rubrics 02	20	42.00	1.91	0.53			
SPS Rubrics 03	20	53.00	2.41	0.67			

The results showed a significant difference in the mean scores of the science process skills at each of the three-time intervals, X^2 (2) = 40.84, $p < .001$. The results showed that the mean practical skill scores at the final stage of the intervention, M = 53, SD =0.67, were higher than those in its middle, M = 42, SD = 0.53, and beginning, M = 11, SD= 0.50. The results revealed that students' mean scores increased with time.

The Friedman's Test analysis indicated that there was a significant difference in means between some of the time intervals, but did not (yet) know which. Therefore, the next step was trying and find out which pairs of our time intervals are significantly different then each other. In this regard, the need to correct multiple comparisons arose. However, in the case of Friedman’s test (until now) the code to perform the post hoc test was not as easily accessible (Field, 2013).

Table 4.17 The time series comparisons of students’ practical skills

Between groups	Z	Sig. (2-tailed)
SPS Rubrics 01-SPS Rubrics 02	4.24	.000
SPS Rubrics 01-SPS Rubrics 03	4.24	.000
SPS Rubrics 02-SPS Rubrics 03	3.05	.002

In this regard, the post hoc analysis can be thought of as performing paired Wilcoxon signed Ranks Test with correction for multiplicity. Hence, to analyze the between-group comparison, a Wilcoxon signed Ranks Test was used as shown in Table 4.17. The results showed that there was a statistically significant difference between the start and middle of the intervention, $Z = 4.24$, $p < .001$; the start and end of the intervention, $Z = 4.24$, $p < .001$; and the middle and end of the intervention, $Z = 3.05$, $p =.002$. These results revealed that students engaged in dialogic-practical work prominently improved their practical skills.

4.1.2.3 Analysis of students’ Attitudes toward Physics scores

The third research question was: *Is there a significant mean score difference in students’ attitudes toward physics exposed to dialogic-practical work and recipe-based practical work approaches?*

This study aimed to assess the effects of a dialogic-practical work strategy with practical work based on recipes on students' attitudes toward physics. A questionnaire comprising 30 items was used to gauge the students' attitude scores (*see Appendix C*). Before and after the intervention, this questionnaire was given to the treatment and comparison groups. Each item in the survey was scored on a 5-point Likert scale (ranging from 1-strongly disagree to 5-strongly agree). The average student response on the score varied from a minimum of 1 to a high of 5. The typical result was a 3.00. The comparison group's and the treatment group's mean pre-scores were 3.24 and 3.22 respectively out of a possible 5 points. To ascertain if there was a significant difference in the mean pre-test scores on students' attitudes toward physics between the treatment and comparison groups, an independent sample t-test was conducted.

Table 4.18 Independent sample t-test output for pre-ATP mean scores

Variable	Groups	*N*	*M*	*SD*	*t*	*df*	*Sig.*
Pre-ATP score	Treatment	46	3.22	0.32	-0.34	84	.74
	Comparison	45	3.24	0.26			
Post ATP score	Treatment	46	3.90	0.41	4.53	89	.000
	Comparison	45	3.44	0.48			

The pre-attitudes towards physics score of the comparison group, M=3.24, SD =.26, and treatment group, M=3.22, SD =.32, *t* (84) = -.34, *p* =.74, were not significantly different from one another. As a result, prior to the intervention, the treatment and comparison groups had similar perspectives on physics. This finding demonstrated that the attitudes towards physics in the treatment and comparison groups were similar at the outset. As shown in Table 4.18, an independent sample t-test was conducted following the intervention to see if there was a difference in attitude mean scores between the treatment and comparison groups.

On attitude towards physics post mean scores, there was a statistically significant difference between the treatment and comparison groups, *t* (89) = 4.53, *p* < .001, 95% CI [.26, .66], d = 1.03. The effect size of 1.03 was significantly higher than the normal value. The treatment group's post-test attitude score, M = 3.90, SD =.41 was greater than that of the comparison group, which used a recipe-based practical work approach, M =3.44, SD =.48. The following step was applying a paired sample t-test to analyze students' pre- and post-intervention mean attitude scores within the group. The results are reported in Table 4.19.

Table 4.19 Paired sample t-test comparison of the Attitude towards Physics

Groups	Attitude scores	*N*	*M*	*SD*	*t*	*df*	*Sig.*
Treatment	Pre-mean score	46	3.20	0.67	-6.69	45	.000
	Post-mean score	46	3.90	0.41			
Comparison	Pre- mean score	45	3.12	0.56	-2.08	44	.043
	Post mean score	45	3.44	0.68			

The results of the paired sample t-test showed a statistically significant difference between the post-mean score of the treatment group, M = 3.90, SD = 0.41, and the pre-mean score of the group, M = 3.22, SD = 0.32, *t* (45) = -6.69, *p* < .001, 95% CI [0.55, 0.84], d= 1.99. It had a considerable impact (Cohen, 1988). Additionally, the comparison group displayed a statistically significant difference between the mean post-score, M= 3.44, SD= 0.48, and mean pre-score, M= 3.24, SD = 0.26, *t* (37) = -2.67, *p* =.043, 95% CI [0.05, 0.39], d = 0.41. The impact was minimal. A pairwise positive shift of +0.68 was seen in the treatment group that engaged in dialogic-practical work between the pre-and post-intervention periods. Similarly, the comparison group showed a positive attitude shift by +0.22 points.

4.1.2.3.1 Analyses of the subscales of Attitude mean scores

The sub-research question was: *Are there significant mean scores differences between the treatment and comparison groups on components of attitudes toward physics?*

In the current study, five subscales were used to characterize students' attitudes toward physics, including enthusiasm for physics, physics learning, practical work, physics teacher, and future vocation. MANCOVA analysis was used to ascertain whether the independent variable with two levels had any impact on students' improvement in the attitudes they had toward physics subscales. One-way MANCOVA was employed to see whether there was any significant change between the treatment and comparison groups on the subscales of attitudes toward physics. The normality, outliers, linearity, homogeneity, and multicollinearity presumptions must be verified to perform a one-way MANOVA analysis.

The initial presumption was that there would be two or more dependent variables, each of which would be continuous and assessed at an interval or ratio level. There were five dependent variables in this dataset: enthusiasm for physics, learning physics, practical work, physics teacher, and future vocation. Similarly, the independent variable was split into two distinct independent groups (treatment and comparison), it confirmed this assumption. The second premise was that the data were normal. The Shapiro-Wilk normality test was used to verify this assumption of univariate normality.

Shapiro-Wilk tests revealed that all the dependent variables had normally-distributed distributions in both groups (*p*s >.05), supporting univariate normality. Through the use of Mahalanobis distance, the multivariate assumption was examined. For five dependent variables, all Mahalanobis distance values were below the threshold of 20.52. This provided evidence for multivariate normalcy and suggested that there were no multivariate outliers. The box plot revealed that only three minor multivariate outliers were observed. The scatterplot showed that the dependent variables in the treatment and comparison groups were linearly correlated.

The next presumption was the homogeneity of the variance-covariance matrices. The covariance equality Box's M test was used to verify this premise. The Box's M test revealed that the homogeneity assumptions of variance-covariance matrices were fulfilled, $p = .113$. The data's non-multicollinearity was the final presumption. Analyzing multicollinearity assumptions was proposed by Pearson's correlation analysis. The findings showed that the variables' correlations did not exceed.80, indicating that they were not strongly associated. The preliminary analyses verified that there was no deviation from linearity, homoscedasticity, multicollinearity, or normalcy. A one-way MANOVA was, therefore, an appropriate parametric statistic to analyze the data displayed in Table 4.20.

Table 4.20 The one-way MANOVA results for components of ATP post scores

Subscales of ATP	Groups	*N*	*M (SD)*	*F*	*df*	*sig.*	$n_p{}^2$
Enthusiasm to Physics	Treatment	46	3.92 (.52)	25.77	89	.000	.25
	Comparison	45	3.42 (.65)				
	Total	91	3.67 (.64)				
Learning Physics	Treatment	46	3.88 (.57)	31.86	89	.000	.31
	Comparison	45	3.40 (.68)				
	Total	91	3.65 (.67)				
Practical work	Treatment	46	4.04 (.67)	36.52	89	.000	.33
	Comparison	45	3.44(.60)				
	Total	91	3.75 (.70)				
Physics Teacher	Treatment	46	3.55 (.66)	27.99	89	.000	.27
	Comparison	45	3.00 (.62)				
	Total	91	3.28 (.69)				
Future Vocation	Treatment	46	3.92 (.60)	16.92	89	.000	.18
	Comparison	45	3.37 (.41)				
	Total	91	3.62 (.62)				

Note: The partial eta squared is 0.01 = small, 0.06 = medium, and 0.14 = large (Cohen, 1988).

Out of 5 points the treatment group scored high on practical work, *M* = 4.04, *SD* = .67 and low on physics teacher, *M* = 3.55, *SD*= .66. However, the comparison group scored high on practical work, *M* = 3.44, *SD* = .60 and low on physics teacher, *M* = 3.00, *SD* = .62. As shown in Table 4.20, the one-way MANOVA analysis indicated a statistically significant main effect of learning groups on the five dimensions of attitudes towards physics, *F* (5, 85) = 5.95, *p* <.001; Wilks' Lambda = 0.74, = .56. The result indicated that the dialogic-practical work approach explained 56 % of the variance in the dimensions of attitudes toward physics.

Furthermore, there was a significant difference between the treatment and comparison groups on enthusiasm for physics, F (1, 89) = 25.77, p < .001, ${n_p}^2$ = .25; learning physics, F (1, 89) = 31.86, p < .001, ${n_p}^2$= .31; practical work, F (1, 89) = 36.52, p < .001, ${n_p}^2$ = .33; physics teacher, F (1, 89) = 27.99, p < .001, ${n_p}^2$ = .27; and future vocation, F (1, 89) = 16.92, p< *.001*, ${n_p}^2$= .18. The partial eta squared values of the components of attitude had a large effect. The partial eta squared values of all the subscales were much larger than the typical value.

4.1.2.3.2 Analysis of gender difference on attitudes towards physics scores

The sub-research question was: *How do secondary school female and male students differ in their attitudes towards physics?*

This sub-research question examined the impacts of gender disparities on secondary school students' attitudes toward physics. The pre- and post-scores were analyzed using an independent sample t-test as displayed in Table 4.21.

Table 4.21 Gender comparison in the pre- and post-mean attitudes scores

Groups	Attitude scores	Gender	*N*	*M*	*SD*	*t*	*df*	*Sig.*
Treatment	Pre scores	Females	20	3.22	0.33	0.12	44	.91
		Males	26	3.21	0.28			
Comparison	Pre scores	Females	20	3.24	0.22	-0.73	43	.58
		Males	25	3.29	0.31			
Treatment	Post scores	Females	20	3.84	0.43	4.53	44	.47
		Males	26	3.94	0.40			
Comparison	Post scores	Females	20	3.50	0.49	0.62	43	.54
		Males	25	3.40	0.47			

The pre-intervention result revealed that there were no statistically significant differences between the mean score of female students, M = 3.22, SD = 0.33, and male students, M = 3.21, SD = 0.28 of the treatment group, t (44) = 0.12, p = .91. Female and male students' mean scores, M = 3.29, SD = 0.31 and M = 3.24, SD = 0.22 respectively, did not exhibit any significant differences, t (43) = -0.73, *p* =.58. Regardless of gender, the treatment and comparison groups had similar attitudes toward physics prior to the intervention.

As can be shown in Table 4.21, the post-mean attitude scores for males and females in the dialogic practical work group, M = 3.94, SD = 0.40 and M = 3.84, SD = 0.43 respectively were not statistically significant, *t* (44) = 4.53, *p* =.47, 95% CI [-0.36, 0.17]. Following the intervention, the mean scores of attitudes toward physics in the treatment group's female and male students increased by 0.62 and 0.73, respectively. In the recipe-based practical work group, there was no statistically significant difference in the attitudes of the male and female students toward physics, M = 3.40, SD = 0.47, and M = 3.50, SD = .49 respectively, *t* (43) = 0.62, *p* =.54, 95% CI [-0.23, 0.43]. Both male and female students raised the mean attitude scores for the comparison group by 0.28 and 0.19, respectively.

4.1.2.3.3 Analysis of ability groups' in Attitudes toward Physics scores

The sub-research question was: *How do attitudes toward physics mean scores differ among ability levels exposed to the dialogic practical work approach?*

This study focused on examining the effects of students' achievement levels on attitudes toward physics. To address this sub-research question, the treatment and comparison groups were grouped into three achievement levels (high, medium, and low). Table 4.22 shows the attitude toward physics mean scores of the treatment and comparison groups in terms of varying achievement levels. The shift in attitude was 0.83 for high achievement levels (large positive shift), 0.86 for medium achievement levels (large positive shift), and 0.38 for low achievement levels (positive shift).

These results indicated that the high and medium achievement levels of the dialogic-practical work approach had medium categories of normalized attitudinal learning gains between pre- and post-test scores. While a low achievement level of the dialogic-practical work approach and all achievement levels of the recipe-based practical work approach showed low categories of normalized attitudinal gains between pre-and post-test.

Table 4.22 The descriptive statistics for the treatment group’s achievement levels

Learning Groups	Achievement Level	N	Pre-ATP scores		Post-ATP scores		Shift	Decision
			M	SD	M	SD		
Treatment	High	13	3.28	.29	4.11	.33	.83	Positive
	Medium	15	3.14	.24	4.00	.32	.86	Positive
	Low	18	3.20	.34	3.58	.40	.38	Positive
	Total	46	3.21	.30	3.90	.31		
Comparison	High	13	3.47	.29	3.57	.58	.01	Positive
	Medium	16	3.09	.32	3.37	.70	.28	Positive
	Low	16	2.86	.46	3.16	.71	.30	Positive
	Total	45	3.12	.67	3.35	.68		

A one-way ANOVA was used to analyze the effects of students' achievement levels on their attitudes toward physics as shown in Table 4.23.

Table 4.23 The one-way ANOVA outputs of ATP of the three Achievement levels

Attitude score	ANOVA	Sum of squares	df	Mean of squares	*F*	*Sig.*
Pre-mean scores	Between Groups	0.13	2	0.07	0.73	.49
	Within Groups	3.87	43	0.09		
	Total	4.00	45			
Post mean scores	Between Groups	2.07	2	1.04	0.12	.001
	Within Groups	4.51	43	0.12		
	Total	6.58	45			

Prior to the intervention, there was no statistically significant difference in the attitudes towards physics among students with high, medium, and low achievement levels, *F* (2, 43) = 0.73, *p*

=.49. It indicates that prior to the intervention, there were no mean scores differences on attitude towards physics among students with varying achievement levels. At the end of the intervention, a statistically significant difference in attitudes toward physics was seen between at least two achievement levels of the treatment group, *F* (2, 43) = 0.12, *p* =.001.

A Bonferroni post hoc test was then performed to determine which of these groups had a significant difference as shown in Table 4.24.

Table 4.24 Post hoc test for multiple comparisons between achievement levels

Achievement level (I)	Mean scores	Achievement level (J)	Mean difference (I-J)	Std. Error	Sig.
High	4.11	Medium	.10	.13	.74
		Low	.53	.14	.002
Medium	4.00	High	-.10	.13	.74
		Low	.43	.13	.01
Low	3.58	High	-.53	.14	.002

The results of the Bonferroni post-hoc test analysis revealed a statistically significant difference was observed between students with high achievement levels, M = 4.11, SD = 0.33, and those with low achievement level, M = 3.58, SD = 0.40, *p* =.001, 95% CI = [0.18, 0.88], d = 1.45, with a generally large effect size. Statistically significant differences were detected between low achievement level, M = 3.58, SD = 0.40, and medium achievement, M = 4.00, SD = 0.32, *p* =.01, 95% CI = [0.08, 0.77], d = 1.16, with a typically large effect size.

However, there was no statistically significant difference in post attitudes scores between high achievement level, M = 4.11, SD = 0.33, medium achievement level, M = 3.58, SD = 0.32, or low achievement level, M = 3.58, SD = 0.32, *p* =.74, 95% CI = [-0.24, 0.45], d = 0.34, with a modest effect size. Before the intervention, there was a significant mean score difference between the two achievement levels for the comparison group, *F* (2, 42) = 5.03, *p* =.011. The pre-attitude means scores between the high-achievement level (M = 3.47, SD =.32) and the low-achievement level, M = 2.86, SD =.67, differed significantly, p =.009, 95% CI = [.13, 1.09].

By controlling the pre-attitude mean score, a one-way ANCOVA was used to determine if there was a significant difference between achievement levels and post-attitude scores. After correcting for pre-attitude mean scores, the findings revealed that achievement levels had no discernible impact on the post-attitude scores of the comparison group, F (2, 41) =.46, p =.63, ${n_p}^2$ = .02. The learning normalized gain analysis showed that after students completed practical work based on a recipe, the low achievement levels raised their mean attitude score by +0.3 more than the high achievement levels (+0.1).

4.1.2.4 Analysis of students' Epistemic Beliefs about Physics mean scores

The research question was: *Is there a significant mean score difference in epistemic beliefs about physics between students who engaged in a dialogic-practical work approach and a recipe-based practical work approach?*

This study compared the dialogic-practical work approach to the recipe-based practical work technique in terms of how it affected students' epistemic views about physics. Students' epistemic beliefs about physics were evaluated using a five-point Likert scale questionnaire (*See Appendix D*). The descriptive statistics in Table 4.25 showed that the comparison and treatment groups' mean pre-epistemic beliefs scores, out of five, were 3.15 and 3.16, respectively. Both results were higher than the average score of 3.00. These mean scores showed that secondary school students held epistemic beliefs near sophistication. To examine whether there were significant mean scores differences between the treatment and comparison groups before and after the intervention in epistemic beliefs about physics an independent sample t-test analysis was performed. Table 4.25 shows the independent sample t-test results of the pre- and post-epistemic beliefs about physics mean scores of the treatment and comparison groups.

Table 4.25 Students' Epistemic beliefs about Physics mean scores

Variable	Groups	*N*	*M*	*SD*	*t*	*df*	*Sig.*
Pre-EBPs score	Treatment	46	3.16	0.27	0.08	89	.93
	Comparison	45	3.15	0.26			
Post EBPs score	Treatment	46	3.76	0.22	7.98	89	.000
	Comparison	45	3.31	0.27			

As presented in Table 4.25, there were no statistically significant differences between the epistemic beliefs pretest mean scores of the comparison group, M = 3.15, SD =.26, and the treatment group, M = 3.16, SD =.27, t (89) =.08, p =.93. The pre-data analysis showed that both the comparison and treatment groups had about the same levels of epistemic beliefs about physics prior to the intervention. If the groups' mean scores differ after the intervention, this variation would be ascribed to the implementation of the dialogic-practical work. In a similar vein, the results of the independent sample t-test analysis showed that there was a statistically significant difference in the mean post-test epistemic beliefs scores of the treatment and comparison groups, *t* (89) = 7.98, *p* <.001, 95% CI [.34,.56], d =1.83. The extent of the effect was enormous. The results showed that students in the dialogic-practical work group, M = 3.76, SD =.22, had higher epistemic beliefs post-mean scores than those in the comparison group, M = 3.31, SD =.27.

In order to compare treatment and comparison mean scores before and after the intervention, a paired-sample t-test was performed. Table 4.26 lists the paired sample t-test results. The results of the paired sample t-test, showed that there was a statistically significant difference between the treatment group's pre-and post-intervention epistemic beliefs mean scores, *t* (45) = -12.10, *p*

< .001, 95% CI [-0.67, -0.44], d = 2.07. For the treatment group, the post-epistemic beliefs mean score, M = 3.76, SD =.22, was greater than the pre-epistemic beliefs mean score, M = 3.15, SD =.29. Between pre- and post-intervention, the treatment group showed a positive shift in beliefs about physics 0.61. Whereas, the mean post-test score for epistemic beliefs, M = 3.17, SD =.25 in the comparison group was slightly higher than the pre-test means, M = 3.30, SD =.26.

Table 4.26 The paired sample t-test result between the pre-and post EBPS

Groups	EBPs scores	*N*	*M*	*SD*	*t*	*df*	*Sig.*
Treatment	Pre-EBPs	46	3.15	.29	-12.10	39	.000
	Post EBPs	46	3.76	.22			
Comparison	Pre- EBPs	45	3.17	.25	-2.65	37	.012
	Post EBPs	45	3.30	.26			

The comparison group's pre- and post-mean scores differed statistically significantly, *t* (44) = -2.65, *p* =.012, 95% CI [.03, .23], d =.51. The comparison group, showed a positive shift in beliefs about physics between the pre-test and the post-test by 0.07. A group of students who completed practical work based on recipes likewise significantly improved their epistemic views, however with a modest effect size. In conclusion, the treatment group improved their epistemic beliefs more than the comparison group did between the pre- and post-intervention periods.

4.1.2.4.1 Analyses of mean scores of Epistemic Beliefs about Physics subscales

The first sub-research question: *Do treatment and comparison groups significantly differ in the components of epistemic beliefs about physics mean scores?*

In the current study, the sources of knowledge, the certainty of knowledge, the development of knowledge, justification for knowing, the purpose of knowledge, and the purpose of knowing were the six subscales that comprised the dimensions of students' epistemic beliefs regarding physics. A one-way MANOVA analysis was carried out to see if there were significant differences in the subscales of epistemic beliefs between the treatment and comparison groups. The independent variable was the practical work strategy. Before using the statistical model of multivariate analysis (MANOVA), normality, homogeneity of regression, multicollinearity, equality of variances, and independence of observations assumptions were checked.

The analysis ensured that assumptions about normality, linearity, multicollinearity, or homoscedasticity were not violated. After validation of these assumptions, the MANOVA model was employed to analyze the data as shown in Table 4.27. Epistemic beliefs subscales had five items. Out of five points, the minimum score for each item was one and the maximum score was 5. The average score of an individual item was 3.00. The treatment group performed well on justification for knowing, M = 3.94, SD =.67, and poorly on knowledge development, M = 3.42, SD =.55.

Table 4.27 The one-way MANOVA results for subscales of EBPs post scores

Subscales of EBPs	Groups	*N*	*M (SD)*	*F*	*df*	*Sig.*	$n_p{}^2$
Sources of Knowledge	Treatment	46	3.49 (.71)	4.91	89	.029	.05
	Comparison	45	3.20 (.55)				
Certainty of knowledge	Treatment	46	3.52 (.71)	6.80	89	.011	.07
	Comparison	45	3.14 (.70)				
Development of knowledge	Treatment	46	3.42 (.55)	12.94	89	.001	.13
	Comparison	45	3.05 (.42)				
Justification of knowledge	Treatment	46	3.94 (.67)	23.71	89	.000	.21
	Comparison	45	3.37 (.40)				
Purpose of Knowledge	Treatment	46	3.67 (.55)	11.80	89	.001	.12
	Comparison	45	3.23 (.67)				
Purpose of Knowing	Treatment	46	3.77 (.57)	20.10	89	.000	.18
	Comparison	45	3.24 (.57)				

The comparison group also performed well on justification for knowledge, M = 3.37, SD =.40, but poorly on knowledge development, M = 3.05, SD =.42. The findings showed that, in the justification for knowing dimension, the treatment group held the most advanced epistemic views, whereas the development of knowledge dimension held the least sophisticated beliefs. On the majority of epistemic beliefs measures, the comparison group was slightly close to sophistication.

The one-way MANOVA analysis revealed that a statistically significant main effect of learning groups on the six subscales of epistemic beliefs about physics, $F\ (6, 84) = 7.35$, $p < .001$; Wilks' Lambda = 0.66, $n_p{}^2 = .35$. The result indicated that the dialogic-practical work approach explained 35 % of the variance in epistemic beliefs about physics dimensions. The results further indicated that a statistically significant difference was observed between the treatment and comparison groups on sources of knowledge, $F\ (1, 89) = 4.91$, $p = .029$, $n_p{}^2 = .05$; certainty of knowledge, $F\ (1, 89) = 6.80$, $p = .011$, $n_p{}^2 = .07$; development of knowledge, $F\ (1, 89) = 12.94$, $p = .001$, $n_p{}^2 = .13$; justification for knowing, $F\ (1, 89) = 23.71$, $p < .001$, $n_p{}^2 = .21$; purpose of knowledge, $F\ (1, 89) = 11.80$, $p = .001$, $n_p{}^2 = .12$; and purpose of knowing, $F\ (1, 89) = 20.10$, $p < .001$, $n_p{}^2 = .18$. The partial eta squared values of the subscales of epistemic beliefs about physics had large effect.

Additional analysis was conducted to categorize students' epistemic levels into low (naïve), less sophisticated (medium category), and sophisticated (high category). This category was determined by calculating the mean score on individual dimensions of epistemic beliefs. The level students' epistemic beliefs about physics scores were determined using Taşkin (2021) criteria by considering the lowest and highest scores and standard deviations.

- Low Level (Naïve): $5 \le x < 11.33$,
- Medium level (Less sophisticated): $11.33 \le x < 17.66$,
- High level (sophisticated): $17.66 \le x \le 25$. (Taşkin, 2021).

Table 4.28 Categories of students mean epistemic beliefs about physics on each dimension

Subscales	Groups	N	Pre-Mean	Post-Mean	Out of 25 points	Category
Sources of knowledge	Treatment	46	3.13	3.50	17.5	Medium
	Comparison	45	3.10	3.19	16.0	Medium
Certainty of knowledge	Treatment	46	2.92	3.51	17.6	Medium
	Comparison	45	2.95	3.14	15.7	Medium
Development of knowledge	Treatment	46	2.86	3.42	17.1	Medium
	Comparison	45	2.91	3.05	15.3	Medium
Justification for knowing	Treatment	46	2.92	3.89	19.5	High
	Comparison	45	3.09	3.37	16.9	Medium
Purpose of knowledge	Treatment	46	3.02	3.66	18.3	High
	Comparison	45	3.05	3.23	16.2	Medium
Purpose of knowing	Treatment	46	3.08	3.84	19.2	High
	Comparison	45	3.09	3.21	16.1	Medium
Total	Treatment	46	3.16	3.76	18.8	High
	Comparison	45	3.15	3.31	16.6	Medium

Note: Each dimension has five items.

As shown in Table 4.28, students in both groups had less sophisticated beliefs on each dimension based on their pre-mean scores. Despite individual differences, the pre-mean score results indicated they did not hold naive beliefs. There were improvements in the mean scores of epistemic beliefs components after the recipe-based practical work intervention, however, students still held less sophisticated beliefs (medium category). For the treatment group, students remained on the less sophisticated beliefs (medium category) on sources of knowledge, certainty of knowledge, and development of knowledge even after dialogic-practical work approach intervention.

However, after the dialogic-practical work approach intervention, students transformed from less sophisticated beliefs to sophisticated beliefs on the overall mean score and on the justification for knowing, the purpose of knowledge, and the purpose of knowing. The results indicated that the dialogic-practical work approach was more effective in changing students' beliefs about the justification for knowing, the purpose of knowledge, and the purpose of knowing than on the source of knowledge, the certainty of knowledge, and the development of knowledge.

4.1.2.4.2 Analyses of gender difference on Epistemic Beliefs about Physics scores

The sub-research question was: *How do secondary school female and male students differ in their epistemic beliefs about physics test scores?*

The purpose of this sub-research question was to find out whether there are any differences in epistemic beliefs about physics between female and male secondary school students. Independent samples t-test was performed to find out whether students' epistemic beliefs about physics differed by gender before and after the intervention.

Table 4.29 Female and male students' results of EBPs scores

Variable	Groups	*N*	*M (SD)*	*t*	*df*	*Sig.*
Pre-EBPs score	Female	20	3.16 (.28)	- 0.30	44	.76
	Male	26	3.17 (.23)			
Post-EBPs score	Female	20	3.54 (.34)	- 1.35	44	.19
	Male	25	3.71 (.42)			

As shown in Table 4.29, female and male students showed no significant differences in epistemic beliefs before the intervention, *t* (44) = - 0.67, *p* = .50. Female and male secondary school students had the same epistemic beliefs about physics before the implementation of dialogic-practical work. The result also showed that no gender-specific differences in epistemic beliefs post-mean score were found following the dialogic-practical work intervention, *t* (44) = -1.35, *p* =.19. According to the descriptive statistics, male students, M= 3.71, SD =.42, who used the dialogic-practical work technique had somewhat higher mean scores for their epistemic views about physics than female students, M= 3.54, SD =.34.

Further independent sample t-test analysis was done to see if any significant differences were found on each gender-specific subscale as illustrated in Table 4.30.

Table 4.30 The Independent sample T-test for the subscales of EBPs post mean scores

Subscales of EBPs	Gender	*N*	*M (SD)*	*t*	*df*	*Sig.*
Sources of knowledge	Female	20	3.22 (.46)	- 2.58	44	.01
	Male	26	3.70 (.65)			
Certainty of knowledge	Female	20	3.21 (.50)	- 2.51	44	.02
	Male	26	3.72 (.72)			
Development of knowledge	Female	20	3.41 (.44)	- 0.15	44	.89
	Male	26	3.43 (.58)			
Justification for knowing	Female	20	3.91 (.44)	0.25	44	.81
	Male	26	3.88 (.41)			
Purpose of knowledge	Female	20	3.62 (.60)	- 0.45	44	.66
	Male	26	3.70 (.50)			
Purpose of knowing	Female	20	3.83 (.45)	- 0.11	44	.92
	Male	26	3.85 (.61)			

On the source of knowledge, a statistically significant mean score difference was observed between male and female students who were exposed to the dialogic-practical work method, *t* (44) = -2.58, *p* =.01, d =.74. The results revealed that male students, *M*= 3.70, *SD* = .65, who was assigned to the dialogic-practical work method outperformed female students, *M* = 3.22, *SD* = .46 in sources of knowledge with a medium effect size. Similarly, there was a statistically significant mean score difference between male and female students on the certainty of knowledge, *t* (44) = -2.51, *p* =.02, d =.71. The results showed that male students, *M* = 3.72, *SD* = .72, who were exposed to the dialogic-practical work method scored higher in the certainty of knowledge than female students, *M*= 3.21, *SD* = .50, in the same group with medium effect size.

In contrast, there was no statistically significant post mean scores difference between female and male students on the development of knowledge, *t* (44) = -0.15, *p* = .89; justification for knowing, *t* (44) = 0.25, *p* = .81; the purpose of knowledge, *t* (44) = -0.45, *p* = .66; and purpose of knowing, *t* (44) = -0.11, *p* = .92. These findings showed that male students that employed a dialogic-practical work method performed equally with female students on knowledge development, knowledge justification, knowledge purpose, and knowledge purpose.

4.1.2.5 Analyses of the contributions of dependent variables on Mechanics achievement

The first sub-research question was: *Are there significant correlations between the post-mean scores of science process skills, attitude towards physics, epistemic beliefs about physics, and mechanics achievement?*

First, analyses were done to determine the relationships between achievement in mechanics and science process skills, physics-related attitudes, and epistemic beliefs. The assumptions of measurement level, related pairings, lack of outliers, and linearity should be verified before using the Pearson correlation. The scatterplot shows that the variables are linearly associated and that all the dependent variables are measured at regular intervals. Further investigation revealed no outliers. Therefore, the degree and direction of the link between the five dependent variables may be determined using Pearson's Product-Moment Correlation. Table 4.31 shows the relationships among students' Mechanics Achievement, Science process skills, Attitudes towards physics, and Epistemic Beliefs about Physics.

The magnitude of a correlation coefficient is displayed as follows: $r < 0.19$ (negligible); 0.20 – 0.39 (low); 0.40 – 0.59 (moderate); 0.60 – 0.79 (substantial); and $r > 0.79$ (high to very high) *(*Cohen, 1988). The results revealed a moderately significant positive correlation between mechanics achievement and science process skills, *r* (44) =.57, *p* < =.001. Achievement in mechanics showed a strong correlation with attitudes toward physics, *r* (44) =.64, *p* < .001, as well as epistemic beliefs about physics, *r* (44) =.77, *p* < .001. According to the results, students who performed well in mechanics also performed well in science process skills. Students having positive attitudes about physics also possessed advanced epistemic beliefs about it and vice-versa. While, science process skills had a moderate correlation with epistemic beliefs towards physics, *r* (44) =.44, *p* =. 001 and between epistemic beliefs about physics and attitudes towards physics, *r* (44) = .52, *p* < .001.

Table 4.31 The inter-correlations among dependent variables of the treatment group

Variables	Mean	SD	MA	SPS	ATP	EBP
Mechanics Achievement (MA)	13.22	2.31	1	.57**	.64**	.77**
Science process skills (SPS)	10.83	3.01		1	.30**	.44**
Attitudes towards Physics (ATP)	3.90	.41			1	.52**
Epistemic Beliefs about Physics (EBP)	3.76	.22				1

Note: * *p* < .01, ** *p* < .001.

However, there was only a weakly positive connection between students' science process skills and their attitudes toward physics, *r* (44) =.30, *p* =.023. These results showed a positive correlation between physics learning outcomes. When one variable increases, the others also increase. The correlations between achievement in mechanics, science process skills, attitudes toward physics, and epistemic beliefs about physics for the comparison group are displayed in Table 4.32.

Table 4.32 The inter-correlations among dependent variables of the comparison group

Variables	Mean	SD	MA	SPS	ATP	EBP
Mechanics Achievement (MA)	9.98	2.97	1	.27*	-.03	.11
Science process skills (SPS)	8.87	2.61		1	.06	.56**
Attitudes towards Physics (ATP)	3.44	.48			1	.33*
Epistemic Beliefs about Physics (EBP)	3.31	.27				1

Note: * *p* < .01, ** *p* < .001.

The Pearson correlation results showed that science process skills were moderately correlated with epistemic beliefs about physics, *r* (43) = .56, *p* < .001. Mechanics achievement had a significantly low correlation with science process skills, *r* (43) = .27, *p* = .04. Similarly, attitudes towards physics had a significantly low correlation with epistemic beliefs about physics, *r* (43) = .33, *p* = .013. However, the comparison group's mechanics achievement had a very weak negative correlation with attitudes toward physics.

The second part of the research was: *What is the contribution of science process skills, attitude towards physics, and epistemic beliefs about physics to students' mechanics achievement scores?*

This sub-research question aimed to determine the predictive effects of science process skills, attitudes toward physics, and epistemic beliefs about physics on students' mechanics achievement scores. There was one dependent variable for mechanics achievement and three dependent variables such as science process skills, attitudes towards physics, and epistemic beliefs towards physics. To answer this research question, multiple linear regression was used. There are six assumptions to meet to conduct multiple regressions.

The first assumption was the data's non-multicollinearity. This assumption can be checked in two ways: correlation coefficients and variance inflation factor (VIF) values. The above subsection showed that the correlations between mechanics achievement and science process skills, attitudes towards physics, and epistemic beliefs about physics and vice versa were not more than .80, so they were not too highly correlated. Furthermore, the Variance inflation factor (VIF) scores below 10 and tolerance scores above 0.2 can also be used to assess this assumption. As VIF scores were well below 10 (science process skills = 1.76, attitudes toward physics = 2.19, and epistemic beliefs about physics = 1.94) and tolerance scores above 0.2 (science process skills

= 0.57, attitudes toward physics = 0.46, and epistemic beliefs about physics= 0.52) this assumption has been met. In the same way, the scatterplot indicated a linear relationship between the independent and dependent variables.

The third presumption was the independence of residual values. Durbin-Watson statistics tested the assumption that residuals are independent or uncorrelated. These statistics might range from 0 to 4. To satisfy the third presumption, the value should be close to 2. Values below 1 and over 3 are problematic and may invalidate the analysis. The Durbin-Watson statistical test indicated that the value 1.77 was near to 2, hence, this assumption had been met.

The fourth supposition was the homoscedasticity test. For this assumption to be met, the plot of the standardized residuals versus the standardized projected values must not show overt signs of funneling. The plot demonstrated that homoscedasticity was met. The sixth presumption was the normal distribution of residual data. By examining the model's Predicted Probability (P-P) plot, this assumption was put to the test. When the dots lie closer to the diagonal line, the residuals were normally distributed. The P-P plot for the model indicated that the residual normality assumption appears to have been satisfied.

The last presumption was the existence of notable outliers that may affect the model. All of them had Cook's distance values under 1, indicating that particular situations weren't overly affecting the model. The analysis of the assumptions revealed that multiple regression was a suitable parametric statistic to determine the predictive effects of science process skills, attitudes towards physics, and epistemic beliefs about physics on students' mechanics achievement score. The predicted mechanics achievement score is given by the following linear equations:

$$\text{Predicted MA} = \text{constant} + \beta_1 \text{ SPS} + \beta_2 \text{ ATP} + \beta_3 \text{ EBPs}$$

The multiple regression results indicated that the science process skills, epistemic beliefs about physics, and attitudes towards physics significantly predicted students' mechanics achievement test score, $F(3, 42) = 36.45$, $p < .001$ (i.e., the regression model is a good fit for the data).

Table 4.33 Multiple Regression Analysis of contributing variables of the treatment group

Variables	B	SEB	β	t	Sig.	η^2
Science process skills	.23	.08	.26	2.89	.006	.41
Attitudes towards physics	1.72	.55	.30	3.14	.003	.44
Epistemic beliefs about Physics	2.96	.60	.50	4.92	.000	.60
Constant	-6.65	2.05				

Note: R = .85; $R^2 = .72$; adj. $R^2 =.60$, $F(3, 45) = 36.45$, $p < .001$.

As indicated in the Table 4.33, the adjusted *R* squared value was .60. This result indicated that 60 % of the variance in mechanics achievement was explained by the model. In other words, the three dependent variables (science process skills, epistemic beliefs about physics, and attitudes towards physics) collectively predicted 60 percent of the mechanics achievement score. Cohen (1988) says this is a large effect. The standardized beta coefficient for science process skills, $\beta = .26$, $p = .006$; attitudes toward physics, $\beta = .30$, $p = .003$; and for epistemic beliefs about physics, $\beta =.50$, $p < .001$. Therefore, science process skills, 26%; attitudes toward physics, 30 %; and epistemic beliefs about physics accounted for 50% of the prediction of students' mechanics achievement scores.

$$\text{Predicted MA} = -3.35 + .26 \times (\text{SPS}) + .30 \times (\text{ATP}) + .50 \times (\text{EBPs})$$

The students' achievement in mechanics was significantly influenced by all their science process skills, attitudes toward physics, and epistemic beliefs about physics. The beta weights suggested that good test scores with epistemic beliefs about physics contribute most to predicting mechanics achievement. This indicated that students having sophisticated epistemic beliefs tended to score high in mechanics achievement test. Likewise, students' positive attitudes toward physics also contributed to this prediction. There was a significant contribution from epistemic beliefs about physics for 50 percent of students' mechanical achievements, followed by attitudes towards physics for 30 percent, and science process skills for 26 percent.

4.2.2.6 Secondary school students’ Scientific Argumentation skills scores

The sixth research question was: *Is there a significant difference in secondary school students’ scientific argumentation skills mean scores over eight weeks of intervention?*

This study examined how students’ scientific argumentation skills change over time after exposing them to dialogic-practical work for eight weeks in physics laboratories. While there were eight dialogic-practical work sessions throughout the intervention, only four video recordings of the treatment group were considered for analysis: G2, G4, G6, and G8. These videos were selected so that we could see the potential changes in students’ scientific argumentation skills at the beginning, middle, and end of the intervention. These videos were coded using the Assessment of Scientific Argumentation in the Classroom (ASAC) observation protocol (*See Appendix E*). This rubric contained eighteen items with six items each examining the conceptual, epistemic, and social components of scientific argumentation skills. Each item was rated on a scale from 0 (Not at all) to 3 (Often). Zero was the lowest possible score and 54 was the highest possible score.

The change in scientific argumentation skills was assessed in terms of overall mean improvements in scientific argumentation throughout the eight weeks of dialogic-practical work interventions. It also examined how students' cognitive, epistemic, and social aspects of scientific argumentation skills changed over time. Table 4.34 shows the calculated mean ASAC scores for each scientific argumentation session. The dependent variable was students' scientific argumentation skills, whilst the independent variable was time (i.e. with four related groups where each four-time point was considered a "related group"). Measured by the mean score (± SD), the treatment group's overall scientific argumentation skills increased from 18 (±0.48) at the beginning of the intervention (Time 1) to 31(±0.75) at the end of the intervention (Time 4). The data have marked deviations from normality. Hence, a repeated measures Friedman test was used to analyze students' argumentation skills improvement.

Table 4.34 Descriptive statistics for ASAC scores on each aspect of argumentation

		Means scores of the Scientific Argumentation				
DPW observation sessions	N	Conceptual	Epistemic	Social	Mean	SD
1	18	6	4	8	18	0.48
2	18	7	6	9	22	0.62
3	18	9	7	10	26	0.62
4	18	10	8	13	31	0.75

The ASAC mean scores of the dialogic-practical work group varied statistically significantly across the four-time points, X2 (3) = 21.77, *p* < .001. The findings showed that students who participated in the dialogic-practical work approach performed better in the last time period, M = 31, SD =.75 than they did during the first interval, M= 18, SD = .48; second interval, M = 22, SD =.62; and third interval, M = 26, SD =.62. These results indicated that mean scores increased considerably throughout four intervals of time. However, the final mean score of 31 (time 4) showed that the outcome was still well below the maximum 54 attainable points.

The students' overall average score on conceptual and cognitive components was 8 out of 18, the epistemic component was 6.25 out of 18, and the social aspect was 10 out of 18. This indicated that students showed a positive change in the mean scores within each of the three aspects of scientific argumentation after they were repeatedly exposed to dialogic-practical work in the physics laboratory. However, the improvement was not uniform in all components of scientific argumentation skills. For example, students' scores on conceptual and cognitive aspects of scientific argumentation increased from 6 (1st time) to 10 (4th time). In the epistemic aspects of scientific argumentation, students scored from 4 to 8. In the social aspects of scientific argumentation, students' scores improved from 8 to 13. It indicated that, on the whole, students scored low on epistemic aspects of scientific argumentation. Scientific argumentation requires students to demonstrate progress in each aspect.

A Wilcoxon signed-rank test was used to determine which time periods revealed significant differences as indicated in Table 4.35. The results showed a significant difference between Time 4 and Time 1, Z = -3.36, *p* =.002, Time 4 and Time 2, Z = -2.89, *p* =.008, Time 3 and Time 1, Z = -3.00, *p* = .003, and Time 3 and Time 2, Z = -2.12, *p* =.03, respectively. Between Time 2 and Time 1, Z = -1.73; *p* =.08, and Time 4 and Time 3, Z = -1.27; *p* =.17, there was no discernible change. It indicated that students' argumentation skills improved slowly from the beginning of the intervention session to the final intervention session. This evidence suggested that scientific argumentation skills improvement requires multiple exposures to a dialogic-practical work approach.

Table 4.35 Multiple Comparison Test Using Wilcoxon Test

Time Intervals	N	Z	Sig. (2-tailed)
Time 2-Time 1	18	-1.73	.08
Time 3-Time 1	18	-3.00	.003
Time 3- Time 2	18	-2.12	.03
Time 4- Time 2	18	-2.89	.008
Time 4-Time 3	18	-1.27	.17
Time 4- Time 1	18	-3.36	.002

* Chi-square (X^2) = 21.77, df = 3, $p < .001$.

Table 4.36 shows the students' ASAC scores on individual items. Even after dialogic-practical work, students did not progress on some items of conceptual and cognitive argumentation. For example, on item 4, students had to allow a variety of ideas to be presented as well as challenge and negotiate them critically. Students did not progress on this item. Students simply accepted others' ideas without asking for reasons unless the teacher challenged them. On this item, students did not engage in critical thinking; instead, they simply accepted others' ideas.

Table 4.36 The conceptual and cognitive aspects of ASAC Observation protocol

Item	Descriptive of individual items on each aspect of scientific argumentation.	1st Video	2nd Video	3rd video	4th Video
1	The talk of the group was focused on solving a problem or advancing understanding.	1	1	2	3
2	The participants sought out and discussed alternative claims or conclusions.	1	1	2	1
3*	The participants modified their explanation or claim when they noticed an inconsistency or discovered anomalous information.	1	1	1	2
4	The participants were skeptical of ideas and information.	1	1	1	1
5	The participants provided reasons when supporting or challenging an ideas.	1	1	2	2
6*	The participants attempted to evaluate the merits of each alternative claim or explanation in a systematic manner.	1	1	2	1
Conceptual and cognitive sub score		6	7	9	10

*Note: 0 = not all, 1= once or twice, 2= a few times, 3= often. * These items need reverse rating.*

Table 4.37 shows the students' scores on the epistemic aspect of scientific argumentation items. Despite students showing a positive change in the mean scores of these items, they did not show progress on items 8, 9, and 11. Item 8, focused on students evaluating the amount and kinds of evidence used to support a claim or explanation. Students sometimes work on identifying relationships between multiple pieces of evidence. However, students rarely determine the availability of enough evidence to support their ideas. In item 9, students rarely assessed the quality of the evidence provided for a claim or explanation based on how well the data was gathered, analyzed, and interpreted. In item 11, students did not explicitly understand trends and logical connections among empirical data.

Table 4.37 The epistemic aspects of ASAC Observation protocol scores for each item

Item	Descriptive of individual items on each aspect of scientific argumentation.	1st Video	2nd Video	3rd Video	4th video
7	The participants used evidence to support and challenge ideas or to make sense of the phenomenon under investigation.	1	1	2	1
8*	The participants examined the relevance, coherence, and sufficiency of the evidence.	0	1	1	1
9	The participants evaluated how the data was gathered, analyzed or interpreted.	1	1	1	1
10	The participants used scientific theories, laws, or models to support and challenge ideas or to help make sense of the phenomenon under investigation.	0	0	1	3
11	The participants made distinctions and connections between inference and observations explicit to others.	1	1	1	1
12	The participants used the language of science to communicate ideas.	1	2	1	2
Epistemic sub score		4	6	7	8

Table 4.38 shows that students scored high on social aspects of scientific argumentation. Yet, students did not show changes only on item 17. On item 17 students were expected to engage in in-depth discussions without making implicit judgments or assumptions about other students' ideas or views. However, students used this opportunity rarely (once or twice). Students did not participate in critically rephrasing or summarizing comments and asking each other to identify their strengths and weaknesses.

Table 4.38 The social aspects of ASAC Observation protocol scores for each item

Item	Descriptive of individual items on each aspect of scientific argumentation.	1st video	2nd Video	3rd Video	4th Video
13	The participants were reflective about what they know and how they know.	2	2	2	3
14	The participants respected what each other had to say.	2	3	3	3
15	The participants discussed an idea when it was introduced into the conversation.	1	1	2	2
16	The participants encouraged or invited others to share or critique ideas.	1	1	1	2
17	The participants restated or summarized comments and asked each other to clarify or elaborate on their comments.	1	1	1	1
18	There was equal participation from all members of the group.	1	1	1	2
Social sub score		8	9	10	13

4.2 Qualitative Results

This section focused on qualitative data analysis to answer two research questions. The seventh research question had two sub-research questions, such as:

7.1 How do students interact with each other during dialogic-practical work sessions?

7.2 How does the teacher interact with the students to facilitate dialogic-practical work sessions?

The eighth research question was: *How do students perceive the dialogic-practical work approach?*

This section provides qualitative data and analysis regarding how secondary school students engaged in a dialogic-practical work approach in a physics laboratory. Qualitative data were gathered through small group video recordings and individual semi-structured interviews. The researcher collected four small group video recordings during the eight weeks of the dialogic-practical work approach intervention. The semi-structured interview data were collected at the end of the dialogic-practical work intervention. Qualitative data analysis was used to explore how students and the teacher engaged in dialogic talk moves while exposed to the dialogic-practical work approach. Moreover, this study analyzed how students perceived dialogic-practical work and the elements that were most encouraging and challenging to them.

4.2.1 Students’ dialogic talk moves

The research question was: *How do students interact with each other during dialogic-practical work sessions?*

The first qualitative research question focused on exploring how students interact with each other during dialogic-practical work sessions. The utterances of the students were coded in the current study using a set of preset categories created by Andersson and Enghag (2017). While codifying the dialogic discourses of the students, an equal effort was taken to separate concepts from arguments. According to Nielsen et al. (2016), the definition of a concept or an argument depends on the circumstances. As a result, in order to determine the appropriate context, the coding procedure involved carefully considering what had been stated in the debate before. To make sure the codes accurately represented the content, the coding procedure involved multiple revisions.

Apart from the initial transcription, all video analyses were performed by the researcher and the research assistant. In this analysis, a step-by-step discourse analysis was conducted starting from conceptualization to the scientific explanation stage. Four full-length dialogic-practical work videos were transcribed and themes were categorized in terms of dialogic-talk moves. From the qualitative analysis three major themes emerged: types of talk, purposes of students’ talks, and students’ modes of participation in group work.

Types of talk

The first feature considered in the analysis of student-student interaction was the types of talks students made in the dialogue during dialogic-practical work sessions. These talks are distinguished based on how students interact with each other. Student-student dialogic talks were grouped into three categories: cumulative, exploratory, and disputational talks. In these transcriptions, 138 student-student interactions were coded. In terms of time, the qualitative results indicated that students spent most of the time conducting scientific investigations, which corresponded to 47% of the time, followed by conceptualization, which spent 43 % of the time, while the conclusion and the scientific explanation together consumed 10% of the time.

The percentage of student-student interaction utterances showed that out of the 138 student-student interaction utterances coded, cumulative talk types were the most common (66 instances or 48 percent), exploratory talk types were second (61 instances or 44 percent), and disputational talk was the least (11 instances or 8 percent). This qualitative analysis indicated that students engaged in cumulative, exploratory, and disputational talks during dialogic-practical work investigations. The cumulative talk was the most frequently applied, followed by an exploratory talk, and least in a disputational talk. However, the students' talk types showed variations in the conceptualization, investigation, conclusion, and scientific explanation phases of dialogic-practical work. In general, students engaged in mostly exploratory talk during the conceptualization phase, followed by the conclusion phase of the dialogic-practical work. In the investigation phase, students mainly engaged in cumulative talks. Only occasionally did the students engage in disputation talks. Sample excerpts showing how students were involved in each talk type will be presented and discussed in the next subsection.

The purpose of students' dialogic talk moves

The purpose of the students’ talk was to explore the function for which the students used their dialogic-talk moves during the dialogic-practical work approach. Based on the results of the study, it was found that the different talks promoted different purposes. The purposes of talk moves in dialogic-practical work were categorized into the linguistic level: interaction and content and the cognitive level: interaction and content. Andersson and Enghag (2017) identified 29 dialogic talk moves further grouped into cumulative, disputational, and exploratory talks. Out of 61 exploratory talk moves, the students were frequently involved in qualifier dialogic talk moves (20%), extended (16 %), challenged (13 %), and questioning (10 %). Qualifier, challenged, and extended were categorized at the linguistic level-interaction. Questioning was categorized as cognitive level-content.

Likewise, the percentage of the most frequently implemented cumulative talk moves was confirmation (18%), participation (14%), and repetition (13.5%). Confirmation and repetition were categorized under interaction at the linguistic level and participation at the content linguistic level. The following sample excerpts were provided to show and exemplify how students engaged in different dialogic talk moves and the purposes of each move.

Excerpt 1: Students’ dialogic talk moves during the conceptualization phase

The following activities were handed out for the students to discuss in groups.

Students were given a floating object K with one-third of its parts below water and two-thirds above it. If object K was divided into two pieces (L and M having different sizes), they were asked to predict the positions of L and M when immersed in the same liquid. Will they sink or float? Which explanation is correct?

A. When a floating object is cut into two parts, the volume of the smaller sinking part will decrease.
B. When a floating object is cut into two parts, the volume of the sinking part of the bigger piece will increase.
C. The sinking or floating part of an object does not depend on the object's size.

D. The volume of a liquid in a container does not affect the position of the object in the liquid and its floatation.

Table 4.39 shows an excerpt extracted from student-student discussions on the factors that determine whether an object floats or sinks in a liquid.

Table 4.39 showed student-student dialogic talk moves during discussions of the question.

Line	Participants	Student-student dialogic talk moves	Types of talk moves
6	Abel	Already object K is a floating object, then when it is cut into two parts (L and M); each part will float.	Qualifier
7	Daniel	Yes, both L and M will float.	Confirmation
8	Abel	Hence, both alternatives A and B are wrong.	Considering
9	Daniel	[Yeah], I agree with Abel both alternatives A and B are false.	Accepting
10	Sammy	If we agree that floating does not depend on the volume of an object, then it also does not depend on size.	Extended
11	Abel	I think C is correct.	Accepting
12	Momina	Does the volume affect the floating of an object?	Questioning
13	Daniel	It does not affect.	Confirmation
14	Momina	[Then] the correct answer should be either C or D.	Engaging
15	Abel	No, the correct answer is only C.	Challenged

As can be seen in Table 4.39, the students were involved in hot discussions. Students did well on the questions and completed the discussion within the given time frame. It was found that most of the students' conversations were primarily exploratory. Among the exploratory talk moves, students offered qualifiers for others to consider (line 6), accepted a statement and broadened it (line 9), and challenged the qualifiers (line 15). The dialogic talk moves in this episode contains a lot of questions and answers (line 12). In this exploratory talk sequence, the students consider and challenge each other’s ideas, and they contribute by sharing relevant information and building on previous experiences.

The students seek agreement through discursive moves such as qualifier, which could be challenged or accepted and thereafter extended by others. These talk moves were categorized under linguistic level interaction. Students, however, failed to challenge each other's ideas by providing enough evidence, arguments, and counterarguments to the expected level. For example, the group mates raised similar ideas simply by extending Abel's ideas from the volume of an object to the size of an object (Line 9). They seemed to focus on reaching consensus on the fact that the volume and size of the object did not affect the floating and sinking of the object. Similarly, the group members changed their minds without justifying why they took that position. On few occasions, students were involved in exploratory talk moves including considering (Line 8), questioning (Line 12) and engaging (Line 14). These talk moves were categorized at the interaction-cognitive level, which focused on enabling students to act and make progress on the task. On the other hand, the students were also involved in confirmations twice which was cumulative talk. These talk moves were further categorized as linguistic level-interaction.

Excerpt 2: Students’ talk during the conceptualization phase

Further excerpts were presented in table 4.40 to illustrate students' dialogic-talk moves part of the dialogic-practical work approach.

Which of the following affects the magnitude of the friction force exerted between two contacting bodies?
A. The roughness or smoothness of the two contacting bodies.
B. The speed of the moving.
C. The surface area of the two contacting bodies.
D. The mass of the object sliding over another object.
E. The normal perpendicular force acting on the contacting bodies.

As shown in Table 4.40, the students presented exploratory talk moves including qualifiers (2 instances), challenges (2 instances), and extending (one instance). Compared to the first transcript, students demonstrated more exploratory talk moves. The discussion began with Mohamed’s response to the teacher’s question about surface nature on friction force magnitude. Mohamed replied that rough objects exert more friction than smooth surfaces and his group mates also agreed with his answer. They proceeded to the second alternative.

Table 4.40 Sample excerpt extracted from the dialogic practical work video recordings

Line	Participants	Student-student dialogic talk moves	Types of talk moves
35	Mohamed	[Yeah] Alternative A is correct. Rough surfaces exert more friction than smooth surfaces.	Qualifier
37	Yonas	Alternative B is correct. Yes, the speed of a moving object affects the magnitude of the friction force. Objects travelling with high speed creates less friction.	Qualifier
38	Hailu	No, fast moving objects have more friction than slowly moving objects.	Challenged
39	Tigist	No, the magnitude of the friction force does not depend on the speed of a moving object.	Challenged
40	Yonas	[Yeah]. You [Tigist] are correct, friction force does not depend on the speed of the object.	Extended

While in the second alternative students raised various contrasting ideas. For instance, Yonas claimed that objects traveling at high speed exert less friction than slow-moving objects (Qualifier). Immediately, Hailu opposed his idea that fast-moving objects resulted in more friction than slowly-moving objects (Challenged). Hailu argued that it is more difficult to stop a car from moving at fast speeds than slowly moving cars. Contrarily, Tigist challenged both ideas and took the position that friction force did not depend on the speed of an object (Line 39). Here, no one challenged her. Why? She did not even provide a valid justification.

Yonas changed his initial claim that objects traveling at high speeds create less friction and agreed with Tigist's idea (Line 40). The strong side of this episode was that students had a heated discussion among themselves by raising various ideas. However, students still had difficulties challenging others' qualifiers by presenting sound evidence, quality arguments, claims, and justifications to either convince or refute each other's ideas.

Excerpt 3: Students' dialogic talk moves during the conceptualization phase

Table 4.41 shows the third excerpt taken while students engaged in a dialogic-practical work approach. The students were asked to determine the effects of amplitude, length of a string, and the mass attached to a string on the period of a simple pendulum.

Discuss in groups to decide whether the following claims is/are true.

A. The amplitude affects the oscillation's period.
B. The rope length has an inverse relationship with the pendulum's vibration period.
C. The pendulum's swinging mass affects the vibration period.
D. The period of a pendulum shortens as it becomes heavier.
E. As the oscillation angle widens, a simple pendulum's period lengthens.

Table 4.41 Sample excerpt extracted from the dialogic practical work video recordings

Line	Participants	Student-student dialogic talk moves	Types of talk moves
82	John	Mass affects the period of a simple pendulum.	Qualifier
83	Members	Yes, the mass impacts the oscillation period of a simple pendulum.	Accepted
84	Eden	It will quickly complete the oscillation as the mass falls.	Extended
86	John	No, the period shortens as the mass increase.	Challenged
87	Abel	I disagree with your contentions. There is no correlation between mass and time period.	Challenged
88	Member	Spoke aloud in groups to show their disagreement with Abel.	
89	Eden	The period decreases with increasing mass. In short, the oscillation duration is shortened with increasing mass.	Repetition

As shown in Table 4.41, the students engaged in exploratory talk moves such as qualifiers, challenges, and extensions. In the beginning, John said the period depends on the mass attached to the string. All the group members agreed on the effect of mass on the period of a simple pendulum. However, they raised contradictory ideas about the relationship between mass and period. For example, Eden stated that as the mass decreases, the oscillation will be completed in a short time (Line 84). While John challenged Eden’s idea (Line 86). In line with this, Abel challenged the above arguments by simply saying that the period does not depend on the masses attached to a string (Line 87). Abel tried to convince them by providing examples.

However, no one provided arguments or counterarguments to convince him or consider his doubts and justifications. His group members ignored his idea and moved on to the next alternative. Eden stated that as the mass increases, the period decreases (Line 89). The teacher understood that the students were reaching the wrong conclusion, however, allowed them to entertain diverse ideas and refrained from directly correcting them. He asked them to verify their hypothesis through practical investigations. This indicated that the teacher allowed students to engage in diverse ideas. From the above three excerpts, it can be concluded that in the conceptualization phase, students argued with each other about the topics of investigation.

The students were mainly engaged in exploratory talk moves such as presenting qualifiers, challenging others' ideas, and extending them by fully or partially accepting other ideas. Linguistically, these talk moves were grouped in the interaction. As the dialogic-practical work sessions progressed, students engaged in more exploratory talk moves. For example, in the first excerpt, students provided qualifiers and challenged only once. In the second excerpt, they provided qualifiers twice and were challenged twice. In the third excerpt, they raised the qualifier once and were confronted by other students twice. As the dialogic-practical work session progressed, students engaged in a more exploratory talk during conceptualization even though engagement was not uniformly improved.

However, most student-student interactions failed to provide quality scientific arguments and counterarguments, evidence, and justification to convince or challenge others’ ideas. Most often students confirmed or repeated others' utterances instead of raising their own opinions in line with or against others’ ideas. Sometimes students participate in cumulative talks during the conceptualization phase.

Excerpt 4: Students' dialogic talk moves during the investigation phase

Table 4.42 presented the transcript to show how students were involved in dialogic talk moves during the investigation phase.

Table 4.42 Sample excerpt extracted from the dialogic practical work video recordings

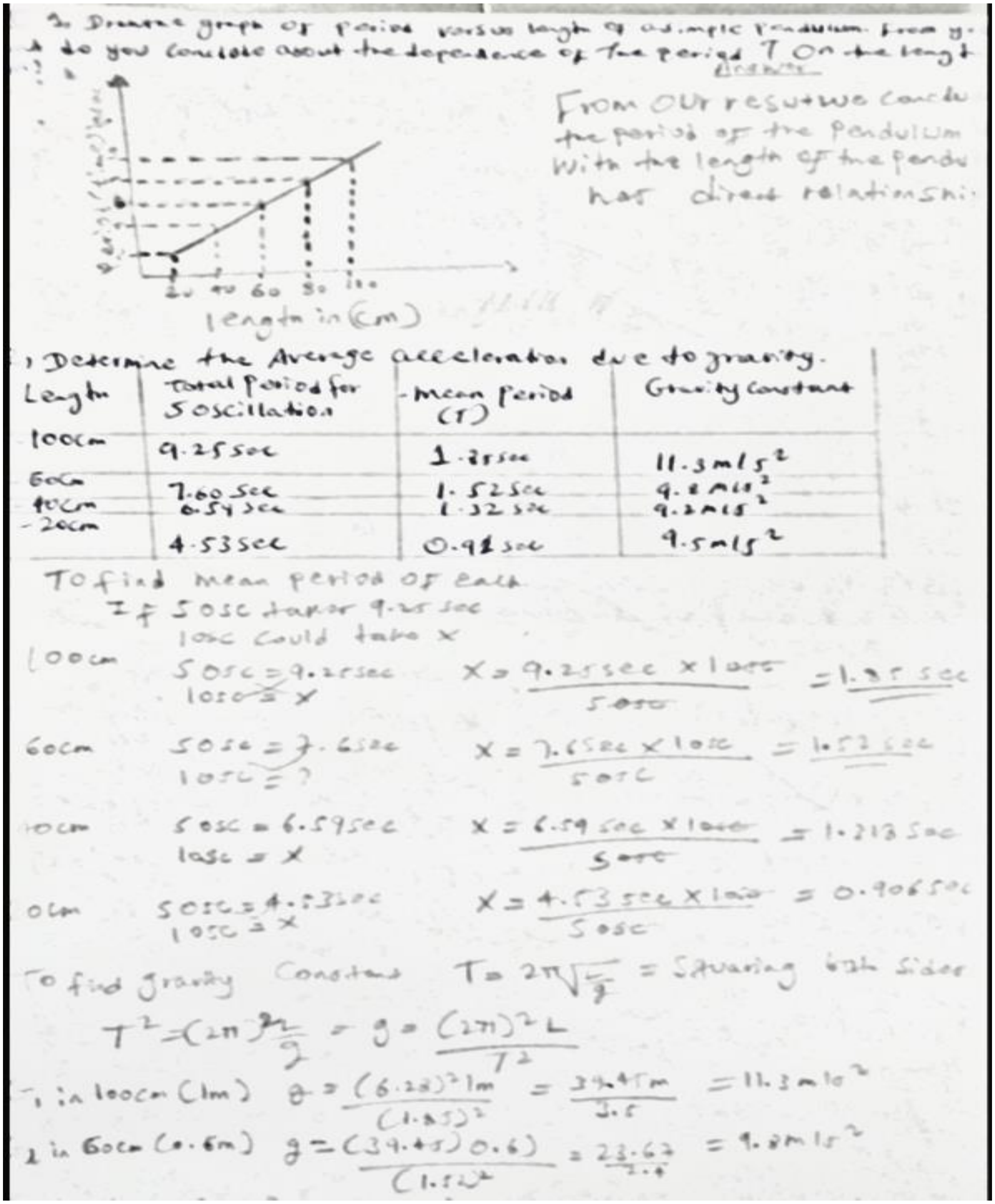
Lines	Participants	Student-student dialogic talk moves	Types of talk moves
88	Yonas	[Ahmed], please tell us what we should do.	Request for action
89	Ahmed	Take l = 100cm, and angle = 10 degrees constant. Let's start by using mass m_1= 200g. (They collaborated together on setting up the apparatus).	Use of equipment Participation
90	Eden	Please do not change the angle.	Instructing
91	Members	They discussed on how to measure time using a stopwatch.	use of equipment
92	Abel	Tell me when to start the stop watch.	Instructing
93	Yonas	[Abel] you did not record the time correctly, let's repeat this experiment once more. They repeated the experiment once again.	Instructing Targeted work
94	Yonas	Is the length of the string 100 cm?	Requesting
95	Ahmed	[Yeah] it is 100 cm which is still constant. We cannot change the length for the time being.	Use of equipment
96	Abel	The time t_1= 9.45 sec., please record it, Yonas.	Taking notes
97	Yonas	Now, let's take one additional measurement by changing the mass to m_2 = 100g.	Instructing
98	Eden	Now the time becomes t_2= 9.61 sec.	Taking notes
99	Abel	[Yeah] as the mass decreases the period increases. Others also agreed that as the mass decreases, the period increases.	Meaning of a physics concept
100	Teacher	Please repeat the procedure for another mass, m_3= 5g to enable them to consider their conclusions.	Prediction
101	Eden	Now the time t_3 = 9.47 seconds.	Taking notes
102	Ahmed	Something must be wrong.	Informing
103	Teacher	Experimentally you may get different measurements, however, if you critically observed the results, you can conclude that the period of a simple pendulum does not depend on mass.	Generalization

Excerpt 4.42 showed the student-student dialogic talk moves while they conducted practical investigation to verify the relationship between the period of a simple pendulum and length, mass, and amplitude of oscillation. The above excerpt shows that students collaborated to verify the relationship between mass and period of a simple pendulum. They discussed how to set up the equipment, use it, and take notes. These dialogic-talk moves were categorized as cumulative

talk. They started the investigation by seeking actions to initiate students’ participation. For example, Ahmed told them what to do (Line 89) and they participated in setting up the equipment, recording data, and implementing. They also engaged with each other in instructing three times and requesting once, which were categorized at an interaction-cognitive level.

These talks were focused on collecting data. These talk moves helped students make progress on the task. It provided them with smooth interactions directed from one person to another, for example, instructing and informing and concerned about what they are about to do and how they should do it, for example, measuring or recording time. In the cumulative talk, the aim was to help the group progress with the task. During the investigation phase, the students were primarily involved in confirmation, participation, and repetition. A few times the students were involved in participation and targeted work which indicated the purpose of the students' talk sequence. However, the students were not critically arguing with each other to understand the trends of the data and the effects of experimental errors on the data.

Two sample data analyses and interpretations performed by a group of students were presented in Figures 4.1 and 4.2. In Figure 4.1, the students in this particular group drew the graph of the period versus the length of a simple pendulum. They concluded that the pendulum period increases with pendulum length and has a direct relationship. Next, they calculated the acceleration due to gravity constant using the investigation value. Students in this group found that the average gravity acceleration was 9.95 m/s^2. In Figure 4.2, they drew the graph of the period of a simple pendulum versus the mass attached to it. Based on the graph, they reached the following conclusion: “Period and mass have an inverse relation. Period decreases with mass increase". In fact, this conclusion was wrong.



3. Draw the graph of period versus length of a simple pendulum. From y... do you conclude about the dependence of the period T on the length?

Answer

From our result we conclude the period of the pendulum with the length of the pendulum has direct relationship

1) Determine the Average acceleration due to gravity.

Length	Total Period for 5 oscillation	Mean Period (T)	Gravity Constant
100cm	9.25 sec	1.85 sec	$11.3 m/s^2$
60cm	7.60 sec	1.52 sec	$9.8 m/s^2$
40cm	6.54 sec	1.32 sec	$9.2 m/s^2$
20cm	4.53 sec	0.91 sec	$9.5 m/s^2$

To find mean period of each

If 5 osc takes 9.25 sec
1 osc could take x

100cm 5 osc = 9.25 sec
1 osc = x
$x = \frac{9.25 sec \times 1 osc}{5 osc} = 1.85 sec$

60cm 5 osc = 7.6 sec
1 osc = ?
$x = \frac{7.6 sec \times 1 osc}{5 osc} = 1.52 sec$

40cm 5 osc = 6.59 sec
1 osc = x
$x = \frac{6.59 sec \times 1 osc}{5 osc} = 1.213 sec$

20cm 5 osc = 4.53 sec
1 osc = x
$x = \frac{4.53 sec \times 1 osc}{5 osc} = 0.906 sec$

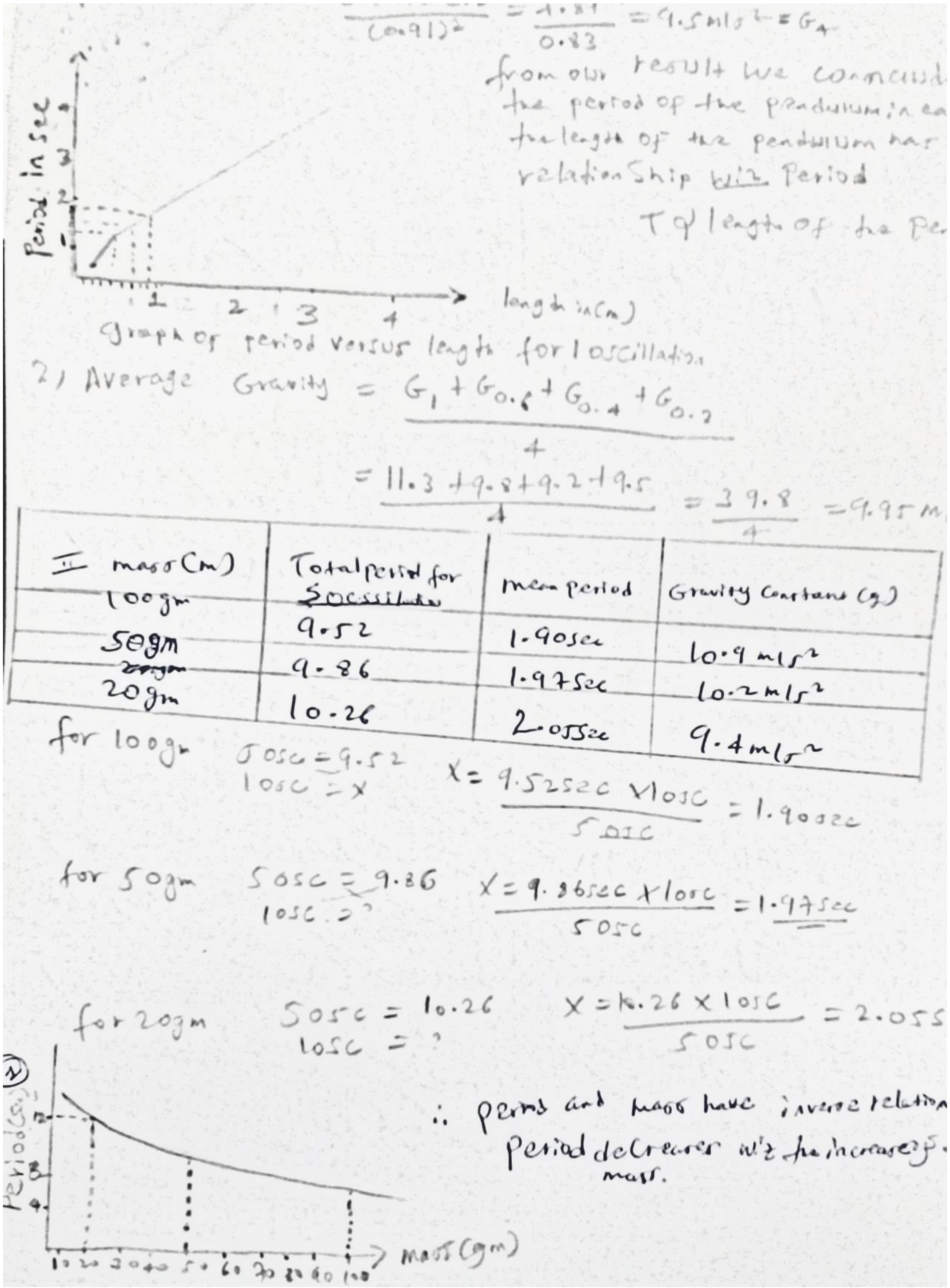
To find gravity constant $T = 2\pi\sqrt{\frac{L}{g}}$ = Squaring both sides

$T^2 = (2\pi)^2\frac{L}{g} = g = \frac{(2\pi)^2 L}{T^2}$

1 in 100cm (1m) $g = \frac{(6.28)^2 1m}{(1.85)^2} = \frac{39.45m}{3.5} = 11.3 m/s^2$

2 in 60cm (0.6m) $g = \frac{(39.45)(0.6)}{(1.52)^2} = \frac{23.67}{2.4} = 9.8 m/s^2$

Figure 4.1 An example of a data analysis prepared by a group of students.



$\frac{\quad}{(0.91)^2} = \frac{\quad}{0.83} = 9.5 m/s^2 = G_4$

from our result we concud
the period of the pendulum in ca
the length of the pendulum has
relationship w/z Period

T ∝ length of the pe

graph of period versus length for 1 oscillation

2) Average Gravity = $\frac{G_1 + G_{0.6} + G_{0.4} + G_{0.2}}{4}$

$= \frac{11.3 + 9.8 + 9.2 + 9.5}{4} = \frac{39.8}{4} = 9.95 m$

II mass (m)	Total period for 5 oscillation	mean period	Gravity Constant (g)
100gm	9.52	1.90sec	10.9 m/s²
50gm ~~20gm~~	9.86	1.97sec	10.2 m/s²
20gm	10.26	2.055sec	9.4 m/s²

for 100gm 5osc = 9.52
1osc = x

$x = \frac{9.52 sec \times 1 osc}{5 osc} = 1.90 sec$

for 50gm 5osc = 9.86
1osc = ?

$x = \frac{9.86 sec \times 1 osc}{5 osc} = 1.97 sec$

for 20gm 5osc = 10.26
1osc = ?

$x = \frac{10.26 \times 1 osc}{5 osc} = 2.055$

∴ period and mass have inverse relation
period decreases w/z the increasing of mass.

Figure 4.2 An example of a data analysis prepared by a group of students participants.

Excerpt 5 – Students' dialogic-talk moves during the investigation phase

Table 4.43 Sample excerpt extracted from the dialogic practical work session

Lines	Participants	Student-student dialogic talk moves	Types of talk moves
148	Jemila	The first mass is at a distance of 25.5 cm and the second mass is at a distance of 26.5 cm. Hence the two masses are not equal (seesaw principles should be implemented).	Taking notes/ participation
149	Yacob	Take an unknown mass of a stone and determine its' mass.	Participation
150	Tringo	Let's work out using equilibrium conditions.	Instructing
151	Bekele	The distance is changed, so what is the distance?	Requesting
152	Jemila	I think we should count the readings from the meter stick.	Implementation
153	Yacob	Are we subtracting from 51.5cm to 25 cm?	Requesting
154	Yacob	Let's use the equilibrium formula to determine the unknown mass.	Targeted work
155	Bekele	[Yeah]: m= 100 g, g = 10 m/s^2, s_1= 27.5 cm = .275 m; they collaborate on the calculation. r_2= 26.5 cm = .265m, unknown mass =?	Participation
156	Tringo	We should convert 100 g into kilograms and lengths into meters.	Instructing
157	Jemila	The formula is $m_2 = m_1 g x_1 / g x_2$= 27.5 cm/26.5 cm.	Participation
158	Bekele	Do you have scientific calculator?	Requesting
159	Yacob	Asked some inactive group members whether they are clear or not, they responded that we are clear about it. Some students were not actively engaged in doing the discussion.	Confirmation
160	Members	Few students are continuing to do the calculations: $m_2 = m_1 g x_1 / g x_2$= 27.5 cm/26.5 cm = 105.8 gram, which is the mass of unknown object.	Informing

Throughout Table 4.43, the students communicated on how to take measurements (Line 148) and then determined the mass of an unknown object (Line 160). During this time, students participated in cumulative talk moves like confirmation, action request, participation, and informing. These cumulative talk moves were categorized as interaction at linguistic levels. There were also questions posed to ask permission to talk or do something. They also interact with each other to respond, inform others, and show their confirmation or react to the questions they were asked. Sometimes students used talk moves to encourage others to record measurements. The students used these talk moves in the form of questions that required reactions from their peers in the form of confirmation, some required the provision of some kind of known information, and the rest required answers from the other members of the group. The qualitative analysis results extracted from these two excerpts revealed that during the investigation phase, the students were mainly involved in cumulative talk. The next two excerpts illustrate how students were involved in dialogic-talk moves at the conclusion and scientific explanation phases.

Excerpt 6 – Students' talk during the conclusion and scientific explanation phase

Table 4.44 Sample excerpt extracted from the dialogic practical work session

Lines	Participants	Student-student dialogic talk moves	Types of talk moves
120	Teacher	Who can summarize what we have learnt today?	Evaluation
121	Ahmed	Today we learned that the length of a string has a direct effect on the period of a simple pendulum.	Creating a new knowledge
122	Abel	Today we learned about the relationship between period and mass, length, and amplitude. We saw that period does not depend on mass, however, has direct relationship with length of a string.	Conceptual understanding
123	Teacher	The teacher summarized the daily lesson by explaining the direct relationship between period and length, and no relationship between mass and the period. The formula for period of a simple pendulum is $T = 2\pi\sqrt{\frac{l}{g}}$ where l represents length and g is acceleration due to gravity.	Generalization

Table 4.44 shows how the teacher concluded the dialogic-practical work session. In this episode, the teacher did not provide an opportunity to reflect on their findings to the whole class. In this respect, the teacher asked the students to summarize the daily practical work lesson. Abel summarized that the period of a simple pendulum has a direct relationship with the length of the string. It is independent of the mass attached to it and the amplitude of its oscillation (Line 122).

The teacher used the formula of the period of a simple pendulum to explicitly conclude its direct relationship with the square root of the length. It is inversely proportional to the square root of gravity acceleration.

Excerpt 7: Students' talk during the conclusion and scientific explanation phase

Table 4.45 shows a sample excerpt from the last dialogic-practical work session. As opposed to the excerpts above, the teacher used authoritative-interactive communication by frequently intervening in interactions between students.

Table 4.45 Sample excerpt extracted from the dialogic practical work session

Lines	Participants	Student-student dialogic talk moves	Types of talk moves
161	Bekele	I think we did something wrong because the masses are not the same.	Qualifier
162	Jemila	We are correct, because the distances are not the same.	Challenged
163	Members	We should repeat the procedures by changing the unknown mass as well as the mass of the meter stick.	Participation
164	Yacob	Write the given values, Mass = 0.1 kg, x_1= 13.5 cm, x_2= 40 cm, then m_2=?	Participation
165	Jemila	Please make sure that your measurements are correct. $m_2 = m_1x_2/x_1 = 0.1kg \times .40m/.135m$ =? It is not correct I think you did wrong.	Informing
166	Bekele	Let me tell you once again, x_1= 65 cm-51.5cm = 13.5cm, x_2= 40cm.	Informing
167	Yacob	Write the formula to find the unknown mass as: $m_2 = m_1x_2/x_1$= 100g x 40cm/13.5cm = 296g= .296kg.	Participation
168	Members	They proceeded to the next question.	
169	Teacher	How a father and a child can balance each other in a seesaw?	Prompt for justification
170	Bekele:	Based on the formula: $m_2 = m_1x_1/x_2$. If $x_1 > x_2$, then $m_2 > m_1$ and if $x_1 < x_2$, then $m_2 < m_1$.	Creating new knowledge
171	Teacher	Who can tell me how it is possible to determine the mass of a meter stick using the conditions of equilibrium?	Prompt for prediction
172	Yacob	Let's shift the position of the center of mass of the meter stick to the left. Now its distance becomes: x_1= 3.5 cm, the mass of the known object is m_1 = 200 g is located at a distance of x_2= 7.5 cm from the pivot point.	Participation/requesting for actions
173	Bekele	Now we can determine the mass of the meter stick using the formula: $m_2 = m_1gx_1/gx_2$= 100 g. Hence, the mass of the meter stick is 100g.	Evaluating results

In particular, the teacher did not effectively implement the conclusion phase of the dialogic-practical work approach. The possible reason extracted from the video recording was the lapse of time. Because this session was conducted in the morning when the students finished the regular class. Hence, they were exhausted to argue with their peers. That was why at some points a student presented qualifiers (Line 161) and the other students challenged this claim (Line 162). These conversations were exploratory. In the next line, they began to collaborate with each other to take measurements, which was a cumulative talk. To conclude the teacher took only a few minutes to wrap up the dialogic-practical work session on time. Each group did not get an opportunity to present their findings to the whole class. This indicated that the teacher used too much control to make conclusions and address students' misconceptions associated with the topic being investigated.

Students’ modes of group work participation

The third feature of student-student interaction analyzed in this study was how students participated in group work. The analysis was made based on the number of talk turns used by the group members during the dialogic-practical work sessions. As can be seen from the transcription, variations were noticed in the students' participation in their group work across the dialogic-practical work sessions. In most dialogic-practical work sessions, students actively participated without dominance of one or two students. Each group member was active in student-student interactions. The whole episode showed that students collaborated at each phase of the dialogic-practical work sessions. However, in some episodes of the transcript, there was a dominance of one or two students who made many talk turns. For example, the video recorded during the second dialogic-practical work session (see Table 4.39) showed that two students

(Abel and Daniel) interacted with each other more than the other group mates. In this episode, Sammy spoke only once during the conceptualization phase, while Abel spoke four times. In the remaining episodes, student-student interactions were improved. In the last episode, however, some students did not actively participate in the discussion (Table 4.43). These students ignored a group member's invitation to participate in group work and continued talking sideways. During this dialogic-practical work session, unlike the other episodes, the teacher was observed to apply an authoritative interactive approach in the conceptualization phase. Most students were inactive during this session. The present study suggests that teachers should closely guide each group member in participating actively in dialogic-practical work. In addition, the guiding questions should not be too challenging and beyond the students' understanding levels.

Summary

Qualitative data analysis revealed that students were engaged in various dialogic talk moves in the dialogic-practical work approach. Throughout the dialogic-practical work sessions, cumulative talk was the most frequently implemented talk type, followed by exploratory talk and disputational talk in varying degrees. In the conceptualization and conclusion phases, the students engaged in more exploratory talk. During the investigation phase, most students were involved in cumulative talk moves whereas, they were involved in disputational talk only on a few occasions. The cumulative talk serves to facilitate students' practical work progress, while exploratory talk is used to direct students' conceptual progression initiated by cumulative talk sequences.

Although the cumulative talk moves are less in-depth cognitively than the exploratory talk sequences, they appear to be used as a compass during practical work, allowing students to use action moves like instructing, seeking, and providing information, keeping them on track, and directing them forward. It can be said that exploratory talk is the most beneficial type of educational talk because it encourages students to challenge, accept, and extend each other's statements and work toward consensus at the linguistic level. Indeed, it enables them to assess prior knowledge and create connections between new and old knowledge on a cognitive level. Additionally, throughout the dialogic-practical work sessions, the students produced more features of dialogic talk moves and showed significant progress in the number of dialogic talk moves generated from the beginning to the last session.

The results of the study showed that groups did not adequately organize dialogic talk to the expected level during each phase of dialogic-practical work. For example, students did not reflect on their findings to the whole class and defend their claims against classmates' critiques. The students also failed to realize the importance of justifying their claims and rarely challenged their colleagues' views. When controversial ideas were discussed, groups did not see the need to settle their differences through scientific argumentation. Neither side provided sufficient counterarguments, claims, and arguments to support their reasoning scientifically.

This study was conducted in a secondary school setting in Ethiopia where the traditional lecture method is a deeply ingrained norm in the classroom. Moreover, practical work in a physics laboratory was used sparingly. Teachers sometimes use teacher demonstrations and infrequently practical work based on recipes. Therefore, this qualitative analysis revealed that there is a promising possibility to implement dialogic-practical work in secondary schools. It can also positively affect the quality and quantity of students' dialogic talk moves elicited in dialogic-practical work. Even though most of the students’ talks were both related and relevant to students’ learning, a close analysis of the talks showed that they were not enough to promote knowledge co-construction. First, the students’ poor background knowledge of the topic being investigated prevented them from critically providing arguments, evidence, and counterarguments. When students had difficulties understanding the topic, they failed to participate actively during small group discussions.

The second reason was some students' dominance. In a few dialogic-practical work sessions, some students were dominant, while others did not actively participate in discussions. It resulted in a small number of talk turns during group discussions and data analysis and interpretations. Third, the teacher struggled to manage time to implement the whole dialogic-practical work activity in a single period. Due to the insufficient amount of time given to each phase of the dialogic-practical work approach, students were limited in their participation in critical arguments and forced to stop group work to move on to the next phase. Students should thus be given adequate time and room for dialogic-practical work sessions so that they can manage all aspects of finishing the task at hand as well as develop new knowledge. It is critical to picture a conducive classroom setting where students are allowed to speak in their ordinary language and are also encouraged to use physics terminology in relevant tasks.

4.2.2 Teacher’s dialogic-practical work talk moves

The second sub-research question was: *How does the teacher facilitate students’ dialogic-talk moves during dialogic-practical work sessions?*

This subsection analyzes how teachers scaffold, support, and promote dialogic-practical work by using dialogic talk moves. Teachers must think about how to scaffold their students' learning and create activities that will guarantee students' active engagement in the learning process. As a result, the teacher's role is crucial in determining how and where students learn. This can be achieved through communicating with one another, exchanging ideas, and scaffolding students' learning through language. The main aim of the qualitative analysis is to identify characteristics of the dialogic discourse moves employed by the teacher. It also highlighted how these discourse moves involved students in the creation, defense, and assessment of knowledge claims during dialogic-practical work sessions.

Qualitative analysis was conducted based on these three themes: knowledge construction, evaluation, and justification. The qualitative analysis indicated that the teacher engaged in dialogic talk moves that focused on knowledge construction (62 %), evaluation (25 %), and justification (13 %). The teacher used 44 dialogic talk moves in the construction of knowledge claims (23 instances during the conceptualization phase, 12 instances during the investigation phase, and 9 instances during the conclusion and scientific explanation phase). On the justification for knowledge claims, 4 out of 9 (conceptualization phase), 3 out of 9 (investigation phase), and 2 out of 9 (conclusion and scientific explanation phase).

Construction of knowledge

Among indicators of constructing knowledge, the teacher was involved most in prompts for arguments (11.3%) in which students were asked to present their argument to convince others, prompts for evidence (10 %), and providing evidence (10 %). The prompt for counter-argument accounted for 7% and allowed students to consider alternative positions to their own or others' ideas. These dialogic talk moves were to motivate students to participate in productive dialogic teaching. The analysis indicated that the teacher appropriately implemented various epistemic actions throughout various phases of the dialogic-practical work. The qualitative analysis showed that the teacher's dialogic talk moves were not consistent across phases of dialogic-practical work. The following sample excerpts show how the teacher implemented various talk moves that focused on knowledge construction at different phases of the dialogic-practical work sessions.

Excerpt 7: Teacher's talk moves during the conceptualization phase

The conceptualization phase was used to brainstorm students' ideas about the topic to be investigated. The teacher would initiate the discussion by introducing arbitrary data, and asking students to explain and justify their claim based on quality evidence.

Table 4.46 Sample except showing students' discussion on the floating and sinking.

Line	Participants	Students' transcription	Discursive move
1	Teacher	This lesson is about determining the factors that affect the floating and sinking of objects. Please go through all the alternatives one by one and choose the correct answers.	Explanation
17	Teacher	Object K is floating in a liquid. One-third part of K is above the liquid and its two third part is below the liquid. If this object is cut into different size pieces (L and M), what do you think are the positions of L and M when immersed in the same liquid?	Prompt for description Prompt for argument
25	Teacher	I think you still have confused about the positions of objects L and M when they are immersed in the same liquid. For example, let's take a floating wooden block, cut it into two different pieces, and immersed it in the liquid. Can these pieces float or sink in the same liquid?	Analogies and metaphors Prompt for evidence
30	Teacher	[Yeah], C is the best answer. Because the size and volume of an object do not affect the floating and sinking of the object. It is only the density of an object that determines the floating and sinking of the object. Alternative D is about the effect of the volume of the liquid, not the object. The volume of the liquid does not affect the levels of floating and sinking of an object. Hence, both C and D are correct answers.	Generalization Evaluation

During this session, students were asked to determine the factors that affect the floating and sinking of objects in liquids. In this transcript, the teacher explained what the students should workout. In most cases, the teacher waited patiently for different voices from the students as they interacted. He gave the students the opportunity to reflect on their ideas about the investigation topic by posing various questions. When he observed that students had confusion about the question, he described it in greater detail (prompt for description) followed by posing questions as a prompt for argument (Line 17). The findings of the qualitative analysis shown in Table 4.46 revealed that the teacher used a variety of dialogic talk strategies, including explanation, prompts for description, argument, and evidence, as well as analogies and metaphors, to encourage students to share their claims and provide support for them in their groups.

These dialogic-talk techniques helped advance knowledge and highlight facts that students may utilize to deepen their comprehension of the subject under investigation. For instance, a description often gives the lesson's or activity's context. These talk moves were used to construct scientific knowledge. This indicates that the teacher attempted to engage students in knowledge construction during the conceptualization phase. This signifies that the teacher guided students to develop an understanding of new concepts. However, a few times, the teacher was observed to hurry up to conclude that the sinking and floating of an object in a liquid does not depend on the shape, size, and volume of objects (Line 30).

Excerpt 8: Teacher’s talk moves during the conceptualization phase

The next sample excerpt shown in Table 4.47 was taken from students' discussions about the factors that affect the period of a simple pendulum.

Table 4.47 The following excerpt showed the period of a simple pendulum

Lines	Participants	Students' transcription	Discursive move
58	Teacher	Here as usual questions are given with alternatives. You can discuss the effects of amplitude, length, and masses on the period of a simple pendulum. Please go through each alternative in detail.	Explanation
65	Teacher	Amplitude means the maximum distance from the equilibrium position. It indicates the angle of inclination with the vertical position either to the left or to the right. Period refers to the time required to make one complete oscillation. How do you see the relationship between the amplitude and period of a simple pendulum?	Explanation Prompt for justification
70	Teacher	What do you think is the relationship between the length and period of a simple pendulum by pointing his finger at a female student [Eden]?	Prompt arguments
74	Teacher	You do not seem to understand what direct and inverse relationships mean. Ahmed said that as the length decreases, the period decreases. However, he said that the relationship is inverse. Do you agree with his idea?	Prompt for counterarguments
79	Teacher	What do you think is the relationship between the period and length of a simple pendulum?	Prompt for evidence
81	Teacher	What is the relationship between the period and mass of a simple pendulum?	Evaluation
83	Teacher	Is there anyone who has a different position?	Prompts for counter-argument

In the above dialogic-talk dynamics, the teacher implemented various dialogic-talk moves to sustain student-student interactions. The teacher, for example, used dialogic talk to introduce the topic (Line 65). Instead of giving students information directly, the teacher gave them prompts to help them build an understanding of the scientifically accepted explanation of a phenomenon (Lines 70 and 79). He accomplished this by juxtaposing many opposing viewpoints with the scientific theory. He actively included students in the formulation and critique of knowledge claims by allowing them to examine how accurate the various alternatives were.

These discourse strategies also assisted the students in shifting their focus from the superficial elicitation of ideas to the development of deeper thinking and reasoning.

The teacher also applied dialogic talk moves that guide student-student interactions by giving hints and posing questions. The analysis indicated that during the conceptualization phase, the teacher applied more dialogic talk moves focused on knowledge construction. At least, the teacher did not directly attempt to provide correct answers even when students formulate wrong hypotheses. However, student-student interactions were short-lived and focused on consensus. The teacher was unable to provide an extended discussion by providing sound evidence and arguments. Moreover, the teacher lacked the expertise to critically challenge the reasons why the students agreed with the statements. The researcher suggested that the teacher should implement more epistemic actions to engage students to argue with each other by presenting valid arguments to promote the construction of knowledge.

Excerpt 9: Teacher's dialogic talk moves on dialogic-practical work session

Table 4.48 shows the teacher's dialogic talk moves during the investigation, conclusion, and scientific explanation phases. During the investigation phase, the students formulated a wrong hypothesis about the relationship between mass and period. The teacher asked students to verify their hypothesis by conducting investigations. The teacher patiently waited for the students to verify their hypothesis through investigation. After taking two measurements, the students still could not reach the correct conclusion about the relationship between the period of a simple pendulum and the mass attached to the string. The teacher still asked them to take more measurements (Line 100). However, they decided to stay with their initial claim that as the mass increases, the period of a simple pendulum decreases. The teacher generalized that the period of a simple pendulum does not depend on mass.

Table 4.48 The following excerpt showed the period of a simple pendulum

Lines	Participants	Students' transcription	Discursive move
100	Teacher	Please repeat the procedure for another mass, m_3= 5g to enable them to consider their conclusions.	Prediction
103	Teacher	Experimentally you may get different measurements, however, if you critically observed the results, you can conclude that the period of a simple pendulum does not depend on mass.	Generalization
104	Azeb	Teacher, do you mean that the mass does not affect the period of a simple pendulum?	Repetition
105	Teacher	[Yeah]. The period of a simple pendulum does not depend on the mass.	Generalization
106	Eden	What happen if we use a balloon instead of such bobs of mass?	Challenged/ student questions
107	Teacher	Due to air resistance, the period cannot be constant compared to these masses.	Evaluation
108	Teacher	We are running out of time, please proceed to the second practical activity. Here you should keep the mass and amplitude constant, then measure the period by varying the length of the string [The teacher do not forward the question to other group members'].	Explanation
120	Teacher	The theoretical value for acceleration due to gravity was 9.81 m/s^2. To verify the result, please calculate the acceleration due to gravity based on the measured data. The formula for the period is T= $2\pi\sqrt{\frac{l}{g}}$. string. However, acceleration due to constant is the same on the surface of the earth. However, acceleration due to constant is the same on the surface of the earth.	Compare and contrast Generalization
123	Teacher	Using this formula, it is possible to determine the acceleration due to gravity to verify it. Do not forget to divide the time by 5 to get the period for a single complete oscillation.	Description
124	Teacher	The teacher summarized the daily lesson by explaining the direct relationship between period and length, and no relationship between mass and the period. The formula for period of a simple pendulum is T= $2\pi\sqrt{\frac{l}{g}}$ where l represents length and g is acceleration due to gravity.	Generalization

In the investigation phase, the teacher did not use talk moves that critically challenge students to present sound arguments. On the other hand, the teacher used dialogic-talk moves such as explanation, description, generalization, and prompts for arguments. These talk moves focused on introducing a topic, sharing scientific, and concluding results. These talk moves resulted in the students' collaborating to collect data, do calculations, and reach conclusions. They had little value in critically engaging students in knowledge construction. During the conclusion phase, the teacher was expected to apply dialogic talk moves that guide the students to share their findings and arguments with peers, give feedback to other groups, realize the strengths and weaknesses of findings, and arguments to revise.

The teacher ought to have taken advantage of this chance to include students in the process of knowledge development. The teacher failed to appropriately use dialogic talk moves that would have allowed students to share their results with the entire class. The teacher employed talk moves techniques during the scientific explanation phase that were specifically focused on summarizing the key ideas of the practical work. To help students establish a scientific perspective, build models, support scientific perspectives, and amend the proposed hypothesis, the teacher primarily generalized the key findings of the dialogic-practical work inquiry. Although the teacher encouraged students to engage in argument construction, he did not adequately use these strategies.

Justifying knowledge claims

In this context, justifying knowledge claims focuses on argument strength. Dialogic-talk move prompt for justification (13%) was the most commonly implemented epistemic operation. It focused on asking students to justify how they know their opinions or actions. Sometimes the teacher used these talk moves by using questions such as ‘why’ and ‘how do you know’ to strengthen an argument. The teacher used the following question to prompt students for justification, for example: How can a father and a child balance each other on a seesaw? In this respect, the researcher would argue that prompting for justification serves a significant function in physics practical work. Physics teachers should consistently use it as part of their talk moves.

Evaluating knowledge claims

The teacher also used dialogic talk moves such as evaluation, prompt for evaluation, compare and contrast, prompts for comparison, counter-argument, and prompt for counter-argument to evaluate knowledge. Students were engaged in evaluation (10%) and in counter-argument (7%) by the teacher. On the evaluation of knowledge claims, 8 out of 18 (conceptualization phase), 6 out of 18 (investigation phase), and 4 out of 18 (conclusion and scientific explanation phase). As shown in Table 4.49, the teacher assessed the students by (a) asking more questions during which he offered other perspectives or encouraged them to examine alternative ideas, and (b) giving further explanations or making generalizations in front of the entire class. Sometimes, the teacher's questioning sequence led the class immediately to the right response or justification for the subject under discussion. As an example, the teacher provided the students with responses (Line 30).

In another instance, the teacher asked students to answer the questions: Why the larger mass is needed to be near the pivot? However, only one student answers the question, and the teacher does not react to the response. This means that such interactions lack uptake and coherence. Because, neither the student was asked to elaborate or clarify the response nor to another student to create social interactions among students.

Table 4.49 A sample excerpt showing teacher’s dialogic-talk moves

Lines	Participants	Students’ transcription	Discursive moves
30	Teacher	[Yeah], C is the best answer. Because the size and volume do not affect the floating and sinking of the object. It is only the density that determines the floating and sinking of the object. Alternative D is about the effect of the volume of the liquid, not the object. The volume of the liquid does not affect the levels of floating and sinking of an object. Hence, both C and D are correct answers.	Evaluation Generalization Evaluation
43	Teacher	Yes, of course, you are right, let’s use the same type of materials with different masses. Then, the teacher demonstrated how mica is sliding on a horizontal table and overlapped two micas, then slide them on a horizontal surface.	Evaluation. Prompt for comparison
81	Teacher	What is the relationship between the period and mass of a simple pendulum?	Evaluation
127	Teacher	The result should not deviate this much from the actual value. I think you did something wrong. Tell me what time and length you used.	Evaluation
130	Yonas	Oke, now the value of g becomes 10.36 m/s^2.	Evaluating results
131	Teacher	Why the value of g is not exactly equal to 9.81 m/s^2?	Evaluation, prompt for argument
132	Ahmed	It is due to experimental errors.	Creating new knowledge

Sometimes, the teacher avoided answering the students’ questions. For example, the teacher engaged students in high-level evaluation questions (Line 131). He was responsive to their ideas and attempted to elicit the answers he wanted through further questioning. He also prompts students to consider alternative evidence and justify their viewpoints. Results showed that the teacher most often used low-level questions, resulting in short responses from students. To improve students' ability to engage in evaluation, the teacher should consistently provide them with high-level evaluation questions and counterarguments.

Summary

The way teachers talk to, and with, their students can influence the dynamics of the teacher-student relationship, which in turn can create space for knowledge construction by teachers and students. A qualitative analysis demonstrated the teacher's willingness to implement dialogic talk moves in dialogic-practical work sessions was a typical characteristic of embryonic forms of dialogic teaching. The findings indicated that several features of a dialogic-practical work approach to planning and decision making could be observed. The teacher involved the students in intense discussions throughout the dialogic-practical work sessions. The observed teacher also attempted to scaffold and support students to engage in a dialogic-practical work approach. It can be understood that these embryonic forms of dialogic teaching signaled that students and teachers were interested in implementing features of this approach. This interest could be encouraging.

However, several indicators of dialogic-talk moves were missing from the quoted extract. Most often, students were not encouraged to explain their responses. They could not engage in critical construction of ideas that would enable them to develop arguments. The teacher rarely encouraged students to explain their ideas with sound evidence, arguments, and justifications. Furthermore, the teacher did not appropriately use justificatory talk such as *Prompts for justification* and evaluative talk: *Prompts for Evaluation* and *Prompts for Counter-Argument*. This inconsistency would suggest that justificatory and evaluative talk moves were not sufficiently embedded in the dialogic-practical work sessions compared to knowledge claims construction. This deficiency was noted in many of the recorded episodes of the dialogic-practical work sessions. Very few students find it difficult to realize dialogic-practical work and its features. It was difficult for teachers to balance its full implementation with the goals of their school curricula.

4.2.3 Students’ perceptions about Dialogic-Practical work approach

The eighth research question was: *What are students' perceptions about the dialogic-practical work approach in physics laboratories?*

In this section analyses of students’ perceptions about dialogic-practical work were presented. A semi-structured interview was conducted with four students from the dialogic-practical work group (*See Appendix G*). This interview was to understand students' perceptions about dialogic-practical work. Semi-structured interviews were conducted with each student individually. Students were interviewed about their prior practical work experiences and feelings about dialogic-practical work. During the interviews, students reflected on their opinions about dialogic-practical work. The interviews were conducted by the researcher in a quiet and comfortable environment and lasted approximately 25 minutes.

Using QDA Lite software, the audio-taped data were transcribed and examined. Finally, the transcribed data revealed five key themes. These themes included the students' prior experiences with practical work, the value of practical work in general, the value of dialogic-practical work in particular, the role of the teacher during dialogic-practical work, and elements of dialogic-practical work that they found enjoyable. This qualitative analysis was discussed and illustrated by informative examples of students responses.

Theme 1: Students' previous experiences with practical work

When the participants were asked about their previous practical work experiences, some representative responses of the interviewees were given below.

Interviewee I mentioned explicitly that:

> The physics book recommended doing practical activities on different topics, however, teachers most often ignored them. We did not conduct practical work at all, especially in grade 11. However, I remembered that in grade 9 the teacher demonstrated for us only once and in grade 10 the teacher showed us three demonstrations about electric circuits. This might be due to a shortage of laboratory rooms in the school and teachers' workloads. There is only one physics laboratory room for all grades 9 to 12 so they could not manage all classes to do practical investigations. Personally, I had a few experiences doing practical work in groups organized by Bahir Dar University to promote students' learning in Science, Technology, Engineering, and Mathematics (STEM) disciplines.

The second interview added that:

> We did not conduct practical work very often. The teacher demonstrated practical investigations in the chemistry laboratory only once. The possible reason would be due to a shortage of time to conduct practical work with large class sizes in 40 minutes.

The fourth interviewee was added:

> We did not have practical work experience. In grade 9, the teacher performed a demonstration. Teachers most often claim that there are no materials and laboratory rooms to conduct a practical investigation in physics.

Most of the students responded that they did not work in physics laboratories. Some students mentioned one or two practical work experiences in biology, chemistry, or physics throughout grades 9 to 11. In grade 11 all interviewees concluded that there was no physics practical work at all. Furthermore, these students mentioned that teachers demonstrated for them when practical work was involved. Students did not get an opportunity to conduct practical investigations by doing setups either individually or in groups. In short, students had very little experience of practical work in groups in secondary schools.

Theme 2: The importance of practical work

The second interview question was about the importance of practical work in secondary physics laboratories. The responses of the two students were presented below.

The third interviewee explained the following:

> I think practical work can help understand the topic. It can help us verify what we have learned in theory. Seeing things in the real world allows us to see how things fit together and what's behind the bigger picture.

The first interviewee also mentioned a proverb:

> I hear I forgot. I see I remember. I do understand. Practical work helped us understand physics concepts and ideas better than the lecture method. Getting real-world experiences can help us retain them in our brains for a long period.

These interviewees agreed on the importance of practical work for physics learning. It is helpful to verify facts, theories, laws, and principles learned in class. The interviewees commented that practical work can improve students' knowledge and understanding of the subject. In addition, they added that practical work can help them make a physics phenomenon more real through experience. Some of the students also believed that practical physics helped reinforce the theory taught in class. But the majority of these students only highlighted cognitive outcomes when talking about practical work. They were just concerned with mastering the topic. They did not specifically mention developing practical skills, comprehending the complexity of empirical experiments, fostering an interest in science and a desire to learn about it, understanding the nature of science, and developing scientific reasoning and collaboration skills.

Theme 3: The importance of engaging in a dialogical-practical work approach

When students were asked about their real experiences of dialogic-practical work, some interviewees responded as follows:

The first interviewee replied:

> I think providing guiding questions can help us enhance our thinking skills and empower us to better understand the topic. Arguing with each other helped us present diverging ideas before reaching a consensus. The teacher gave us hints for each question, entertained diverging ideas, and encouraged us to do it in groups. The teacher refrained from directly telling the answers to the students. Instead, he gave us freedom while doing practical work and encouraged us to work without frustration.

The fourth interviewee also replied:

> Limiting the roles of our teachers to guiding us while conducting practical investigations helped us to gain more autonomy. It was my first experience conducting practical work in groups with minimal teacher support. Hence, I enjoyed it.

Interviewee 2 also added that:

> The experience was enjoyable. The dialogic-practical work exposed us to physics things we did not know before. For example, we exchanged ideas. Of course, some students with low academic performance relied on students with high academic performance. The teacher gave us hints about questions, procedures, data collection, and analysis. Like the apparatus we used during practical investigations and physics concepts we learned in class.

The third interviewee also added that:

> We enjoyed the actual experiences of handling equipment, observing, measuring, analyzing, and interpreting data in groups. Engaging students in such types of practical work strategies allowed us to express and defend our ideas without fear of being right or wrong. Most practical work activities were implemented well. However, in a few experiments, there was an absence of equipment which limited us to doing all the practical activities as intended. In addition, due to a shortage of time for some practical work, we were in a hurry to finish the tasks.

Based on these quotations, it was evident that students who participated in dialogic-practical work found the practical activities helpful and gave them greater confidence in doing practical work. Students felt that practical activities were not difficult and exposed to new knowledge and apparatus. Additionally, the students mentioned that dialogic-practical work enabled them to freely exchange ideas with their group mates, maximized their learning, and empowered them to express themselves without fear. By arguing with each other, we raised divergent ideas based on evidence.

Theme 4: The teacher's role during practical work

The role of the teacher during practical work was the fourth theme. The interview question prompted students to consider their views on the role of teachers and lab assistants during practical work.

The first interviewee responded:

> The role of teachers should be to distribute the manual beforehand to guide students to conduct practical investigations by themselves. When guidance is needed, teachers should help

> us. I think students can conduct practical investigations alone with minimal teacher support. I don’t advise teachers to demonstrate for us.

The second interviewee was added:

> I believe that the teacher first should show us how to do it, then give us full autonomy to conduct practical work by ourselves.

The third student also responded:

> The teacher's role should be to guide the group while conducting practical work. The teacher should give us partial autonomy to do it alone. He/she should only guide us when doing practical work.

The fourth respondent added:

> I think conducting practical investigations in groups is far better than teacher demonstrations. Teachers should guide and support us when it is needed at any stage of the practical work.

Almost all the interviewees agreed that the teachers' and laboratory assistants’ roles should be limited to giving them hints in the form of questions instead of providing answers directly to them. Additionally, they felt that the teacher should empower students to conduct practical work independently and give them time to discuss diverging ideas with each other. To sustain the argumentation process, the teacher must motivate and provide clues to questions. Responses from the students suggested that the teacher's involvement should be restricted to assisting and leading students' hands-on explorations. The students liked to have some degree of independence while planning the experiment, gathering and analyzing the data, and drawing conclusions. Students have constructivist perspectives on education. Secondary school physics teachers occasionally favored laboratories, in contradiction to the opinions of students.

Theme 5: Aspects of dialogic-practical work that they enjoyed the most

The interviewees explained that practical work in groups was their first experience. They had never had such an opportunity before.

The third respondent mentioned that:

> I think dialogic practical work gives us more opportunities to conduct practical activities on our own. It makes us think about what we are doing and gives us the opportunity to challenge ourselves. For example, okay maybe if I do this and then may it will work. If we do this let us see what happens on our own. And if we are unable to do so, we can ask the teacher to come and help.

The third interviewee explicitly explained as follows:

> Dialogic practical work helped us express and share ideas with the group. Students got a chance to go further to raise even contrasting ideas and were freely entertained before we reached a consensus. This exchange of ideas helped us maximize our physics learning. It was impossible to know whether a student is right or wrong unless they expressed and shared their ideas. Sometimes students change their ideas immediately when confronted by others. It might be due to a lack of confidence in their understanding of the topic.

The second student replied:

> It was my first time getting such an opportunity to conduct practical investigations in groups under the teacher's guidance. To complete the task on time, the teacher only guided us by asking questions. We enjoyed these aspects of dialogic-practical work the most.

Interviewees found dialogic-practical work beneficial to their learning and enhanced their confidence. Dialogic-practical work activities exposed them to new experiences and taught them how to apply physics in real-world situations. Respondents explained that dialogic-practical work provided greater autonomy and encouragement. Furthermore, they added that dialogic-practical work enabled them to express and argue their ideas with each other based on evidence. However, they commented that teachers should devise additional strategies to sustain students' dialogic talk by motivating and giving them more clues to the guiding questions.

Respondents felt that dialogic-practical work investigations were not difficult. Instead, it improved their understanding of physics concepts and gave them more confidence in applying physics. Guidance questions allowed students to construct scientific knowledge. These participants expressed the view that dialogic-practical work encouraged collaboration, equipped them with skills in presenting arguments and evidence, and assisted them to associate theories with real-life experiences.

CHAPTER 5: DISCUSSIONS AND CONCLUSION

Introduction

In this study, the effects of the dialogic-practical work strategy on secondary school students' learning outcomes in physics were compared to those of students who used the practical work approach based on recipes. The practical work method was the independent variable. In this study, mechanics achievement, scientific process skills, attitudes towards physics, epistemic beliefs about physics, and scientific argumentation skills were the dependent variables. The results of the research questions were presented in the previous chapter. The main conclusions of the current study were covered in this chapter, along with studies that supported or refuted it. The key findings of the current study's analysis and its suggested recommendations will then be presented.

5.1 Discussions

5.1.1 Students Mechanics Achievement

The first research question sought to compare the impact of the dialogic-practical work method and the recipe-based practical work approach on secondary school students' mechanics achievement. The results of the independent sample t-test result revealed that the dialogic-practical work method considerably improved students' mean mechanics achievement scores. According to the results of this study, dialogic-practical work approach improved secondary school students' mechanics achievement more significantly than method-based practical work method. The findings of the qualitative data analysis demonstrated that students’ social interactions with one another during the conceptualization phase helped them to gain better understanding about the mechanics topic to be learnt. Besides, the dialogic-practical work approach provided students ample opportunities to share their findings with other groups and dealt with the teacher. Finally, at the scientific explanation phase, the teacher got a chance to clarify any misconceptions students had during dialogic talk.

In the literature, identical results have been reported (Ates & Eryilmaz, 2011; Chambers, 2014; Radulovic et al., 2016). According to Ateş and Eryilmaz (2011), hands-on and mind-on activities improved ninth-grade students' performance in physics. In a similar vein, Radulovic et al. (2016) discovered that, in comparison to conventional teaching methods, inquiry-based experiments and interactive computer-based simulations improved high school students' physics achievement. Additionally, Chambers (2014) revealed that introductory physics students who took part in guided inquiry labs performed higher on mechanics tests. Uniquely, the dialogic-practical work approach explicitly allowed students to engage in exploratory talks. Hence, students argued based on evidence so that they learned the physics contents which directs them to the correct learning track. Indeed, the dialogic-practical approach positively affected students' mechanics achievement.

The findings of the present study also agree with scholars who implemented an argument-driven inquiry strategy (Demircioglu & Ucar, 2015; Taylor et al., 2018; Walker et al., 2012). Taylor et al. (2018) found that students with disabilities who engaged in a structured inquiry-based argument approach scored significantly higher in science achievement with a stronger effect size than the comparison groups. Similarly, Demircioglu and Ucar (2015) found that argument-driven inquiry applied in a physics laboratory improved students’ geometrical optics achievement compared to traditional laboratory instruction with a larger effect size. Unlike, the present study, Demircioglu and Ucar (2015) conducted a study on pre-service science teachers with long years of practical work experience. Hence, the present study found that the dialogic-practical work approach became an alternative teaching method to enhance mechanics achievement of students with low exposure and experience to practical work at secondary school levels.

Similarly, Sedova et al. (2019) showed examined how students' active participation in classroom talk may be connected with better their achievement. Their results showed that the more a student talked in class, the better they performed in a reading literacy test. Moreover, the more a student engaged in reasoning in class, the better their results in reading literacy test regardless of student socio-economic background or gender. However, only a few studies (Baloyi, 2017; Walker et al., 2012) revealed findings that were at odds with the current study. For instance, Baloyi (2017) came to the conclusion that in the written practical exam, the recipe-based practical work group outperformed the explicit reflective guided inquiry laboratory group.

Likewise, Walker et al. (2012) found that the argument-driven inquiry technique used in college chemistry laboratories did not improve students' performance in chemistry. These studies did not provide similar results with the present study due to the variation in the context and settings. For example, the current study was carried out on secondary school students, while, Baloyi (2017) and Walker et al. (2012) worked with freshmen students on introductory laboratory courses. The other reason for the contradiction of results with Baloyi (2017) might be due to the absence of argumentation in the guided inquiry approach. The deviation of the present study from Walker et al. (2012) in the case that the dialogic-practical work approach was more structured, a teacher guided students' learning by delivering the problems being experimented with and the objectives being achieved which ultimately had a significant effect on their achievement.

The current study found that the dialogic-practical work strategy produced substantial gains in mechanics achievement scores between pre and post-interventions. The treatment group's normalized mechanics achievement gain fell into the medium category. This result implied that the students did not perform as expected on the mechanics achievement test. Therefore, students required additional weeks of dialogic-practical work interventions to achieve the intended levels of achievement. This result was in line with those of other studies conducted in the past (Arslan et al., 2023; Parno et al., 2021). For example, Parno et al. (2021) found that the argument-driven inquiry approach increased grade ten students' mechanics performance in the medium category (0.42), while the comparison group’s normalized gain was in the low category (0.06). Their results indicated that the ADI approach can improve students' understanding of Newton's Law concepts. Moreover, Parno et al. (2021) showed that after the implementation of the ADI approach, students still had difficulties understanding some mechanics concepts.

The current study also revealed that the recipe-based practical work group had substantial gains in mechanics performance scores between the prior and following the intervention. However, this group's average normalized learning gain was incredibly low, which was in line with earlier research (Walker et al., 2012). Walker et al. (2012) discovered that both traditional practical work and the argument-driven inquiry groups had higher post-intervention performance throughout the course of the semester with very tiny normalized gains.

5.1.1.1 Gender difference and Mechanics achievement

This section provided the results of the dialogic-practical work approach's influence on the achievement scores in mechanics for male and female students. The findings of the independent sample t-test showed that the dialogic-practical work strategy allowed students of both sexes to do better in mechanics achievement than the recipe-based practical work approach. Similarly, the results of the current study revealed that there was no discernible gender difference among the students who used the recipe-based practical work technique. The results of this study further demonstrated that dialogic practical work, as opposed to the method of practical work based on recipes, increased the accomplishment of both male and female students in mechanics.

Only a few investigations (Kibirige et al., 2014; Walker et al., 2016) supported the present findings. Kibirige et al. (2014) showed that there were no appreciable disparities in physics ability between males and females as a result of the practical work that was implemented. Despite consistent results were reported these scholars applied for practical work on tenth-grade students only for three weeks and compared it with the lecture method. Moreover, the dialogic-teaching features of practical work were absent in this study. In this study, students did not interact socially with each other or with the teacher. Similar results were observed by Walker et al. (2016), who found that the recipe-based practical work performed worse than the argument-driven inquiry approach on the practical test for both male and female students.

However, Walker et al. (2016) found no significant difference in performance between males and females within any group. These researchers provided evidence that students' performance was enhanced by the argument-driven inquiry approach with no appreciable performance distinctions between males and females. There were also findings that contradicted the present study (Lee & Sulaiman, 2018; Musasia et al., 2016). For instance, Lee and Sulaiman (2018) found that male students scored significantly higher than females, despite the fact that practical work tremendously improved female students’ physics achievements. Unlike these studies, a dialogic-practical work approach presented an opportunity for each small group with mixed ability and gender to argue and criticize arguments with each other and the teacher.

This approach encouraged the students to actively engage in dialogic-practical work activities under the guidance of the teacher. It has given them opportunities to write their arguments based on evidence and take responsibility for their own learning. Therefore, regardless of gender differences, students who were exposed to the dialogic-practical work method outperformed those who were exposed to the recipe-based practical work approach. As a result, the mechanics achievement disparity between male and female students was minimized. It can be concluded that the dialogic-practical work approach was a suitable strategy to minimize gender gaps that most nations seek to achieve.

5.1.1.2. Achievement levels and Mechanics achievement

The second subsection focused on the effects of the dialogic-practical work approach on students with varying ability levels' mechanics achievement mean scores. The results from the one-way ANOVA indicated that the dialogic approach to practical work effectively improved mechanics achievement at high, medium, and low achievement levels compared to the recipe-based practical work approach. It was found that the dialogic-practical work approach benefited all students with diverse abilities greatly and resulted in significantly higher mechanics achievement scores on the posttest. According to the findings, low achievement levels had a very large effect size compared with medium and high achievement levels between pre-and post-dialogic practical work intervention.

This finding was of importance because the dialogic-practical work approach resulted in students exposed to this approach improving mechanics achievement. After eight weeks of engagement in a dialogic-practical work approach, the achievement gap between the different ability levels progressively diminished as those at the low achievement level shifted toward the high and medium achievement levels end. For example, applying a dialogic-practical work approach reduced the percentage of students in a low category by 47.5 percent. This approach also increased the percentage of students in the medium and high categories by 20 percent and 21.5 percent respectively. These findings revealed that the dialogic-practical work approach moderately benefited low, medium, and high achievement levels.

The students who achieved the lowest scores on the pre-mechanics achievement test benefitted most from continuous engagement in the dialogic-practical work approach to making sense of the mechanics topics included in the investigation. In the comparison group, the percentage of students in the low category decreased from 73 percent to 40 percent. The percentage of medium category students increased from 25 percent to 47 percent. In the same way, the percentage of students transforming from the low and medium categories to the high category increased from 2 percent to 13 percent. The findings of the pairwise comparison illustrated that students with high achievement levels and medium achievement levels benefitted more from a dialogic practical work approach to improving mechanics achievements than those with low achievement levels.

There were very few studies that agreed with the present results (Gambari & Yusuf, 2016; Yaduvanshi & Singh, 2019). Gambari and Yusuf (2016) found that the computer-assisted Jigsaw II cooperative setting benefitted the high, medium, and low achievement levels with a significant difference among the three achievement levels. Yaduvanshi and Singh (2019) found that secondary school students with low, medium, and high achievement levels who learned with a structured cooperative learning approach outperformed in biology compared to the conventional lecture method. However, some studies contradicted the present finding (Buchs et al., 2015; Eshetu et al., 2017; Han et al., 2015). Buchs et al. (2015) found that highly structured cooperative learning conditions resulted in medium achievement levels progressing more than other achievement levels. Contrarily, Eshetu et al. (2017) found that the cooperative learning method benefited low achievement levels more than high achievement levels.

Han et al. (2015), on the other hand, found that STEM project-based learning activities resulted in low-achievement levels showing higher mathematics growth rates than high and medium levels. These findings contradict the present study for the following reasons. Firstly, STEM project-based learning activities were implemented for three years, while the dialogic-practical work approach lasted only eight weeks. Walker et al. (2016) found that students in the argument-driven inquiry approach performed considerably worse on the practical test than students in the traditional laboratories for students with poor prior academic performance.

Contrarily, Stockdale and Williams (2004) found that the cooperative learning approach resulted in the low achievement levels’ mean exam score increasing by 11 percent. In addition, the medium achievement levels' mean score increasing by 5 percent and the high-achievement levels’ mean scores decreasing by 2 percent. Stockdale and Williams (2004) concluded that cooperative learning substantially benefited the low-achievement levels, moderately benefited the medium-achievement levels, and had minimal impact on the high-achievement levels. In the present study, students worked interactively to argue with their peers. All students benefit from constant coaching, encouragement, and constructive feedback from the teacher.

In the dialogic-practical work approach, the tasks were structured to encourage different achievement levels to argue with each other without fear of ridicule. This approach provided students opportunities to engage in a wide range of activities, such as the generation of hypotheses, providing evidence, arguments and counterarguments, designing laboratory set-ups, data analysis, and discussion of findings. During student-student interactions, high achievement levels explained and clarified the contents to fill the understanding gaps of low achievement levels. As a result, low achievement levels of any concept became clearer, misunderstandings were resolved, and a deep understanding was developed. Meanwhile, the teacher also got a chance to address students' misconceptions and difficulties about the topic while they argued with each other and the teacher.

Likewise, students with medium achievement levels enjoyed and felt challenged to complete their assigned role during the dialogic-practical work approach. Relative to low achievement levels, medium achievement levels felt engaged and active during dialogic-practical work when working with their peers in small groups. These opportunities might be the reason for diverse ability levels' better mechanics performance. However, the findings of the present study showed that the high achievement levels showed significantly high mechanics improvements than the low achievement levels. The first reason might be low achievement levels need more time to adapt to the newly implemented dialogic-practical work approach.

Second, low-achievement levels who lack practical experience and come from a transmissionist classroom culture could face more cognitive demands than medium and high achievement levels. Lastly, low achievement levels might have poor background knowledge of the topic being investigated relative to high and medium achievement levels. It might negatively impact the low achievement levels while working with their peers in small groups, hence, they performed lower than the two achievement levels.

5.1.2 Students Science process skills

The findings of the second research question focused on the effects of dialogic-practical work on students' science process skills in secondary schools. The quantitative analysis results revealed that the dialogic-practical work method improved the science process skills of secondary school students. The results showed that the dialogic-practical work method was highly effective than the practical work based on recipes in promoting secondary school students' science process skills. The analysis of qualitative data results revealed that students who were exposed to the dialogic-practical work approach had an opportunity to participate in a broad range of science practices, such as arguing with their peers and with the teacher; formulating hypotheses; setting up equipment; collecting, analyzing, and interpreting data; reflecting on the findings; evaluating and critiquing others' ideas; and concluding the findings.

Many scholars found results consistent with the present study (Athuman, 2017; Chambers, 2014; Damopolii et al., 2020; Hikmah et al., 2018; Jiang & McComas, 2015). Athuman (2017) found that inquiry-based practical work improved students’ science process skills compared to the lecture method. These scholars did not specify the kinds of inquiry-based methods they employed. However, most studies conducted on the inquiry-based approach showed that guided inquiry was less effective at enhancing science process skills than the open inquiry practical work approach (Chambers, 2014; Jiang & McComas, 2015). In a similar vein, Demircioglu and Ucar (2015) demonstrated that using an argument-driven inquiry practical work method led to more significant gains in pre-service physics teachers' science process skills than using a recipe-based practical work approach.

The findings of the present study indicated that students' science process skills had a medium effect size. This might be due to the following reasons. First, unlike the argument-driven inquiry approach, the dialogic-practical work approach was more structured such that the teacher identified the research problems and objectives of practical work. Studies suggested that more structured approaches were less effective at developing students’ science process skills (Chambers, 2014). Second, the qualitative data analysis results indicated that the students did not effectively implement the conclusion phase of the dialogic-practical work approach. In the present study, the students had little opportunity to reflect on their findings with each other and the teacher. The analysis of the paired-sample t-test result showed that students exposed to a dialogic-practical work approach significantly developed their science process skills between pre- and post-intervention with a very large effect size.

However, a low category for the normalized learning gain did exist. Similar to the recipe-based practical work improved students' science process abilities between pre-and post-intervention, which had a tiny impact size and a very low normalized learning gain. When compared to the recipe-based practical work, students who participated in dialogic-practical work demonstrated significantly better skills in observation, classification, inferences, controlling variables, experimenting, formulating a hypothesis, and interpreting data. However, there were no appreciable differences between the dialogic and recipe-based practical work strategies in the skills of prediction, operational definition, drawing, and reaching conclusions.

Additionally, the findings of the present study revealed that students who used a dialogic-practical work style scored highest on inference skills and lowest on the operational definition. Due to the seldom use of a practical work based on recipes by secondary school students, the operational definition was the skill that was least mastered. Except for the operational definition, the percentage of scores for the students exposed to a dialogic-practical work method had medium categories. The results of this study supported those of Demircioglu and Ucar (2015), who showed that all components of students' science process skills were enhanced by argument-driven inquiry. However, the present study contradicted Demircioglu and Ucar (2015) on prediction, operational definition, reaching conclusions, and drawing graphs. This was because before the intervention, the teacher did not fully optimize science process skills in the learning process and secondary school students rarely conducted practical work (Nigussie et al., 2018).

Second, Demircioglu and Ucar (2015) worked with pre-service teachers having long years of practical work experience. However, the students participated in the present study had very low practical work experience. This idea was supported by Silay and Çelik (2013) who showed that students’ mastery of science process skills was influenced by their practical work experiences. Gultepe and Kilic (2015) found that implementing an argument-driven inquiry approach on 11th grade students over 29 weeks developed their skills of forming data tables, formulating hypotheses, controlling variables, drawing graphs, and graph interpretations. They found results that contradicted the present study on graph drawing skills and graph interpretation in favor of argument-driven inquiry. Contrarily, they found that the argument-driven inquiry approach did not improve students' experiment design skills. However, the present study found that the dialogic-practical work approach enhanced students’ experiment design skills.

The possible reasons for these contradictions might be the nature of the study participants. Gultepe and Kilic (2015) implemented argument-driven inquiry on seventeen highly successful students. It made the study findings difficult to replicate in high schools with diverse backgrounds (prior knowledge, large class size, and gender). The second difference was related to the length of the interventions. They applied argument-based inquiry for an extended time. It might contribute a lot to developing students' science process skills. However, the present study was conducted for only eight weeks for secondary school students who were not familiar with practical investigations before the intervention. Third, these academics given the experiments and results as homework, which could cause significant contradictions.

The present study indicated that dialogic-practical work has improved students' skills in controlling variables. However, several studies found that controlling variables were the least mastered skills (Erkol & Ugulu, 2014; Fugarasti et al., 2019; Rahmi et al., 2018). Erkol and Ugulu (2014) revealed that biology teacher candidates could not develop the skills of controlling variables. Similarly, Guevara (2015) reported that students scored low on reaching conclusions compared to other skills. By implementing scientific approach-based learning in a general biology course, Susanti et al. (2018) found similar results. These scholars found that students improved in all aspects of science process skills with the average gain of the medium category. However, they improved in predicting skills with a low category.

However, Siahaan et al. (2017) found that students scored high on the skills of prediction. The present study found that students improved their inference skills. In contrast, Akani (2015) and Kruea-In and Thongperm, (2014) found that students scored low in inference skills. Kruea-In and his co-authors showed that even in-service and pre-service teachers had difficulties mastering inference skills. The inconsistent results for science process skills might be due to the various kinds of practical work approaches that were used. Additionally, the current study revealed that students who applied a dialogic-practical work strategy made gradual improvements to their practical work skills. Similarly, Gultepe and Kilic (2015) demonstrated that argument-driven inquiry enhanced students' science process skills. Although certain activities (such as planning experiments) need more time and effort, Gultepe and Kilic (2015) argued that argument-driven inquiry activities might help students develop their science process skills.

5.1.3 Students' attitudes toward physics

The third research question looked at how secondary school students' attitudes toward physics were affected by the dialogic-practical work style. According to the independent sample t-test results, students who performed the dialogic-practical work strategy showed more favorable changes in attitudes toward physics than those who used the recipe-based practical work approach. The dialogic-practical work method successfully improved secondary school students' attitudes toward physics. The results of the qualitative study confirmed the aforementioned findings. It was found that students exposed to the dialogic-practical work method were motivated and eager to participate in lively debates with their classmates and the teacher. Conversely, engaging students in recipe-based practical work approach might be too simplistic and boring for them.

Similar results to those of the present study have been reported (Kurniawan et al., 2021; Walker et al., 2012; Yap & Chew, 2014). For instance, Kurniawan et al. (2021) showed that secondary school students exposed to the Jigsaw and inquiry learning methods had more favorable attitudes toward physics than those who used lecture methods. Yap and Chew (2014) also found that demonstrations supported by ICT tools developed upper-secondary school Singaporean students’ attitudes toward physics. In a similar vein, Sesan and Tehran (2013) found that inquiry-based laboratory activities caused significantly higher positive attitudes toward chemistry and the laboratory than the recipe-based practical work approach. Despite similar results being reported, the present study differed from the above studies in that dialogic teaching was explicitly incorporated into the secondary school physics laboratory. While Walker et al. (2012) found that incorporating argumentation into an inquiry-based approach improved students’ attitudes toward science.

Some findings (Ates and Eryilmaz, 2011, Demirciolu & Ucar, 2012, Ural & Gençolan, 2019) are at odds with the findings of the current study. According to Ates and Eryilmaz (2011), ninth-grade students who were exposed to hands-on and mind-on activities did not improve their attitudes towards physics in general or physics practical work in particular. This could be because the hands-on and mind-on exercises lacked multi-voiced interactions. Some researchers indicated that an ADI strategy did not change students' attitudes toward science (Demirciolu & Ucar, 2012; Ural & Gençolan, 2019). Despite, there were clear strategies to encourage multi-voiced interaction in these studies, Ural and Gençoğlan (2019) suggested that short intervention period (implemented only for five weeks) on primary school students resulted in lack of change in students’ attitudes toward science. Moreover, Demirciolu and Ucar (2012) recommended that bringing a positive change in students’ attitudes toward science occurs as a result of a wide range of experiences throughout their lives and over a long period.

Additionally, the argument-driven inquiry approach allowed students to design their problem statements and research questions, and reach conclusions alone. In contrast, the present study found that the more structured dialogic-practical work approach improved students’ attitudes toward physics. van Riesen et al. (2022) findings also supported the present argument that students with low prior knowledge and practical work experience benefitted most from the more structured conditions. The semi-structured qualitative analysis also agreed with the findings that students were encouraged and enjoyed being exposed to a dialogic-practical work approach. Indeed, this might encourage them to develop positive attitudes towards physics. The findings from a paired sample t-test analysis indicated that students engaged in dialogic-practical work significantly developed a positive attitude toward physics between pre- and post-interventions.

The results showed that the dialogic-practical work method had a learning benefit in the medium category and favorably influenced students' attitudes toward physics. Similarly, both before and following the intervention a practical work approach based on recipes greatly improved students' attitudes toward physics. The learning benefit was, however, not very high. Comparing the dialogic-practical work method to the practical work approach based on recipes, the current study found that the latter group's students were less enthusiastic about physics, physics learning, practical work, physics teaching, and future careers.

The partial eta-squared values of all the subscales were much larger than the typical values. The larger partial eta-squared showed the positive impact of the dialogic-practical work approach on enhancing attitudes toward physics. Similarly, Kurniawan et al. (2021) found that inquiry learning and Jigsaw learning models collectively also developed attitudes toward investigation in physics, enjoyment in learning physics, adoption of scientific attitudes, and increased their time for study compared to the lecture method.

5.1.3.1 Gender differences and attitudes toward physics

The results of the current study showed that there were no significant attitudes toward physics disparities between male and female students as a result of the dialogic-practical work method. This result showed that, regardless of gender differences, both male and female students benefited from the dialogic-practical work method to develop favorable attitudes toward physics. The attitudes of male and female students towards physics did not significantly change throughout the recipe-based practical work, either. Additionally, the results indicated that a sizable proportion of both male and female students exposed to the dialogic-practical work strategy had more favorable attitudes toward physics than those exposed to the recipe-based practical work approach.

The results of the present study were supported by certain studies (Sakariyau et al., 2016; Zeidan & Jayosi, 2015). For instance, Zeidan and Jayosi (2015) showed that attitudes toward science among Palestinian secondary school students, both male and female, were not significantly different. In Nigeria, secondary school pupils' views towards science did not significantly change between male and female students (Sakariyau et al., 2016). Ibrahim et al. (2019) revealed both female and males students have favorable attitudes toward physics regardless of gender differences.

Several research findings (Anwer et al., 2012; Heng & Karpudewan, 2015; Kousa et al., 2018; Walker et al., 2012) contradicted the findings of the present study. Some of them (Anwer et al., 2012; Heng & Karpudewan, 2015; Walker et al., 2012) showed that females had more favorable attitudes toward science than males did. For instance, Walker et al. (2012) found that argument-driven inquiry significantly increased the attitudes of female students toward chemistry compared to their counterparts. While others (Kousa et al., 2018) indicated that male students had higher positive attitudes toward science than females. The results of this study might be encouraging. This is due to studies done in the Ethiopian environment showing that there is a huge gap between male and female students overall learning achievements in physics and attitudes towards physics in particular (Gbre-Eyesus, 2017). Therefore, this finding showed that the dialogic-practical work approach could be used as an alternative strategy to develop students' attitudes toward physics regardless of gender differences.

5.1.3.2 Achievement levels and Attitudes toward physics

This subsection presents the findings concerning the impact of the dialogic-practical work method on students with various achievement levels attitudes towards physics. The results of the current study revealed that there was a statistically significant change in the treatment group's attitudes toward physics between at least two achievement levels. The results of the Bonferroni pairwise comparison revealed that students with high and medium achievement levels who participated in a dialogic-practical activity developed their attitudes towards physics at about the same rates. Compared to low accomplishment levels, these two success levels fostered more favorable attitudes towards physics. The finding of the present study also indicated that high and medium achievement levels engaged in dialogic-practical work approach had medium normalized attitudinal gain. There was a low category of normalized attitude gain for those who had a low achievement level.

Contrary to this finding, all ability levels exposed to the recipe-based practical work approach did not differ significantly in attitude mean scores. The average attitudinal learning gain for the three ability levels who conducted the recipe-based practical work approach was a low category. Few studies agree with the present study (Kingir & Aydemir, 2012; Kousa et al., 2018). For instance, Kingir and Aydemir (2012) revealed only a positive relationship between students' overall achievement and attitudes towards physics. Others have come across a positive correlation between students' attitudes toward physics and their academic achievement (Cheng & Wan, 2016; Kousa et al., 2018). According to Kousa et al. (2018), attitudes have a favorable impact on students' achievement in school. However, several research (e.g., Fulmer et al., 2019; Osborne & Dillon, 2008; Potvin & Hasni, 2014) disagreed with the findings of the current study.

According to Fulmer et al. (2019), students in high-performing schools had less positive attitudes toward science than students at low-performing schools. Similar findings were made by Potvin and Hasni (2014) and Osborne and Dillon (2008) who found that regardless of variations in achievement levels, students developed negative attitudes towards physics. These two survey studies were conducted in highly developed countries and students involved in many years of practical work experience. Kind et al. (2007), similarly, showed that students at primary levels had positive attitudes toward physics, but developed negative attitudes when promoted to secondary schools. These studies examined the general trends in students' attitudes towards physics in countries with a high-human-index, rather than investigating the effectiveness of a particular instructional strategy.

However, the present study was conducted in secondary schools with limited resources and students with low practical work experience. Therefore, the results obtained from the present study indicated that applying a dialogic-practical work approach in secondary schools had positive effects on students’ attitudes towards physics regardless of ability level differences.

5.1.4 Students’ Epistemic Beliefs about Physics

This section's findings sought to ascertain how the dialogic-practical work method affected students' epistemic beliefs about physics. The results of the current study showed that, in terms of enhancing secondary school students' epistemic views about physics, the dialogic-practical work method outperformed the recipe-based practical work approach. Students who performed a dialogic-practical work method had more advanced views about physics than those who were exposed to practical work based on recipes. The results of the qualitative data analysis indicated that the dialogic-practical work approach enhanced students' capacity to assess the veracity of given information, defend claims, assess the availability of evidence, and assess the legitimacy of the source of information, which in turn promoted their epistemic beliefs about physics.

Despite, the progress was not enough, the students were engaged in providing evidence, arguments, and counterarguments go or against their peers. Studies (Cotabish et al., 2013, Hong et al., 2016, Schiefer et al., 2020, Shi et al., 2020) all support the findings of the current study. According to these researchers, inquiry-based laboratory activities strengthened students' epistemic views more than recipe-based lab activities. Iordanou (2016) found that sixth graders who participated in dialogic argumentation activities acquired more sophisticated domain-specific epistemic knowledge. Similarly, Kızkapan and Bektaş (2021) found similar results that engaging students in an epistemologically enriched Toulmin argumentation model resulted in significant improvements in 7th-grade students' epistemic beliefs.

In contrast, Mekbib (2015) revealed that peer-led scientific argumentation did not bring a significant effect on pre-service physics teachers' epistemic beliefs. A dialogic-practical work approach was more effective than the peer-led scientific argumentation in enhancing students' epistemic beliefs because it blended dialogic teaching and practical investigations. Kind et al. (2011) argued that effectively designing dialogic-practical investigations in science laboratories provides students with more opportunity to present evidence, arguments, and counterarguments. Kind et al. (2011) added that students discussing pre-collected data about the experiment generated the most argumentation units per unit of time.

However, Cheng and Wan (2016) found that Mainland Chinese and Taiwanese school students held sophisticated epistemic beliefs regardless of their instruction style. The reason for such contrasting findings might be the difference in students' backgrounds. Cheng and Wan (2016) revealed that students in Mainland Chinese and Taiwanese schools were among the top high-performing in international standardized tests. These students may already have highly developed sophisticated views. Therefore, these results did not negate the significance of dialogic-practical work in developing students' epistemic beliefs about physics.

The results of this study also demonstrated that students who used a dialogic-practical work method had a significant improvement in their epistemic views from pre- to post-intervention. It concurred with Ozgelen's (2012) findings that students had more developed beliefs before and after the inquiry-based laboratory method interventions. The students who employed a dialogic-practical work method saw normalized gains that fell into the medium category. This result showed that the dialogic-practical work group's physics epistemic beliefs still require further enhancement. The results of this study also demonstrated that students who used the recipe-based practical work saw a weak positive gain (normalized gain of +0.07) in their epistemic beliefs between before and after the interventions.

The findings of the present study disagreed with Shi et al.'s (2020) findings that recipe-based laboratories led to significant negative shifts in students' epistemic views. These scholars suggested that cookbook labs are commonly used to teach science in the K-12 education system in China. Hence, students are displaying a ceiling effect in their views of recipe-based practical work activities, so that it would be difficult for these students to make significant improvement.

Furthermore, compared to students who utilized the practical work focused on recipes, those who employed the dialogic-practical work approach had more advanced epistemic views about physics. Comparing the dialogic-practical work approach to the recipe-based practical work group, the latter generated sophisticated epistemic views about the justification for knowing, the purpose of knowledge, and the purpose of knowing. The source, certainty, and development of knowledge were all found to have medium-sized effects. The results also revealed that students who carried out a dialogic-practical work method held less sophisticated views about the sources of information, the certainty of knowledge, and the development of knowledge with a medium category. While the dialogic-practical work group possessed complex (high category) views on the justification for knowing, the purpose of knowledge, and the purpose of knowing. Contrarily, the students who were involved in practical work based on recipes exhibited views in the medium category (less complex beliefs) for all subscales epistemic beliefs about physics.

The present study's findings on knowledge certainty and knowledge sources aligned with those of Ozgelen (2012). With a large effect size, Ozgelen showed that inquiry-based laboratory caused students to have more sophisticated epistemic views regarding the certainty of knowing and the source of information. Additionally, the results of the present study ran counter to Ozgelen's findings about the justification for knowing. After carrying out an inquiry-based experiment, research by Ozgelen found that students still had naïve beliefs about the Justification for Knowing.

The findings of the present study was consistent with that of Schiefer et al. (2020), who demonstrated that students' views about the certainty, development, and justification of their knowledge were enhanced by the inquiry-based learning strategy. It also concurred with Ozgelen (2012), who revealed that prospective teachers had more sophisticated views about certainty and the source of knowledge as a result of the inquiry-based laboratory approach. The finding of the present, however, went against Ozgelen's justification for knowing. After completing an inquiry-based laboratory, Ozgelen demonstrated that students still had naive views about the justification for knowing. These conflicting outcomes may have been produced due to the types of interventions used.

For instance, Ozgelen compared the effects of inquiry-based activities on students before and after intervention mean test scores within the group. Besides, a dialogic practical work approach would provide students additional chances to assess the credibility of knowledge claims and the use of evidence. Yet, students who employed dialogic practical work held less sophisticated beliefs regarding the sources of knowledge, its certainty, and its development. This may be related to the brief intervention times. Based on his 12-week intervention research, Mekbib (2015) hypothesized that sustained application of the intervention is necessary to dramatically improve students' epistemic views.

Similarly, Kızkapan and Bektaş (2021) found that after eight weeks a significant difference was observed between the treatment and comparison groups on justification of knowledge, simplicity of knowledge, certainty of knowledge, and attainability of truth. However, a significant difference in sources of knowledge was observed between the treatment and comparison groups after 15 weeks of the intervention. Based on this finding, it can be suggested that students should be engaged in a dialogic-practical work approach for an extended period of interventions until they doubt their current beliefs to realize the change in epistemic beliefs.

5.1.4.1 Gender difference and Epistemic beliefs

The results of this sub-research question demonstrated that high school students from both genders did not have significantly different epistemic ideas about physics, regardless of the difference in practical work approaches. Both male and female students who participated in dialogic-practical work demonstrated advanced physics beliefs as compared to the strategy that relied on recipe-based practical work. This result was in agreement with studies (Ali et al., 2021; De-Juanas et al., 2014; Chen et al., 2019) that suggested gender did not significantly affect how students developed their epistemic views. Ali et al. (2021) indicated that gender disparities did not significantly affect students' epistemic views.

The work of Chen et al. (2019) found that gender and university tier had no significant relation to students' epistemic beliefs about physics. They added that only domain-specific characteristics such as students majoring in education resulted in better performances in epistemic beliefs than engineering and other non-education majors. The present study used a dialogic-practical work intervention to investigate its effect on female and male students’ epistemic beliefs. These two studies used a survey approach to ascertain whether or not there was a statistically significant difference in the epistemic views of male and female students.

The results of the current study also showed that there were no gender differences in students' acquisition of more complex beliefs about how information is acquired, justifications for knowing, the purpose of knowledge, and the purpose of knowing. This finding was consistent with the study of Ongowo (2020) who found that no gender difference was observed in the justification of knowing. However, it contrasted with Ozkan and Tekkaya (2011) who revealed that females showed more sophisticated beliefs in the justification of knowing compared to males. For the dimension of knowledge development, Ongowo (2020) revealed that gender has a statistically significant difference in favor of males.

Even though, female and male students' showed a statistically significant difference in the dimensions sources and certainty of knowledge in favor of male students. It indicated that dialogic practical work favored male students over female students in holding sophisticated beliefs about sources of knowledge and certainty of knowledge. Some studies found females held more naïve beliefs than males regarding certain and simple knowledge (De Juanas & Beltrán, 2012; Ongowo, 2020; Ozkan & Tekkaya, 2011).

On the contrary, Chiu et al. (2015) found that students showed significant gender differences in uncertainty, complexity, and sources of knowledge; however, no gender difference was found in the Justification for knowing dimension. De Juanas and Beltrán (2012) revealed that in fixed ability and quick knowledge females' exhibit significantly more elaborated epistemic beliefs than males. While, on simplicity and certainty of knowledge males showed more elaborate beliefs than females. The above mentioned studies only surveyed the effect of gender differences on students’ epistemic beliefs about physics. As a result of the present study, dialogic-practical work approach proved to be a suitable method for enhancing students' epistemic beliefs about physics without gender differences.

5.1.5 Correlations among the dependent variables

This research question aimed to investigate the correlation and contribution of science process skills, attitudes toward physics, and epistemic beliefs about physics to students’ mechanics achievement. According to the Pearson correlation, science process skills had a moderately significant correlation with mechanics achievement. In addition, attitudes toward physics and epistemic beliefs about physics had a substantial correlation with mechanics achievement. The Pearson correlation indicated science process skills had a moderate correlation with epistemic beliefs and a low positive correlation with attitudes towards physics. A moderate correlation was found between epistemic beliefs and physics attitudes.

These results demonstrated a favorable correlation between the dependent variables. Indeed, the improvement in one dependent variable was more likely correlated with the increase in the second variable. Similar to the current study, Zeidan and Jayosi (2015) discovered a significant positive link between secondary school students' attitudes toward science and their knowledge level of science process skills. Additionally, Sadi and Dayar (2015) showed that students with complex beliefs typically have a higher degree of learning concepts and do better in physics. Additionally, Sadi and Dayar (2015) discovered a strong and favorable correlation between students' views towards biology and epistemic beliefs.

Likewise, for students who engaged in a recipe-based practical work approach science process skills were moderately correlated with epistemic beliefs about physics. However, mechanics achievement had a significantly low correlation with science process skills. In addition, attitudes towards physics had a significantly low correlation with epistemic beliefs about physics. For the comparison group, mechanics achievement had a very weak negative correlation with attitudes towards physics. The findings from the multiple regression analysis indicated that science process skills, epistemic beliefs about physics, and attitudes towards physics positively contributed to students' mechanics achievement test scores.

Study results showed that the dialogic-practical work approach predicted 60 percent of mechanics achievement with science process skills, epistemic beliefs about physics, and attitudes toward physics. These findings reveal that students' science process skills, attitudes toward physics, and beliefs about physics are necessary but not sufficient to achieve mechanics. The findings of the present study also indicated that students' epistemic beliefs about physics dominantly predicted mechanics achievement followed by attitudes toward physics and science process skills. Students with sophisticated beliefs about physics score high on the mechanics achievement test.

For the treatment group, secondary school students who scored high in science process skills and developed positive attitudes toward physics performed well in mechanics achievement. Similar findings were observed by several research. For instance, Kimba et al. (2018) showed a substantial positive association between students' attitudes toward physics and their mastery of science process skills. Similarly, Abungu et al. (2014) revealed that student success in Chemistry was substantially predicted by their science process skills. Similarly to this, Shahali et al. (2017) found that improving students' science achievement necessitates improving their science process skills.

Other research (Cheng & Wan, 2016; Kousa et al., 2018; Musengimana et al., 2021) revealed a connection between students' academic success and their attitudes toward science courses. For example, Kousa et al. (2018) stated that students with a positive attitude toward science are motivated to excel in the science subjects being taught compared to those with a negative attitude. Similarly, Shana and Abulibdeh (2020) found a positive relationship between attitudes toward practical work and students’ science achievement.

5.1.6 Students’ scientific Argumentation skills

The results of this part concentrated on how a dialogic-practical work style affected students' scientific argumentation skills. The results demonstrated that a dialogic-practical work style had a good overall increase in scientific reasoning skills. The data also showed that from the start of the intervention until the last intervention session, the students' skills to make scientific arguments increased gradually. It has been found that in order to develop their skills for making scientific arguments, students need to be subjected to repeated dialogic-practical work interventions.

The qualitative analysis indicated that students in each small laboratory group underwent hot discussions. Additionally, during the conceptualization and conclusion stages of the dialogic-practical work method, the students mainly participated in exploratory talk. The students participated actively in meaning-making interactions by asking questions, coming up with a cogent explanation, using adequate and relevant data to shape evidence, defending or disputing claims in light of the evidence, and making an effort to come to an understanding by creating shared understandings. Moreover, the video recordings also revealed that students speak often, and their utterances are long and elaborate and include reasoning words; the utterances are clearly directed to others; teachers ask open-ended questions that encourage thinking; teachers are responsive to students, paying attention to students' thoughts, building on them, and developing them; and students listen to each other, asking questions and having discussions.

The results of the current study agreed with those of Hosbein and colleagues (2021). These researchers revealed that students subjected to argument-driven inquiry over the course of two semesters demonstrated improvement in their overall scientific reasoning. In agreement with the current study, Hosbein et al. (2021) showed that students' overall and cognitive, epistemic, and social aspects of argumentation scores dramatically improved from the start of General Chemistry I to the conclusion of General Chemistry II. These scholars showed that, despite the growing intricacy of the practical investigations, this approach resulted in the cognitive, epistemic, and social components of scientific argumentation have been promoted. Similarly, Demircioglu and Ucar (2015) showed that at the end of the interventions, the treatment group outperformed the comparison group. Walker et al. (2016) indicated that the levels of argumentation varied significantly across the treatment and comparison groups. These researchers revealed how the Argument-Driven Inquiry laboratory causes a semester's worth of noticeable improvement in argumentation skills.

In contrast to a more conventional structured inquiry method, Seda Cetin et al. (2018) found that students who received an argument-driven inquiry for seven weeks outperformed in the argumentative test. In addition, female students who received instruction in argument-driven inquiry performed better on tests of argumentation than their male counterparts in the same class. The current study found that when given the opportunity to argue, students failed to pay equal attention to the cognitive, epistemic, and social parts of scientific reasoning. They received good marks for the social components of scientific reasoning but low marks for the epistemic ones.

In agreement with the findings of the current study, Hosbein et al. (2021) found that students' development in the cognitive, epistemic, and social facets of scientific reasoning was not equal. Demircioglu and Ucar (2015) similarly showed that there was no discernible change between the start and halfway of the intervention. The qualitative analysis results revealed some significant difficulties faced by the students during the dialogic-practical work sessions, which might be the cause of the variation in scientific argumentation components. First, the qualitative analysis showed that students struggled to consider alternative explanations, judge their peers' explanations, and understand what counts as good evidence.

Second, the students spent much of their time in the conceptualization and investigation phases rather than explicitly engaged in the conclusion phase. It might be the reason why students' change in epistemic aspects of scientific argumentation was relatively low compared to cognitive and social aspects. This might resulted in the students to show low improvements in epistemic components. Third, the teacher displayed a limitation in effectively facilitating students' dialogic-practical work sessions by posing enough open-ended questions and challenging students' superficial arguments, and providing sound arguments and counterarguments. Fourth, the short duration of the dialogic practical work sessions also had a significant contribution. This finding indicated that scientific argumentation skills improvement would be more noticeable with a longer dialogic-practical work session and more practical work activities.

In agreement with the current study, Walker et al. (2019) revealed that applying an argument-driven inquiry in a two-semester general laboratory course did not result in improving students' argumentation skills. Moreover, Walker et al. (2019) further revealed that students did not demonstrate claim change as a legitimate part of the reasoning. Walker and his colleagues found that students had the hardest time revising their claims when they saw conflicting information (cognitive) and used theories or models to make sense of phenomena (epistemic). Similar findings were made by Sadler (2004), who showed that students frequently make unjustifiable statements, have difficulty identifying counterarguments, and seldom utilize scientific evidence to back their decisions.

5.2 Conclusions of the study

The key findings of the current study are presented in this part. In addition, recommendations for future research investigations and their implications for science education. The study investigated how secondary school students' learning outcomes in physics were affected by dialogic practical work. It looked at how dialogic practical work affected secondary school students' physics learning outcomes compared with recipe-based practical work. In the current study, the dialogic practical work method was used in a physics lab at a secondary school. Qualitative and quantitative data were collected for the study. The analysis and findings led to the following conclusions.

First, we asked: *Do dialogic-practical work and recipe-based practical work approaches significantly affect students' mechanics achievement*? The dialogic-practical work method was an effective and innovative pedagogy to promote students' mechanics achievements compared to recipe-based practical work. The inherent social aspects of the DPW approach also provide an opportunity for a wider diversity of students to become active participants in scientific practices. Indeed, the dialogic-practical work approach was a suitable strategy to enhance female and male students as well as students with different ability groups' mechanics achievement irrespective of gender differences and ability differences.

Second, we asked: *Do dialogic-practical work and recipe-based practical work approach significantly affect students' science process skills*? The dialogic-practical work approach was more effective at developing secondary school students' science process skills than the recipe-based practical work approach. Moreover, the dialogic-practical work approach was a suitable approach to improve the skills of observation, classification, inferences, controlling variables, experimenting, formulating a hypothesis, and interpreting data as compared to the comparison group. However, the dialogic-practical work approach did not develop students' skills in prediction, operational definition, reaching conclusions, and drawing graphs compared to the recipe-based practical work approach. It was found that students improved their practical work skills over time when assessed while engaging in dialogic-practical work sessions.

Third, we asked: *Do students' attitudes toward physics differ substantially between dialogic-practical work and recipe-based practical work*? The dialogic-practical work method significantly resulted in a positive shift in students' attitudes toward physics more effectively than the practical work strategy focused on recipes. In comparison to the group that used a recipe-based approach to practical work, the dialogic-practical work method significantly increased students' excitement for physics, physics learning, practical work, physics teaching, and future careers. The dialogic-practical work approach successfully benefitted female and male students to develop a positive attitude towards physics irrespective of gender difference. Dialogic-practical work effectively affected attitudes towards physics among the different ability groups compared to recipe-based practical work. As well, those with high and medium achievement levels who engaged in dialogic-practical work showed more positive attitudes than those with low achievement levels.

Four, we asked: *Is there a substantial difference between students who utilized dialogic-practical work in their epistemic beliefs about physics and those who utilized recipe-based practical work?* The dialogic-practical work method was effective than the recipe-based practical work approach in enhancing students' epistemic views about physics. The implementation of the dialogic-practical work approach for eight weeks helped students advance their epistemic views about physics. Compared to practical work based on recipes, the dialogic-practical work approach allowed students to hold more sophisticated beliefs about the justification for knowing, the purpose of knowing, the source of knowledge, the certainty of knowledge, and the development of knowledge. Without regard to gender, dialogic-practical work successfully encouraged students' beliefs about the development of knowledge, the rationale for knowing, the purpose of knowledge, and the goal of knowing. However, male students outperformed female students in the dialogic-practical work method in terms of acquiring sophisticated views about knowledge sources and knowledge certainty.

Fifth, we asked: *Does the treatment group make a significant difference in students' scientific argumentation skills over time*? It was found that exposing students repeatedly to dialogic-practical work approach effectively promoted students’ scientific argumentation skills over time. However, the dialogic-practical work approach did not uniformly improve scientific argumentation skills. Students scored high on social components and low on the epistemic aspects of scientific argumentation.

The sixth research question asked: *Does science process skill development, attitudes toward physics, and epistemic beliefs about physics significantly impact secondary school mechanics achievement?* Students' science process skills, epistemic beliefs about physics, and attitudes towards physics positively contributing to students' mechanics achievement. Students' epistemic beliefs about physics had a dominant predictive effect on mechanics achievement, followed by attitudes toward physics and science process skills.

The seventh research question has two parts. The first sub-research question asked: *How do students interact with each other during dialogic-practical sessions?* The students engaged in hot discussions by applying cumulative, exploratory, and disputational talks throughout the dialogic-practical work with varying degrees. However, the students failed to realize the importance of justifying their claims and rarely challenged their colleagues' views to the expected level. The second sub-research question was: *How did the teacher engage in dialogic-talk moves to facilitate students' dialogic-practical work sessions?* The teacher implemented features of dialogic talk moves categorized into knowledge construction, evaluation, and justification. The teacher scaffolded activities to facilitate students' implementation of dialogic-practical work. However, the teacher's dialogic talk moves mainly focused on knowledge construction and not sufficiently embedded justification and evaluation in the dialogic-practical work sessions. It can be concluded that the teacher rarely encouraged students to explain their ideas with sound evidence, arguments, and justifications.

The eighth research question was: *What are students' perceptions about the dialogic-practical work approach in the physics laboratory?* The students perceived that the dialogic-practical work approach provided them with an experience to do practical work in groups with some degree of independence, enabled them to freely exchange ideas with their group mates, maximized their learning, and encouraged collaboration, equipped them with skills in presenting arguments and evidence, and assisted them to associate theories with real-life experiences.

5.3. Recommendations and Implications

The findings of the present study had the following contributions. First, drawing on both the sociocultural theory of learning and scientific practice, the present study offered secondary school physics teachers the opportunity to engage students in a dialogic-based practical work approach against the practical work based on recipe approach to advance their physics learning. This pedagogical approach encourages dialogic talks during practical investigations to help students acquire deep scientific knowledge. It also helps students understand why some scientific theories are accepted as *right* and alternative theories are rejected as *wrong*.

Second, this research may provide a theoretical addition to physics by shedding light on how a dialogic-practical work method might be implemented in physics labs and the implications for student learning. The results of the current study establish a substantial body of work that demonstrates that students may make significant improvements in their learning outcomes and ability to participate in argumentation when DPW is conducted in secondary school physics labs. The research also illustrates the inadequacy of recipe-based practical work approach to achieving these goals. The possibility that DPW instruction could mediate these issues is very encouraging and holds promise for better meeting the needs of a wide range of science students through non-traditional practical work methods. Thus, this study provides evidence that students' learning can be improved by transforming traditional expository laboratories into DPWs.

Third, this study might contribute to developing countries having similar contexts (such as limited equipment and resources, low practical work experiences, and classrooms dominated by lecture methods) on how to apply dialogic-practical practical work approach to improve students' learning outcomes. Third, this study can be used as a comparative study to fill the research gap that existed in the Ethiopian context about the usefulness and importance of the dialogic-practical work approach on secondary school students’ physics learning outcomes.

Fourth, for secondary school physics instructors and school management, this study offers knowledge on dialogic-practical work and how to use it to improve students' understanding of physics. This study can help curriculum designers and physics instructors reevaluate the necessity of including dialogic teaching in students' practical work in order to improve their learning outcomes in physics. In this sense, designers of science curricula can create a lab curriculum that contrasts the prevalent practical work based on recipes with dialogic-based practical work. Additionally, other interested researchers might use the dialogic-practical work method in different physics laboratory courses and look at how the students learned.

The results of this study suggest that to significantly enhance students' learning outcomes in physics, practical activity should move away from recipe-based and towards dialogic. Students should come out of a laboratory trend where they are provided with instructions that are so exhaustively detailed that they can just follow a recipe without having to think. First, the physics textbooks writers, curriculum planners, and teacher educators should review the practical activities to incorporate both basic and integrated science process skills in a fair distribution. Similar to this, national and classroom evaluation systems should include questions about science process skills. Second, secondary schools must first be well-stocked with the laboratory tools and supplies required to promote high-quality physics education. Second, the government should use maximum efforts to minimize students per classroom. In most secondary schools under study, the average student population per classroom was above 60. In these relatively crowded classrooms, teachers either abandon conducting practical work or force them to rarely apply demonstrations.

Third, the Ministry of Education should organize seminars, workshops, and continual professional development training to increase physics teachers' understanding of the advantages of the dialogic-practical work approach and the best means to apply the strategy. Teachers need to know how to lead productive physics conversations. They should be familiar with designing various practical work activities to provide students the chance to talk about physics. The researcher also suggested that to improve students' physics learning they should be exposed repeatedly to a dialogic-practical work approach for extended semesters. The current study also recommended teachers to incorporate activities that encourage collaborative talks without dominating the students. Such collaborative talk with critical engagement can allow students to be familiar with scientific investigation processes. In the dialogic-practical work approach, teachers should also provide scaffolding to help students engage in arguing based on sound arguments and counterarguments.

The present study was conducted with 91 participants selected from two governmental secondary schools. Therefore, to acquire a clear picture of secondary school students' physics learning results, this research has to be applied broadly. Further study is needed to better understand the effects of the other factors on students' learning in this area. A further study is also required to examine the retention ability of students after dialogic-practical work sessions have ended. The present study showed that some components of science process skills (e.g., predictions, operational definition, reaching conclusions, and drawing graphs) did not improve during eight weeks of dialogic practical work sessions.

It is therefore necessary to conduct further research with extended dialogic-practical work approaches in order to examine the improvement of these skills in the science process. Moreover, female students showed naïve epistemic beliefs about sources and knowledge certainty compared to males. Thus, further study is needed on how to improve female secondary school students' beliefs about sources and certainty of knowledge. Further research is needed to explore additional strategies that could be implemented to further enhance students' ability in developing the science process skills to provide quality scientific argumentations.

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APPENDIX A

Mechanics Achievement Test

Addis Ababa University
College of Education and Behavioral studies
Department of Science and Mathematics Education

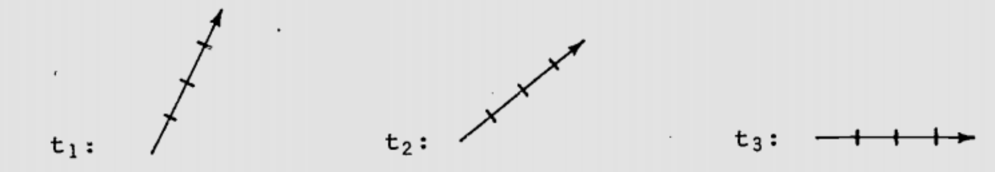
The purpose of this test is to investigate how much students' understand mechanics topics. There are 25 multiple choice items. Please carefully read each questions before you decide to choose one of the alternatives. This test is prepared for research purpose only. Your privacy is assured and any of your personal details will not be disclosed. ***No item has more than one correct answer.*** Answer all the questions by circling the letter of your choice.

Thank you in advance for your cooperation!!

Name: ______________________________________ Grade: ____________________________
Sex: ____ School: ______________________________

Time allowed: **40 minutes**

1. The following three velocity vectors represent the magnitude and direction of a plane taken at three consecutive times.

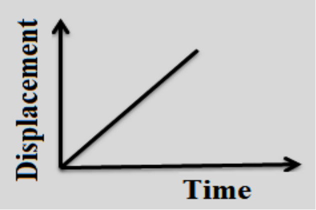


What can you conclude about the velocity of jet? It is:
(A) Speeding up (B) Slowing down
(C) Changing direction (D) Maintaining a constant velocity

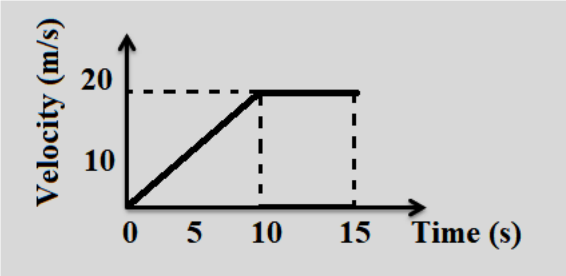
2. A car is starting from rest and accelerates uniformly to a final velocity of 32 m/s in 4 seconds. What is the magnitude of the acceleration?
(A) 2 m/s^2 (B) 4 m/s^2 (C) 8 m/s^2 (D) 16 m/s^2

3. If two metal balls having 5kg mass and 10 kg mass are dropped at the same time from the top of a tower. **In the absence of air resistance**, the time it takes the balls to reach the ground below will be:
(A) About half as long for the heavier ball.
(B) About the same time for both balls.
(C) Considerably less for heavier ball, but not necessarily half as long.
(D) Considerably less for lighter ball, but not necessarily half as long.

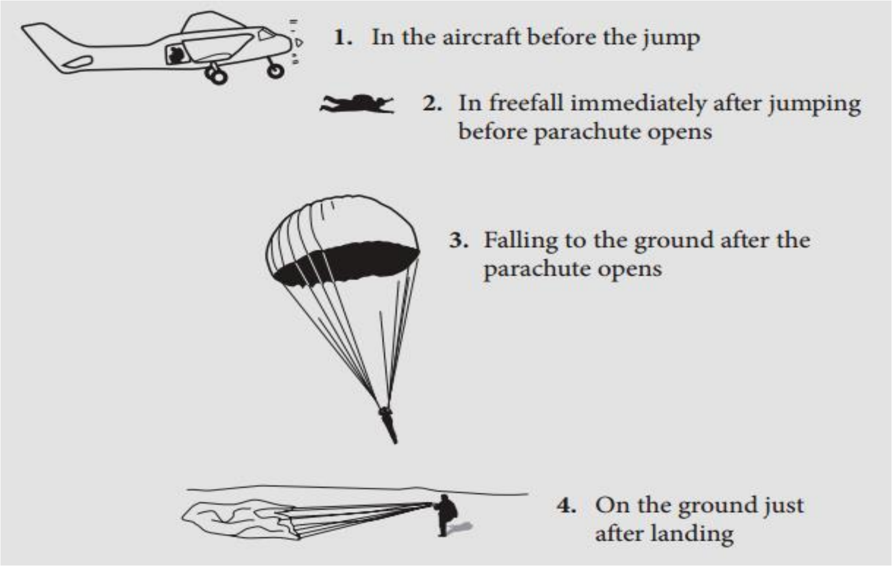
4. The figure given below represents a graph of an object's straight line motion. Which sentence is the best interpretation?
(A) The object is moving with a constant, non-zero acceleration.
(B) The object does not move.
(C) The object is moving with a uniformly increasing velocity.
(D) The object is moving with a constant velocity.



Questions 5 and 6 refer to the following kinematical graph. The velocity versus time graph represents the motion of an object moving in one dimension.



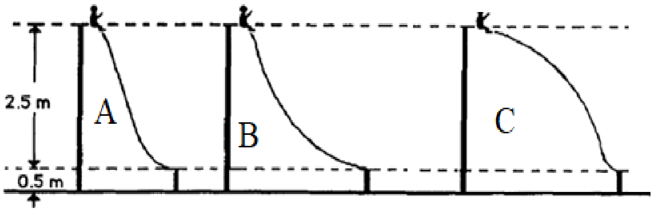
5. What is the acceleration of the object between t=5 s and t= 10 s?
   (A) 0 m/s^2 (B) 2 m/s^2 (C) 3 m/s^2 (D) 4 m/s^2
6. What is the distance travelled by the object between t=0 and t= 15 s?
   (A) 100 m (B) 200 m (C) 300 m (D) 400 m
7. The figure shows a parachute jumper in four positions.



In which of the positions does the force of gravity act on the jumper?
(A) Position 2 only (B) Positions 2 and 3 only
(C) Positions 1, 2 and 3 only (D) Positions 1, 2, 3, and 4

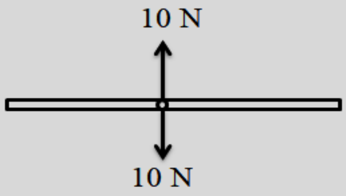
8. Given that a car moves in a circular path at a **constant speed**. Which of the following is **true**?
   (A) The car’s acceleration is zero because it has a constant speed.
   (B) The car’s acceleration is not zero and causes the car to slow down.
   (C) The car’s acceleration is not zero and causes the car to speed up.
   (D) The car’s acceleration is not zero and causes the change in the direction of the car’s velocity.

9. A bus which took several passengers was travelling at a highway. In the middle of the trip, the driver suddenly braked because a passenger asks to stop the bus. All the passengers of the bus were pushed forward. Which law describes this phenomenon?
   (A) Newton's 1st law (B) Newton's 2nd law
   (C) Newton's 3rd law (D) Newton's law of gravitation
10. While, this test booklet is resting on your desk, which of the following statement/s applies most nearly to this situation?
   (A) There are no forces acting on your booklet.
   (B) Only the weight of the booklet is acting on the table.
   (C) Your booklet exerts no force on the desk.
   (D) There are many forces acting on your booklet, but they balance each other.
11. A woman pushes on a large box with a constant horizontal applied force across a horizontal surface. If the box moves at a constant speed, the force she applies:
   (A) has the same magnitude as the weight of the box.
   (B) has the same magnitude as the total force which resists the motion of the box.
   (C) is greater than the total force which resists the motion of the box.
   (D) is greater than either the weight of the box or the total force resisting its motion.
12. A large truck makes a head on collision with a small compact car. Which statement **best** describes the event during collision?
   (A) The truck exerts a greater amount of force on the car than the car exerts on the truck.
   (B) The car exerts a greater amount of force on the truck than the truck exerts on the car.
   (C) The truck exerts a force on the car, but the car does not exert a force on the truck.
   (D) The truck exerts the same amount of force on the car as the car exerts on the truck.
13. A girl starts sliding down a differently shaped **frictionless** surface at the same height 2.5m and end at the same level as shown below.

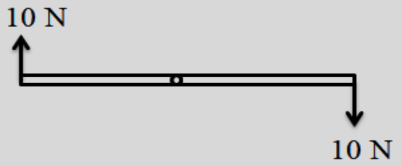


   In order to give her the greatest possible speed when she reaches the bottom of the slide, which of the slides in the above diagram above should she choose?
   (A) A (B) B (C) C (D) It does not matter, her speed would be the same for each.
14. A car of mass 1500kg is moving the right at 4m/s and collides with another car of mass 3000kg that is moving to the right at 3m/s. If the cars stick together, what is the magnitude of their speed immediately after the collision?
   (A) 0.67 m/s (B) 1.67 m/s (C) 3.33 m/s (D) 7 m/s
15. If the brakes of your bicycle have failed, which statement **best** justifies why hitting a haystack is a wiser choice than crushing in to a concrete wall?
   (A) The haystack gives you a smaller impulse than the concrete wall.
   (B) The haystack changes your momentum over a longer time.
   (C) Your change in kinetic energy is smaller if you hit the haystack than the concrete wall.
   (D) Your change in momentum is smaller if you hit the haystack than the concrete wall.

16. In a perfectly **elastic** collision, which of the following statement is **true**?
    (A) Linear momentum is always conserved and kinetic energy is never conserved.
    (B) Both linear momentum and kinetic energy are conserved.
    (C) Kinetic energy is always conserved and linear momentum is never conserved.
    (D) Neither linear momentum nor kinetic energy is conserved.
17. Almaz weighs 50 kg and her young brother weighs 25 kg. Where do they need to sit on a uniform bar pivoted at its center in order to be balanced?
    (A) She should sit twice as far as her brother.
    (B) She should sit at equal distance as her brother.
    (C) She should sit half as far as her brother.
    (D) By any means they cannot be balanced.
18. A uniform rod is pivoted at its center. It is acted on by two forces in the same plane. Each force has the same size, equal to 10N. Which pairs of forces can produce a torque (**turning effect)**?



(A)

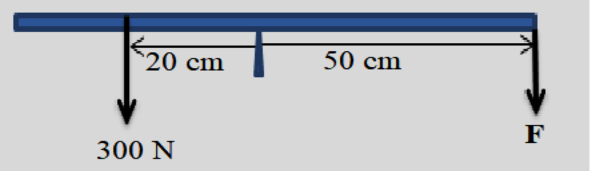


(B)

(C)

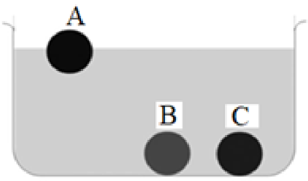
(D)

19. A 1m uniform bar weighing 100 N is balanced at its midpoint with several forces acting on it as shown below. If the bar is in equilibrium, what is the magnitude of the force F?



(A) 120 N (B) 220 N (C) 300 N (D) 520 N

20. Three objects are made of different materials having the same volume. They were placed in a vessel filled with liquid water. Objects **A** floats on the surface, objects **B** and **C** sink to the bottom. Which statement **must** be correct?
    (A) All three objects possess the same mass.
    (B) Objects **B** and **C** possess the same density.
    (C) Object **A** possesses a greater mass than **B** and **C**.
    (D) Object **A** possesses a smaller density than **B** and **C**.

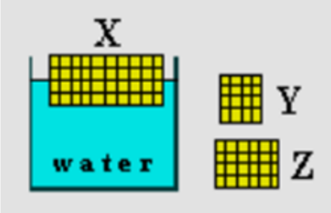


21. The mass and the volume of four objects are given in the table below.

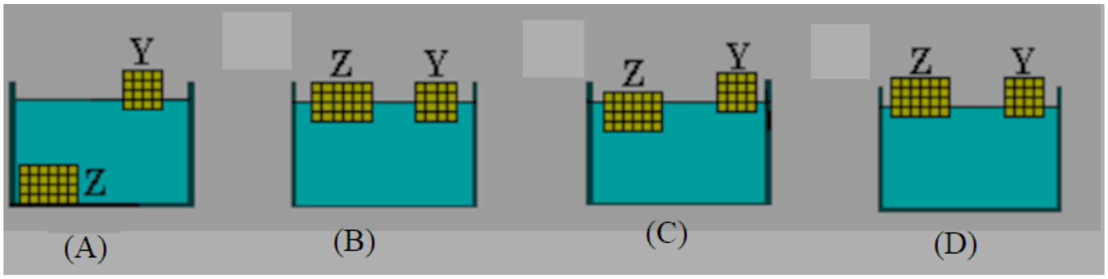
Object	Mass of object (grams)	Volume of object (cm^3)
Object 1	20.0	25
Object 2	10.0	12
Object 3	5.0	4
Object 4	5.0	10

Which object will **sink** in liquid water having a density of 1000 kg/m^3?
(A) Object 1 (B) Object 2 (C) Object 3 (D) Object 4

22. Object X is floating in the water as shown in the figure below.



If the object X is cut in two pieces (Y and Z) whose sizes are different and then, they are put into water one by one, which figure given below will best describe the positions of Y and Z in water?



23. An object with a mass of 20 g is totally immersed into a Eureka can filled with water. The water flows out of the can into a measuring cup when an object is immersed as shown in the following figure below. The buoyant force acting on a 20g object is:
    (A) The weight of the fluid contained in the measuring cup plus the weight of the object 20 g.
    (B) The weight of the fluid contained in the measuring cup.
    (C) The weight of the fluid contained in the measuring cup minus the weight of the object.
    (D) The weight of an object 20 g measured in air.
24. According to Hook's law when the mass attached to the spring doubles, which statement is correct?
    (A) The spring constant of a spring doubles.
    (B) The force that the spring exerts on the mass doubles.
    (C) The force the spring exerts on the mass quadruples.
    (D) The restoring force exerted by the spring becomes half.
25. A simple pendulum undergoes a simple harmonic motion. Which of the following does **not** affect the period of a simple pendulum?
    (A) The amplitude of oscillation (B) The mass attached
    (C) The length of the string (D) The acceleration due to gravity

APPENDIX B

PHYSICS PROCESS SKILLS TEST

Addis Ababa University
College of Education and Behavioral studies
Department of Science and Mathematics Education

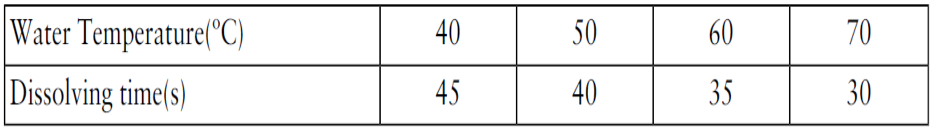
The purpose of this test is to investigate **students' science process skills** after doing physics practical work. There are 20 multiple choice items. This test is prepared for research purpose only. Your privacy is assured and the researcher will not disclose any of your personal details. Please read each question carefully and think critically before you decide to choose each item. **No item has more than one correct answer.** Answer all the questions by circling the letter of your choice.

Thank you in advance for your cooperation!

Name: ________________________________ Sex: _______________
Grade: ________________________________ School: _____________

Time allowed: **30 minutes**.

1. Which of the followings could be observed with the sense of sight?
   (A) The temperature of the air. (B) The ice floats on water.
   (C) The sweetness of a new chemical. (D) The smell of perfume.
2. Which of the following is an observation **only**?
   (A) The piece of metal is red, so it must be hot. (B) The street is wet, so it must have rained.
   (C) The table looks like it made of wood. (D) The child's block is orange.
3. The following units of length are given. (1) one millimeter (2) one nanometer and (3) one micrometer. Which one is the correct arrangement in order of increasing magnitude?
   (A) 1, 2, 3 (B) 2, 3, 1 (C) 3, 1, 2 (D) 3, 2, 1
4. Recently, Abebech heard an ambulance sirens roaring from a nearby street. The next day when she went to school she saw a house covered with wide black spots and smoke. The most reasonable inference that she could make when describing what she saw was:
   (A) The house was destroyed by a tornado. (B) The house was destroyed by a wild animal.
   (C) The house was destroyed by a fire. (D) The house was destroyed by a hurricane.
5. An object travels a distance of 20 kilometers in 10 minutes along a straight line. What is the moving object most likely to be?
   (A) A car (B) A person walking (C) A person running (D) A cyclist
6. Rehmet records following table as measuring dissolving time of her grandmother's calcium tablets in different temperatures of water.



Water Temperature(°C)	40	50	60	70
Dissolving time(s)	45	40	35	30

   Predict at which temperature, the water will dissolve a calcium tablet in 20 seconds.
   A) 100 B) 90 C) 80 D) 75

7. Two substances are mixed in four beakers, and a thermometer is placed in each beaker. The thermometers are checked every minute for five minutes, and the temperature is recorded in the table.

Time (min)	**Beaker A** (^{0}C)	**Beaker B** (^{0}C)	**Beaker C** (^{0}C)	**Beaker D** (^{0}C)
0	20	20	20	20
1	21	19	21	20
2	22	18	22	20
3	20	18	23	20
4	20	17	24	20
5	20	16	25	20

Which beaker shows the greatest temperature change over five minutes?

(A) Beaker A (B) Beaker B (C) Beaker C (D) Beaker D

8. Almaz sets up an experiment to see how the mass of a ball affects the distance it rolls off a ramp. What is the dependent variable *(what is it that she is testing?)*?

(A) Distance traveled by the ball (B) Height of the ramp
(C) Mass of the ball (D) Where the experiment took place.

9. A student wants to test the following question: “Which substance: copper, aluminum or iron, conducts heat faster?” What is the independent variable (or the cause of the outcome) in this experiment?

(A) Size of metal (B) Type of metal
(C) Time it takes to heat up (D) Shape of the metal.

10. A student sets up an investigation to test the strength of magnets. He has several magnets of different sizes, shapes, and masses. He uses the magnets to lift metal paper clips. How is the strength of a magnet defined in the investigation?

(A) By the mass of the magnet lifting the metal paper clips.
(B) By the size of the magnet lifting the metal paper clips.
(C) By the number of metal paper clips lifted by the magnet.
(D) By the time the metal paper clips stay on the magnet.

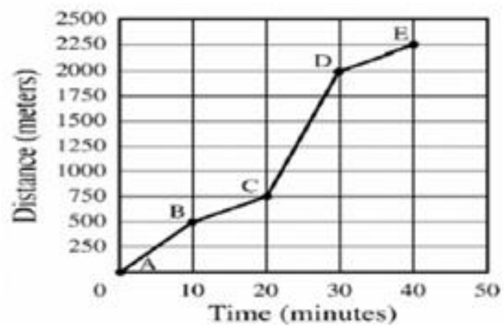
11. Hawa thinks that the more the air pressure in a football, the further it moves when kicked. To investigate this idea, she uses several footballs and an air pump with a pressure gauge. How should she test her idea?

(A) Kick the foot balls with different amounts of force from the same point.
(B) Kick the foot balls having different air pressure from the same point.
(C) Kick the foot balls having the same air pressure at different angles on the ground.
(D) Kick the foot balls having different air pressure from different points on the ground.

12. Sara made three building models with the same surface areas but different heights. The height of the first model was 20 cm, the second model was 40 cm and the third model was 60 cm. All models were placed on the table, shaken and the stability of the models was determined. Which of the following is the **hypothesis** that was tested by her in this investigation?

(A) If the size of the model increases, its stability will increase.
(B) If the base area of the model increases, the stability will increase.
(C) If the height of the model decreases, the stability will increase.
(D**)** If the weight of the model increases, the stability will increase.

13. The graph shows the distance traveled over time of a person. What is the speed of the person from point C to point D?
    (A) 25 m/min
    (B) 20 m/min
    (C) 50 m/min
    (D) 125 m/min



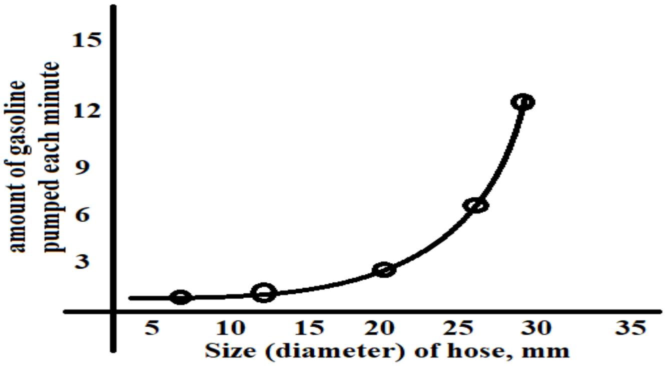
14. Ahmad wanted to *find out the factors that affect the brightness of a bulb in a series circuit*. He built three series circuits. Each circuit has two bulbs and wires of the same length. The first circuit has one battery, the second circuit has two batteries and the third circuit has three batteries. After the brightness of the bulbs in each circuit was observed and recorded, which one is the **hypothesis** tested in this investigation?
    (A) The brightness of the bulbs decreases when the number of bulbs increases.
    (B) When the number of batteries decreases the brightness of the bulb also decreases.
    (C) The longer the wires the dimmer the brightness of the bulb.
    (D) If the number of batteries increases, more electricity is produced.
15. A motorist wants to find out if a car uses more fuel when it is driven at high speed. What is the best way of doing this investigation?
    (A) Ask several drivers how much fuel they use in one hour, when they drive fast, and find the average amount of fuel used per hour.
    (B) Use his own car to drive several times at different speeds, and he should record the amount of fuel used each time.
    (C) He must drive his car at high speed, for a week, and then drive it at low speed for another week, and record the amount of fuel used in each case.
    (D) Ask several drivers to drive different cars covering the same distance many times, at different speeds, and record the amount of fuel used for each trip.
16. The table shows data of an experiment to find out how length (l) of a spring changes when more masses (m) are hung on it. What is the best **conclusion**?

Mass (grams)	Length of spring (cm)
0	5
10	7
20	9
30	11
40	12
50	13
60	13

    (A) The length of a spring increases the same for each added mass.
    (B) The length increases differently each time a mass is added.
    (C) The length increases the same for each mass in the beginning, but not towards the end.

(D) The length of the spring stays the same for all masses.

17. A student prepares an experimental setup to test the hypothesis of '*Melting time of an ice cube thrown into a hot water will reduce if the water temperature is increased*.' He added 5 g of ice cube into one liter of hot water at 60^0C and added another 5g of ice cube in to the same volume of water at 80^0C. Which measurement should the student do to collect the data?
   (A) Measure the water temperature from the moment of throwing ice cubes.
   (B) Measure heat of the water in the containers with calorimeter before and after melting of the ice.
   (C) Measure melting time of the ice cubes in the both containers.
   (D) Measure the temperature of the water after ice–melting.
18. Five different hosepipes are used to pump diesel from a tank. The same pump is used for each hosepipe. The following diagram shows the **results** of an investigation that was done on the amount of diesel pumped from each hosepipe.



Which of the following statements describes the effect of the size of the hosepipe on the amount of diesel pumped per minute?
   (A) The larger the diameter of the hosepipe, the more the amount of diesel pumped.
   (B) The more the amount of diesel pumped, the more the time used to pump it.
   (C) The smaller the diameter of the hosepipe, the higher the speed at which the diesel is pumped.
   (D) The diameter of the hosepipe has an effect on the amount of diesel pumped.
19. The following table contains the characteristics of several objects. **Given**: Water mass = 20 g and Water volume = 20 cm^3.

Characteristics of Several Objects

Object	Mass (g)	Volume (cm^3)	Sink or Float
red ball	30.0	40.0	float
bottle	4.0	9.0	float
paper clip	1.0	0.4	sink
wooden block	12.8	16.0	float
magnet	2.2	0.2	sink
gold earring	1.5	1.7	float
ruler	14.0	12.0	sink
pink eraser	6.0	4.5	sink

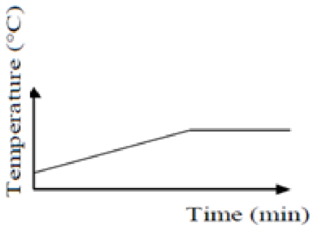
Which conclusion is best supported by the data in the table?

(A) Metal objects are more likely to float in water.
(B) The color of an object determines if it will sink or float in water.
(C) The shape of an object determines if it will sink or float in water.
(D) An object floats in water if its mass is less than its volume.

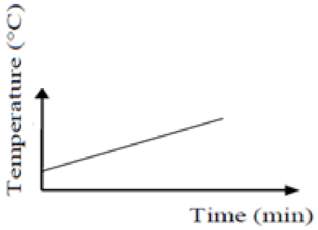
20. Zinash boiled some water in a beaker. The water temperature was measured with a thermometer. The table below shows the temperatures of water measured by him.

Temperature (^{0}C)	25	34	51	74	91	100	100
Time (min)	0	4	6	8	10	12	14

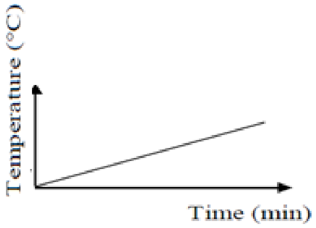
Which of the following graphs shows the result of his investigation?



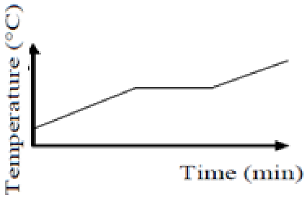
(A)



(B)



(C)



(D)

APPENDIX C

PHYSICS ATTITUDES SCALE

Addis Ababa University
College of Education and Behavioral studies
Department of Science and Mathematics Education

Instruction: The following questionnaires are prepared to investigate students' attitudes towards physics. The 30-items indicated the students' agreement or disagreement using Likert-type, a 5-point response scale. This test is prepared for research purpose only. Your privacy is assured and the researcher will not disclose any of your personal details. You are asked to rate each statement by circling a number between 1 and 5 where the numbers mean the following:

1= Strongly Disagree; 2=Disagree; 3=Neutral; 4=Agree; 5= Strongly Agree.

Choose one of the above five choices that best expresses your feelings about the statement.

Name: ______________________________ Grade: ______________________________
Sex: ________________________________ School: ______________________________

Enthusiasm toward physics						
1	Physics as subject is not exciting for me.	1	2	3	4	5
2	Studying topics on physics in greater detail is not that much important.	1	2	3	4	5
3	Learning physical phenomena and their description is most enjoyable to me.	1	2	3	4	5
4	I am punctual with physics homework.	1	2	3	4	5
5	I wait eagerly for physics period.	1	2	3	4	5
6	I discuss physics with my friends.	1	2	3	4	5
Physics learning						
7	I feel very pleased and satisfied on answering the questions in physics class.	1	2	3	4	5
8	I keep on practicing the problems done in the class till I attain proficiency.	1	2	3	4	5
9	I try to correlate the physics problem with daily life situation.	1	2	3	4	5
10	It is very difficult to succeed in physics exam without cheating.	1	2	3	4	5
11	I study physics only when my exams are around.	1	2	3	4	5
12	Learning physics is beyond my capability.	1	2	3	4	5
Practical work						
13	Practical work in physics is exciting.	1	2	3	4	5
14	My confidence level increases by doing physics experiment in laboratory.	1	2	3	4	5
15	The successful completion of a physics experiment excites me to do other experiments.	1	2	3	4	5
16	I like practical work in physics because it gives me more autonomy to do by myself.	1	2	3	4	5

17	I would like to have more practical work in my physics course.	1	2	3	4	5
18	Doing more practical work is wastage of time, instead I want to devote more time in studying theory.	1	2	3	4	5
Physics teacher						
19	I am afraid of my physics teacher.	1	2	3	4	5
20	My physics teacher always overburdens the students with assignments.	1	2	3	4	5
21	My physics teacher encourages problem solving and not just memorization.	1	2	3	4	5
22	My physics teacher uses a combination of teaching aids while teaching in the class.	1	2	3	4	5
23	My physics teacher often uses a lecture format to teach.	1	2	3	4	5
24	My physics teacher spends the necessary amount of time helping me understand physics concepts.	1	2	3	4	5
Future vocation						
25	I would like to study more physics courses at college.	1	2	3	4	5
26	Immense patience and tolerance is required to pursue physics.	1	2	3	4	5
27	Physicist is a highly dedicated individual working toward the improvement of society.	1	2	3	4	5
28	Physics plays an important role in the advancement of civilization and society.	1	2	3	4	5
29	Studying physics at a higher level leads to glorious future.	1	2	3	4	5
30	Physicists waste public money as all the research work does not have practical applications.	1	2	3	4	5

APPENDIX D

PHYSICS EPISTEMIC BELIEFS SCALE

Addis Ababa University
College of Education and Behavioral studies
Department of Science and Mathematics Education

The purposes of these questionnaires are to investigate students' epistemic beliefs towards physics. The 30-items indicated the students' agreement or disagreement using Likert-type, a 5-point response scale. This test is prepared for research purpose only. Your privacy is assured and the researcher will not disclose any of your personal details. You are asked to rate each statement by circling a number between 1 and 5 where the numbers mean the following:

1= Strongly Disagree; 2= Disagree; 3= Neutral; 4= Agree; 5= Strongly Agree.

Please read thoroughly before deciding to circle one of the above five choices that best expresses your feelings about the statement.

Thank you in advance for your cooperation!!

Name: ____________________________________ Grade: ___________________________
Sex: _______________________________________ School: ____________________________

Source of knowledge		Scales				
1	Everybody has to believe what physicists say.	1	2	3	4	5
2	You have to believe what is written in the physics books.	1	2	3	4	5
3	Whatever the teacher says in physics class is true.	1	2	3	4	5
4	If you read something in a physics book, you can be sure it's true.	1	2	3	4	5
5	Only physicists know for sure what is true in physics.	1	2	3	4	5
Certainty of knowledge						
6	All questions in physics have one right answer.	1	2	3	4	5
7	The most important part of doing physics is coming up with the right answer.	1	2	3	4	5
8	Physics knowledge is always true.	1	2	3	4	5
9	Physicists take a result from an experiment as the only answer.	1	2	3	4	5
10	Physicists always agree about what is true in physics.	1	2	3	4	5
Development of Knowledge						
11	Some ideas in physics today are different from what physicists were thinking in the past.	1	2	3	4	5
12	The ideas in physics books sometimes change.	1	2	3	4	5
13	Ideas in physics are falsifiable.	1	2	3	4	5
14	New discoveries can disprove what physicists think is true.	1	2	3	4	5
15	Sometimes physicists change their minds about what is true in physics.	1	2	3	4	5
Justification for knowing						
16	In physics, there can be more than one way to test ideas.	1	2	3	4	5
17	One important reason to do experiments is to come up with new ideas about how things work.	1	2	3	4	5

18	It is good to try experiments more than once to make sure of your findings.	1	2	3	4	5
19	A good way to know if something is true is to do an experiment.	1	2	3	4	5
20	Good answers are based on evidence from many different experiments.	1	2	3	4	5
Purpose of knowledge						
21	Scientific knowledge in physics is one of the ways to predict and explain natural phenomenon.	1	2	3	4	5
22	The goal of physics theories is to explain natural processes.	1	2	3	4	5
23	The results obtained from physics research can illustrate, explain or predict the world where we live in.	1	2	3	4	5
24	Scientific knowledge in physics can produce reliable explanations and make accurate predictions to natural phenomenon.	1	2	3	4	5
Purpose of knowing						
25	The purpose of acquiring scientific knowledge in physics is to construct a plausible way to understand one's surroundings.	1	2	3	4	5
26	The purpose of scientific knowledge in physics is to see nature in a new way.	1	2	3	4	5
27	Pursuing scientific knowledge in physics is to find out how nature truly works.	1	2	3	4	5
28	Physics is a process of gaining knowledge.	1	2	3	4	5
29	There is no need to further verify the laws already discovered.	1	2	3	4	5
30	The laws of physics are tentative.	1	2	3	4	5

APPENDIX E

ASAC OBSERVATION PROTOCOL

Item	Description of each aspects of scientific argumentation.	0	1	2	3
	Conceptual and cognitive aspects				
1	The talk of the group was focused on solving a problem or advancing understanding.	0	1	2	3
2	The participants sought out and discussed alternative claims or conclusions.	0	1	2	3
3*	The participants modified their explanation or claim when they noticed an inconsistency or discovered anomalous information.	0	1	2	3
4	The participants were skeptical of ideas and information.	0	1	2	3
5	The participants provided reasons when supporting or challenging an ideas.	0	1	2	3
6*	The participants attempted to evaluate the merits of each alternative claim or explanation in a systematic manner.	0	1	2	3
	Epistemic Aspects				
7	The participants used evidence to support and challenge ideas or to make sense of the phenomenon under investigation.	0	1	2	3
8*	The participants examined the relevance, coherence, and sufficiency of the evidence.	0	1	2	3
9	The participants evaluated how the data was gathered, analyzed or interpreted.	0	1	2	3
10	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
11	The participants made distinctions and connections between inference and observations explicit to others.	0	1	2	3
12	The participants used the language of science to communicate ideas.	0	1	2	3
	Social aspects				
13	The participants were reflective about what they know and how they know.	0	1	2	3
14	The participants respected what each other had to say.	0	1	2	3
15	The participants discussed an idea when it was introduced into the conversation.	0	1	2	3
16	The participants encouraged or invited others to share or critique ideas.	0	1	2	3
17	The participants restated or summarized comments and asked each other to clarify or elaborate on their comments.	0	1	2	3
18	There was equal participation from all members of the group.	0	1	2	3

*Note: 0 = not all, 1= once or twice, 2= a few times, 3= often. * These items need reverse rating.*

APPENDIX F

PRACTICAL SKILLS ASSESSMENT RUBRICS

This scoring rubric is used to assess students' physics practical skills through observation while they are carrying out practical work. These rubrics are organized based on domains to design an experiment, execution, analysis and evaluation. .

1. Domain of data design				
1.1 Identifying variables	0	1	2	3
Identifying variables	Unable to identify any variables	Able to identify the one variable correctly	Able to identify any two variables correctly	Able to identify at least three variables correctly
Formulate Hypothesis	Unable to write a hypothesis	The hypothesis was written irrelevantly	The hypothesis was not written correctly.	Writing a hypothesis in an appropriate format
1. 2. Design functional experimental set up	Unable to draft the experiment set-up while designing the experiment.	Able to draft the experiment set up but the design is not functional.	Able to draft the experiment set up but there is missing apparatus.	Able to draft the experiment set -up in the form of labelled diagram.
1.3 Determine suitable range of manipulated variable	Unable to determine the range while designing the experiment.	Determine the range but is beyond the measurable (minimum or maximum) limit.	Determine the range based on the apparatus available.	Determine suitable range that is within the measurable limit.
1.4 Select suitable interval for values of manipulated variable	Unable to select systematic intervals while designing the experiment.	Select interval for the values of manipulated variable which is not suitable with the task.	Select interval for the values of manipulated variable which are systematic.	Select interval for the values of manipulated variable which are systematic and compatible with the selected range.
2. Domain of Execution				
2.1 Choose suitable apparatus for measurement	Unable to choose suitable apparatus.	Choose apparatus with assistance from other.	Choose apparatus with unsuitable measurement range.	Choose apparatus without assistance from others.
2.2 Check the functionality of the apparatus and instruments	Do not check the apparatus and the instrument before starting the experiment.	Check the physical conditions of the apparatus and the instrument.	Check the sensitivity of the apparatus and instruments.	Check the functionality of the apparatus and instrument, and correct the errors if any.

2.3 Set up functional apparatus	Set up of experiment is not compatible with the task.	Try different set up before deciding the final set up.	Set up is functional but placement of apparatus may cause errors in results.	Set up is suitable and functional.
2.4 Test run the experimental set up	Do not perform any test run.	Check the stability of the experiment set up.	Check the experimental set-up by trying out one measurement.	Test the experimental set up with the minimum and maximum values that can be applied.
2.5 Use measuring instrument with the correct techniques	Unable to use the instrument for measurement.	Need guidance in using the measuring instrument.	Use the instrument correctly but the measurements have errors.	Use the instrument skillfully and correctly.
2.6 Take precautions to improve accuracy of data collected	Show no precaution to improve accuracy of data.	Show effort to avoid parallax error while taking measurements (or any one precaution).	Avoid parallax error and repeat experimental steps to improve accuracy (for any other two precautions).	Take all necessary precautions and checking the constant variables.
2.7 Record all measurements	No record of measurement.	Record measurement but not systematically.	Record all measurements systematically in a table.	Record all measurements systematically to the correct significant figure and unit.
2.8 Title of the table	There was no title table	If the title included one variable	If the table title included two variables	
2.9 Units	If all units were not written	If a unit was not written	If the units were written correctly.	
2.10 Saving data	If all data were recorded incorrectly	If there was more than three mistakes	If 1-2 data groups were incorrect	If all the data were recorded correctly
2.1 Ensure safety in the laboratory	Do not show effort to ensure safety while carrying out the experiment.	Perform experiment with minimum consideration for safety.	Only show effort in ensuring safety at the beginning of the experiment.	Show effort to ensure safety throughout the experiment.
3. Domain of analysis				

3.1 Perform correct calculation for secondary data and analysis of data.	Show no calculation for secondary data and analysis of data.	Calculation is irrelevant to the task.	Show relevant calculations but with errors.	Show all relevant calculations correctly.
3.2 Analysis data to obtain results/ relationships	Do not show any effort in analyzing the data.	Perform analysis which is irrelevant to the task.	Use suitable graph or chart for analysis but with limited graphing skills.	Show good graphing skills in using suitable graph/chart to analyze data.
3.3 State correct relationship/make correct deduction	Make no deduction.	Deduction made is irrelevant to the task.	State a general relationship between variables.	State the specific and correct relationship between the variables based on the graph.
4. Domain of evaluation				
Conclude the findings of the experiment	Do not make any conclusion for the experiment.	Able to state a conclusion but is irrelevant with the experiment.	Able to state a general conclusion for the experiment.	Able to state a conclusion for the experiment based on the relationship.

APPENDIX G

An interview protocol prepared for secondary school students

First of all, thank you very much for volunteering to be interviewed.

1. Would you please tell me your name, grade level, and favorite subject?
2. Do you enjoy physics? What makes you enjoy or dislike physics?
3. Why do you think it is useful to teach physics using practical experiments?
4. Have you done practical work in a laboratory before? Is it planned and programmed or only when teachers think it is necessary? Do you have anything to add?
5. How did you conduct practical work in physics laboratory? For example, only through teacher demonstrations, or in groups by strictly following the procedures written in the manual? Do you have anything else to add?
6. What do you think should be the role of teachers or technicians during practical work? Example: Monitor closely and demonstrate working on each process; give continuous guidance and support so that you can work and discuss in a group; or doing practical work in group by yourselves with full responsibility. If there is anything else?
7. In the past four months you have conducted various practical work activities in the laboratory. What aspects of these practical work experiences did you enjoy most? Is there anything you did not like about the experience? Why?
8. How important do you think it is for students to discuss, argue and challenge each other's ideas based on evidence while doing practical work in the physics lab? In this respect, what should be the role of the teacher and the students?
9. Do you have any suggestions and comments that helps to improve practical work?

APPENDIX H

Sample Activities designed for both practical work Groups

Activity 1: Experiment with a pendulum

Some students did an experiment to find out the time a pendulum takes to swing a full cycle (period). They made five repeated measurements of one period with a stop watch. Here are their results.

Measuring one period	Time (seconds)
1st measurement	1.1
2nd measurement	1.2
3rd measurement	0.9
4th measurement	3.5
5th measurement	1.1

Why did they get the exact same time in each measurement?

Here are some possible reasons:

- They did not read the time accurately from the watch.
- They must have been something wrong with the watch or the pendulum.
- 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?

- Add up all measurements and divide by 5 to get an average
- Task away the 4th measurement, that might be wrong, and then average the rest
- Choose the two measurements that are the same.
- Choose the shortest time.

Explain which method you think is best:

____.

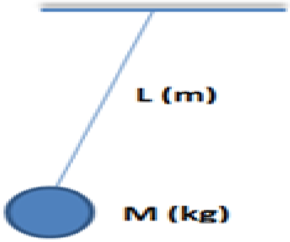
Suggest what they could do to get a more accurate measurement of time?

____.

Activity 2: Control of variables

A pendulum can be long or short, heavy or light. Some students wanted to investigate how mass (M) and string length (L) of the pendulum influences the time (T) it takes to swing back and forth. They did six experiments with different masses and lengths. The results are shown in the table below:

	String length L (m)	Mass M (kg)	Time T(s)
Experiment 1	0.5	0.5	1.4
Experiment 2	0.5	1.0	1.4
Experiment 3	1.0	0.5	2.0
Experiment 4	1.5	0.5	2.4
Experiment 5	2.0	0.5	2.8
Experiment 6	2.0	1.0	2.8



1. What happens to the time when you change the mass?

____.

2. Which experiments are necessary to work this out?

____.

3. What happens to the time when you change the string length?

____.

4. Which experiments are necessary to work this out?

____.

5. Explain why comparing Experiment 1 and Experiment 6 is wrong when you want to investigate the effect of changing string length?

____.

Activity 3: Graphs and Equations

Some students were investigating how a spring stretches when you hang weights on it.

Mass, M (kg)	Displacement, x (cm)
0	0
10	0.9
20	2.1
30	3.0
40	3.9
50	5.2
60	6.1
70	7.0
80	8.1

1. Plot the graph of mass versus displacement.
2. Which equation best describes the trend in the data? (Select one). Describe this trend in your own words. (A) $M = k/x$ (B) $M = kx^2$ (C) $M = kx$ (D) $M = k\sqrt{x}$

   ____

   ____.
3. Find at least three other physics laws that express a similar trend between the variables.

   ____

   ____.

APPENDIX I

Sample activities designed for the Dialogic-practical work group
Topic: Archimedes' principle

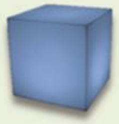
Objectives: - After conducting this experiment students be able to:

- Identify the procedures to be followed in determining the density of irregular bodies.
- Define density as mass per unit of volume.
- Determine the volume and density of an irregular shaped body.
- Apply an object's density is crucial for determining whether it floats or sinks.
- Describe the effect of mass of an object determines whether an object will sink or float.

Part one: Sinking and Floating

Initial discussion questions:

1. What is the density of an unknown metal bar having a mass of 900 g and a volume of 50cm^3? If we break this unknown metal bar into two pieces, what will be the density of each piece? Explain your answer.
2. A 10cm^3 piece of gold has a mass of 193 g. Is gold denser than iron? What will be the density of the gold if you double the volume of gold to make it 20cm^3?
3. Imagine you have the following bodies on the top of your lab bench. Tell us how you would calculate their volume.

A. Cube with an edge length of 2 cm	B. Sphere of radius 3 cm	C. A screw
		

   (i) Imagine you have these four keys to open a door. They are made with four different materials, and only the less heavy key opens the door. Could you tell which key and why?

Chromium Key d = 7,2 g/mL	Iron Key d = 7,9 g/mL	Titanium Key d = 4,5 g/mL	Copper Key d = 8,4 g/mL
			

   (ii) Could you explain why the previous keys weigh differently but they all occupy the same volume?

4. Which of the following **statement/s is correct**?
   (A) Volume determines if an object will sink or float.
   (B) Weight determines if an object will sink or float.
   (C) The volume of a liquid in a container determines whether an object sinks or floats.
   (D) The density determines if an object will sink or float.
   (E) The mass of an object determines whether it will sink or float.
   (F) Geometrical shapes of an object determines whether it will float or sink.

(G) When the volume of a liquid in a container is increased, the volume of the sinking part of an object will decrease.
(H) When the volume of a liquid in a container is increased, the volume of the sinking part of an object will increase, too.
(I) When the volume of a liquid in a container is decreased, a floating object will sink.
(J) Objects which have a hole will sink in the course of time because the liquid fills the hole.
(K) Two different objects which are sinking in a liquid have always the same density.

Apparatus: Electronic scale, a large container, a candle, a marble, metal ball, a rubber ball.

Procedures:

1. Weigh the masses of the candle, the marble, metal ball and the rubber ball by using an electronic scale. Write down the masses of the objects in the table. *Predict which of the objects will sink or float. Please write down your prediction. Why do you think this? Please explain your reasons.*
2. Fill almost half of the container with water. Afterwards, put the candle, the marble, metal ball and the rubber ball into the container gently. *What did you observe? Which sank or floated? Please write down your observations. Were your earlier predictions correct? Compare the differences between the predictions about which objects will sink or float and the result of the experiments. If there is a difference between your predictions and the results of experiment, what do you think your earlier predictions were incorrect?*
3. After the experiments, *do you think that mass or weight determines whether an object will sink or float? Do heavier objects always sink, but lighter objects float?*

Data analysis

1. Calculate the density of the metal solid objects using $\rho = m/V$ and identify the names of the material in which the object is made. Compare your results with the accepted values for each material.
2. Why the density of the metal is not exactly equal to the theoretical density of the substance it is made?
3. Once you determine the density of different objects, identify which object will float or sink in water. Why? Can these objects float or sink in salty solution and edible oil. Why?
4. Make conclusions about your observations.

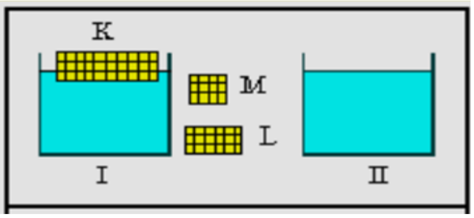
Part two: Archimedes principle

At the end of the experiment students will be able to:

- State Archimedes' Principle.
- Calculate the density of unknown objects and liquids using Archimedes' principle.
- Verify the density of liquid water.

Discussion questions

1. Object K is floating in a liquid as shown in the first figure. If object K is divided into two pieces (M and L) whose sizes are different from each other and then, they are put into the same liquid, what do you predict will be their positions? Will they sink or float? Please explain your reasons.



Which explanation is correct?

(A) When a floating object is cut into two parts, the volume of the smaller sinking part will become less.
(B) When a floating object is cut into two parts, the bigger piece will sink or the volume of the sinking part will increase.
(C) The sinking or floating part of an object does not depend on the size of an object.
(D) The volume of a liquid in a container does not affect the position of the object in the liquid and its floatation.

2. Which statement is correct about buoyancy of an object?
   (A) When the densities of the liquid changes, the buoyancy of an object changes too.
   (B) The volume of the sinking part of an object becomes less when a liquid which is less dense is poured into the container filled with a more dense liquid.
   (C) When two objects, one of which is put on the top of the other, is put into the liquid one by one, the position of the object which is beneath does not change.
   (D) When two objects, one of which is put on the top of the other, are then put into the liquid one by one, the water level in the container does not change.

Apparatus: - measuring cylinder, stones of different sizes, metallic ball, water, string, meter rule and beam balance.

Procedures:

1. Measure the weight of a metallic ball in air.
2. Slowly dip the metallic ball into a container of water. *What do you think will happen to the reading on the balance or the length of the string? Why do you think this will happen?* Record the new reading. *Was it what you expected? What happens when the stone is fully immersed?* How far as the level of the water risen?
3. Repeat the experiment for stones of different sizes. What is the connection between the volume of the stone and the change in the reading on the balance?
4. Repeat steps 1 to 3 in salty water and edible oil.
5. Tabulate your observations in a table.

Related questions

1. Calculate the buoyant force.
2. Calculate the density of liquid water, salty water and edible oil.
3. Draw a graph of mass of liquid (y-axis) against volume (x-axis). Calculate the density of each liquid from the gradient of its graph line.
4. Explain why the density of liquid water is not exactly equal to the theoretical density of water?

APPENDIX J

Sample activity prepared for the Recipe-based practical work group

Topic: The simple Pendulum

Objectives: After completing the experiment students should be able to:

- Get practical skills such as observing, measuring and data analysis
- Determine the dependence of the period of a pendulum on the length of the pendulum and on the mass of the pendulum.
- Determine the gravitational constant using the simple pendulum

Apparatus: 3 pendulum bobs of different mass, thread, retort stand and clamp, meter ruler and stopwatch.

Theory

A simple pendulum consists of a small mass oscillating to and fro at the end of a very light string. If the amplitude of oscillation is small (less than a bout 10^0), it moves with simple harmonic motion. The period does not depend on amplitude; there is a continuous interchange of potential and kinetic energy. The period is given by: $T= 2\pi\sqrt{\frac{l}{g}}$. ($\theta \leq 10^o$)

Procedures

Part One: Keep the mass constant (100 gram) and vary the length

1. Arrange the equipment as given in figure 1.
2. Before you start any experiment, first discuss how you will measure the period of the pendulum. Start measuring the period T for a length of 100 cm, mass= 100 gram. Repeat this experiment at least three times and take the mean period.
3. Repeat step 3 for length 80cm, mass is 100gram; for length 60 cm, mass is 100gram; for length 40 cm, mass is 100 gram; for length 20 cm, mass is 100 gram
4. Complete table 1, using the results from step 3, 4a, 4b, 4c and 4d.

Mass (gram)	Length (m)	Amplitude (θ)	Time (s) 5 cycles
	0.2 m		
	0.4 m		
	0.6 m		
	0.8 m		
	1.0 m		

Part two: Keep the length constant (100 cm) and vary the mass

1. Arrange the equipment as given in figure 1.
2. Before you start and experiment, first discuss how you will measure the period of the pendulum.
3. Start measuring the period T for a length of 100cm, mass = 100 gram. Repeat this experiment at least three times and take the mean period. Repeat step 3 for length 100 cm, mass is 50 gram; for length 1

Mass (gram)	Length (m)	Amplitude (θ)	Time (s) 5 cycles	Period (s)
25				
50				
75				
100				
150				

Part three: Does amplitude affect the period of a pendulum?

Data Table- C: Vary only the pendulum's amplitude by keeping the mass and the length constant.

Mass (gram)	Length (m)	Amplitude (θ)	Time (s) 5 cycles	Period (s)
		10		
		15		
		25		
		35		
		45		

Discuss the following Questions

1. Draw a graph of the mean period T versus length l.
2. Draw a graph of the T^2 versus length l.
3. Draw a graph of the mean period T versus mass m.
4. Draw a graph of the T^2 versus mass m.
5. From the results given in **part one**, what do you conclude about the dependence of the period T on the length of the pendulum?
6. From the results given in in **part two**, what do you conclude about the dependence of the period T on the mass of the pendulum?
7. Discuss the errors you make in this experiment and discuss how you could improve the accuracy of the measurements?